odl Documentation

Release beta

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Operator Discretization Library (ODL) is a python library for fast prototyping focusing on (but not restricted to) inverse problems. ODL is being developed at KTH, Royal Institute of Technology.

The main intent of ODL is to enable mathematicians and applied scientists to use different numerical methods on real-world problems without having to implement all necessary parts from the bottom up. ODL provides some of the most heavily used building blocks for numerical algorithms out of the box, which enables users to focus on real scientific issues.

CHAPTER 1

User's guide to ODL

Welcome to the ODL users guide, this guide is intended to give you a simple introduction to ODL and how to work with it. If you need help on a specific function you should look at its documentation.

1.1 Introduction

1.1.1 About ODL

Operator Discretization Library (ODL) is a Python library for fast prototyping focusing on (but not restricted to) inverse problems. ODL is being developed at KTH, Royal Institute of Technology.

The main intent of ODL is to enable mathematicians and applied scientists to use different numerical methods on real-world problems without having to implement all necessary parts from the bottom up. This is reached by an *Operator* structure which encapsulates all application-specific parts, and a high-level formulation of solvers which usually expect an operator, data and additional parameters. The main advantages of this approach is that

1. Different problems can be solved with the same method (e.g. TV regularization) by simply switching operator and data.
2. The same problem can be solved with different methods by simply calling into different solvers.
3. Solvers and application-specific code need to be written only once, in one place, and can be tested individually.
4. Adding new applications or solution methods becomes a much easier task.

ODL implements many abstract mathematical notions such as sets, vector spaces and operators. In the following, a few are shown by example.

Set

A *Set* is the fundamental building block of ODL objects. It mirrors the mathematical concept of a set in that it can tell if an object belongs to it or not:

```
>>> interv = odl.Interval(0, 1)
>>> 0.5 in interv
True
>>> 2.0 in interv
False
```

The most commonly used sets in ODL are *RealNumbers* (set of all real numbers) and *IntervalProd* ("Interval product", rectangular boxes of arbitrary dimension). For the typical use cases in 1, 2 and 3 dimensions, there are convenience functions *Interval*, *Rectangle* and *Cuboid*:

```
>>> rect = odl.Rectangle([0, -1], [1, 1])
>>> rect.begin
array([ 0., -1.])
>>> rect[0]
Interval(0.0, 1.0)
```

LinearSpace

The *LinearSpace* class is the most important subclass of *Set*. It is a general (abstract) implementation of a mathematical vector space and has a couple of widely used concrete realizations.

Spaces of n-tuples

Large parts of basic functionality, e.g. arithmetic or inner products, rest on array computations, i.e. computations on tuples of elements of the same kind. Typically, these vector spaces are of the type $\mathbb{F}^n$, where $\mathbb{F}$ is a field (usually $\mathbb{R}$ or $\mathbb{C}$), and n a positive integer. Example:

```
>>> c3 = odl.Cn(3)
>>> u = c3.element([1 + 1j, 2 - 2j, 3])
>>> v = c3.one()  # vector of all ones
>>> u.inner(v)  # sum of the elements
(6-1j)
```

Function spaces

A function space is a set of functions $f : \mathcal{X} \to \mathcal{Y}$ with fixed domain and range (more accurately: codomain), where $\mathcal{Y}$ is a vector space. The ODL implementation *FunctionSpace* covers only the cases $\mathcal{Y} = \mathbb{R}$ or $\mathbb{C}$ since the general case has large overlaps with *Operator*. Note that we do not make a distinction between different types of function spaces with respect to regularity, integrability etc. on an *abstract* level since there is no obvious way to check it.

As linear spaces, function spaces support some interesting operations:

```
>>> import numpy as np
>>> space = odl.FunctionSpace(odl.Interval(0, 2))
>>> exp = space.element(np.exp)
>>> exp(np.log(2))
2.0
>>> exp_plus_one = exp + space.one()
>>> exp_plus_one(np.log(2))
3.0
>>> ratio_func = exp_plus_one / exp  # x -> exp(x) / (exp(x) + 1)
>>> ratio_func(np.log(2))  # 3 / 2
1.5
```

A big advantage of the function space implementation in ODL is that the evaluation of functions is vectorized, i.e. that the values of a function can be computed from an array of input data "at once", without looping in Python (which is slow, in general). What follows is a simple example, see the *Vectorized functions* guide for instructions on how to write vectorization-compatible functions.

```
>>> import numpy as np
>>> space = odl.FunctionSpace(odl.Interval(0, 2))
>>> exp = space.element(np.exp)
>>> exp([0, 1, 2])
array([ 1.        ,  2.71828183,  7.3890561 ])
```

```
>>> x = np.linspace(0, 2, 1000)
>>> y = exp(x)  # works
```

Discretizations

A discretization typically represents the finite-dimensional, concrete counterpart of an infinite-dimensional, abstract vector space, which makes it accessible to computations. In ODL, a *Discretization* instance encompasses both continuous and discrete spaces as well as the mappings take one into the other. The canonical example is the space $L^2(\Omega)$ of real-valued square-integrable functions on a rectangular domain (we take an interval for simplicity). It is the default in the convenience function *uniform_discr*:

```
>>> l2_discr = odl.uniform_discr(0, 1, 5)  # Omega = [0, 1], 5 subintervals
>>> type(l2_discr)
odl.discr.lp_discr.DiscreteLp
>>> l2_discr.exponent
2.0
>>> l2_discr.domain
Interval(0.0, 1.0)
```

Discretizations have a large number of useful functionality, for example the direct and vectorized sampling of continuously defined functions. If we, for example, want to discretize the function `f(x) = exp(-x)`, we can simply pass it to the `element()` method:

```
>>> exp_discr = l2_discr.element(lambda x: np.exp(-x))
>>> type(exp_discr)
odl.discr.lp_discr.DiscreteLpVector
>>> exp_discr.shape
(5,)
```

Operators

This is the central class and general notion in ODL. The concept is derived from the mathematical theory of operators and implements many of its core properties. Any functionality that is implemented as an *Operator* has access to the full machinery of operator arithmetic, composition, differentiation and much more. It is the universal interface between application-specific code (e.g. line projectors in tomography for a given geometry) and other parts of the library that are written in an abstract mathematical language. The large benefit of this approach is that once an operator is fully implemented and functional, it can be used seamlessly by, e.g., optimization routines that expect an operator and data (among others) as input.

As a small example, we study the problem of solving a linear system with 2 equations and 3 unknowns. We use Landweber's method to get a least-squares solution and plot the intermediate residual norm. The method needs a relaxation $\lambda < 2/\|A|^2$ to converge - in our case, the right-hand side is 0.14, so we choose 0.1.

```
>>> matrix = np.array([[1.0, 3.0, 2.0],
                       [2.0, -1.0, 1.0]])
>>> matrix_op = odl.MatVecOperator(matrix)  # operator defined by the matrix
>>> matrix_op.domain
Rn(3)
>>> matrix_op.range
Rn(2)
>>> data = np.array([1.0, -1.0])
>>> niter = 5
>>> reco = matrix_op.domain.zero()  # starting with the zero vector
>>> for i in range(niter):
...     residual = matrix_op(reco) - data
```

```
...     reco -= 0.1 * matrix_op.adjoint(residual)
...     print(residual.norm())
1.41421356237
0.583095189485
0.240416305603
0.0991261822124
0.0408707719526
```

If we now exchange `matrix_op` and `data` with a tomographic projector and line integral data, not a single line of code in the reconstruction method changes since the operator interface is exactly the same.

Further features

- A unified structure for representing tomographic acquisition geometries
- Interfaces to fast external libraries, e.g. ASTRA for X-ray tomography, STIR for emission tomography (preliminary), pyFFTW for fast Fourier transforms, ...
- A growing number of "must-have" operators like *Gradient*, *FourierTransform*, *WaveletTransform*
- Several solvers for variational inverse problems, ranging from simple gradient methods to the Chambolle-Pock method (more to come...)
- Standardized tests for the correctness of implementations of operators and spaces, e.g. does the adjoint operator fulfill its defining relation?
- CUDA-accelerated data containers as a replacement for Numpy

Further reading

- *Linear spaces*
- *Operators*
- *Discretizations*

1.1.2 Installing

Installing odl is intended to be straightforward, and this guide is meant for new users. To install odl you need to do the following steps:

1. *Install Python*
2. *Install Git*
3. *Install ODL*
4. *Run tests*

If you have done any step before, you can ofc skip it.

Install Python

To begin with, you need a python distribution. If you are an experienced user, you can use any distribution you'd like.

Anaconda

If you are a python novice using Windows, we recommend that you install a full package such as Anaconda. To install Anaconda

1. Download Anaconda from anaconda's webpage
2. Once installed run in a console

```
user$ conda update --all
```

to make sure you have the latest versions of all packages

Install Git

You also need to install Git to be able to download odl.

Overview

Debian / Ubuntu	`sudo apt-get install git`
Fedora	`sudo yum install git`
Windows	Download and install msysGit
OS X	Use the git-osx-installer

In detail

See the git page for the most recent information.

Have a look at the github install help pages available from github help

There are good instructions here: http://book.git-scm.com/2_installing_git.html

Install ODL

You are now ready to install ODL! To do that, run the following where you want to install it

```
git clone https://github.com/odlgroup/odl
cd odl
```

For installation in a local user folder run

```
user$ pip install --user -e .
```

For system-wide installation, run (as root, e.g. using `sudo` or equivalent)

```
root# pip install -e .
```

(Optional) Install ODLpp

If you also wish to use the (optional) CUDA extensions you need to run

```
user$ git submodule update --init --recursive
user$ cd odlpp
```

From here follow the instructions in odlpp and install it. You then need to re-install ODL.

Run tests

To verify your installation you should run some basic tests. To run these:

```
user$ py.test
```

This requires the module pytest

1.1.3 Getting started

Welcome to the ODL users guide, this guide is intended to give you a simple introduction to ODL and how to work with it. If you need help on a specific function you should look at its documentation.

1.2 In depth

This is a more in depth guide to the different parts of ODL.

1.2.1 Operators

Operators in ODL are represented by the abstract *Operator* class. As an *abstract class*, it cannot be used directly but must be subclassed for concrete implementation. To define your own operator, you start by writing:

```
class MyOperator(odl.Operator):
    ...
```

Operator has a couple of *abstract methods* which need to be explicitly overridden by any subclass, namely

domain: ***Set*** Set of elements to which the operator can be applied

range [*Set*] Set in which the operator takes values

As a simple example, you can implement the matrix multiplication operator

$$\mathcal{A} : \mathbb{R}^m \to \mathbb{R}^n, \quad \mathcal{A}(x) = Ax$$

for a matrix $A \in \mathbb{R}^{n \times m}$ as follows:

```
from builtins import super
import numpy as np

class MatVecOperator(odl.Operator):
    def __init__(self, matrix):
        self.matrix = matrix
        dom = odl.Rn(matrix.shape[1])
        ran = odl.Rn(matrix.shape[0])
        super().__init__(dom, ran)
```

In addition, an *Operator* needs at least one way of evaluation, *in-place* or *out-of-place*.

In place evaluation

In-place evaluation means that the operator is evaluated on a *Operator.domain* element, and the result is written to an *already existing* *Operator.range* element. To implement this behavior, create the (private) *Operator._call* method with the following signature, here given for the above example:

```
class MatVecOperator(odl.Operator):
    ...
    def _call(self, x, out):
        self.matrix.dot(x, out=out.asarray())
```

In-place evaluation is usually more efficient and should be used *whenever possible*.

Out-of-place evaluation

Out-of-place evaluation means that the operator is evaluated on a `domain` element, and the result is written to a *newly allocated* `range` element. To implement this behavior, use the following signature for *`Operator._call`* (again given for the above example):

```
class MatVecOperator(odl.Operator):
    ...
    def _call(self, x):
        return self.range.element(self.matrix.dot(x))
```

Out-of-place evaluation is usually less efficient since it requires allocation of an array and a full copy and should be *generally avoided*.

Important: Do not call these methods directly. Use the call pattern `operator(x)` or `operator(x, out=y)`, e.g.:

```
matrix = np.array([[1, 0], [0, 1], [1, 1]])
operator = MatVecOperator(matrix)
x = odl.Rn(2).one()
y = odl.Rn(3).element()

# Out-of-place evaluation
y = operator(x)

# In-place evaluation
operator(x, out=y)
```

This public calling interface is (duck-)type-checked, so the private methods can safely assume that their input data is of the operator domain element type.

Operator arithmetic

It is common in applications to perform arithmetic with operators, for example the addition of matrices

$$[A + B]x = Ax + Bx$$

or multiplication of a functional by a scalar

$$[\alpha x^*](x) = \alpha x^*(x)$$

Another example is matrix multiplication, which corresponds to operator composition

$$[AB](x) = A(Bx)$$

All available operator arithmetic is shown below. `A`, `B` represent arbitrary *`Operator`*'s, `f` is an *`Operator`* whose *`Operator.range`* is a *`Field`* (sometimes called a functional), and `a` is a scalar.

Code	Meaning	Class
`(A + B)(x)`	`A(x) + B(x)`	*OperatorSum*
`(A * B)(x)`	`A(B(x))`	*OperatorComp*
`(a * A)(x)`	`a * A(x)`	*OperatorLeftScalarMult*
`(A * a)(x)`	`A(a * x)`	*OperatorRightScalarMult*
`(v * f)(x)`	`v * f(x)`	*FunctionalLeftVectorMult*
`(v * A)(x)`	`v * A(x)`	*OperatorLeftVectorMult*
`(A * v)(x)`	`A(v * x)`	*OperatorRightVectorMult*
not available	`A(x) * B(x)`	*OperatorPointwiseProduct*

There are also a few derived expressions using the above:

Code	Meaning
`(+A)(x)`	`A(x)`
`(-A)(x)`	`(-1) * A(x)`
`(A - B)(x)`	`A(x) + (-1) * B(x)`
`A**n(x)`	`A(A**(n-1)(x)),A^1(x) = A(x)`
`(A / a)(x)`	`A((1/a) * x)`
`(A @ B)(x)`	`(A * B)(x)`

Except for composition, operator arithmetic is generally only defined when *Operator.domain* and *Operator.range* are either instances of *LinearSpace* or *Field*.

1.2.2 Linear spaces

The *LinearSpace* class represent abstract mathematical concepts of vector spaces. It cannot be used directly but are rather intended to be subclassed by concrete space implementations. The space provides default implementations of the most important vector space operations. See the documentation of the respective classes for more details.

The concept of linear vector spaces in ODL is largely inspired by the Rice Vector Library (RVL).

The abstract *LinearSpace* class is intended for quick prototyping. It has a number of abstract methods which must be overridden by a subclass. On the other hand, it provides automatic error checking and numerous attributes and methods for convenience.

Abstract methods

In the following, the abstract methods are explained in detail.

Element creation

`element(inp=None)`

This public method is the factory for the inner *LinearSpaceVector* class. It creates a new element of the space, either from scratch or from an existing data container. In the simplest possible case, it just delegates the construction to the *LinearSpaceVector* class.

If no data is provided, the new element is **merely allocated, not initialized**, thus it can contain *any* value.

Parameters:

inp [`object`, optional] A container for values for the element initialization

Returns:

element [*LinearSpaceVector*] The new vector

Linear combination

```
_lincomb(a, x1, b, x2, out)
```

This private method is the raw implementation (i.e. without error checking) of the linear combination `out = a * x1 + b * x2`. *LinearSpace._lincomb* and its public counterpart *LinearSpace.lincomb* are used to covera range of convenience functions, see below.

Parameters:

a, b [scalars, must be members of the space's `field`] Multiplicative scalar factors for input vector `x1` or `x2`, respectively

x1, x2 [*LinearSpaceVector*] Input vectors

out [*LinearSpaceVector*] Element to which the result of the computation is written

Returns: `None`

Requirements:

- Aliasing of `x1`, `x2` and `out` **must** be allowed.
- The input vectors `x1` and `x2` **must not** be modified.
- The initial state of the output vector `out` **must not** influence the result.

Underlying scalar field

```
field
```

The public attribute determining the type of scalars which underlie the space. Can be instances of either *RealNumbers* or *ComplexNumbers* (see *Field*).

Should be implemented as a `@property` to make it immutable.

Equality check

```
__eq__(other)
```

LinearSpace inherits this abstract method from *Set*. Its purpose is to check two *LinearSpace* instances for equality.

Parameters:

other [`object`] The object to compare to

Returns:

equals [`bool`] `True` if `other` is the same *LinearSpace*, `False` otherwise

Distance (optional)

```
_dist(x1, x2)
```

A raw (not type-checking) private method measuring the distance between two vectors `x1` and `x2`.

A space with a distance is called a **metric space**.

Parameters:

x1,x2 [*LinearSpaceVector*] Vectors whose mutual distance to calculate

Returns:

distance [`float`] The distance between `x1` and `x2`, measured in the space's metric

Requirements:

- `_dist(x, y) == _dist(y, x)`
- `_dist(x, y) <= _dist(x, z) + _dist(z, y)`
- `_dist(x, y) >= 0`
- `_dist(x, y) == 0` (approx.) if and only if `x == y` (approx.)

Norm (optional)

`_norm(x)`

A raw (not type-checking) private method measuring the length of a space element `x`.

A space with a norm is called a **normed space**.

Parameters:

x [*LinearSpaceVector*] The vector to measure

Returns:

norm [`float`] The length of `x` as measured in the space's norm

Requirements:

- `_norm(s * x) = |s| * _norm(x)` for any scalar `s`
- `_norm(x + y) <= _norm(x) + _norm(y)`
- `_norm(x) >= 0`
- `_norm(x) == 0` (approx.) if and only if `x == 0` (approx.)

Inner product (optional)

`_inner(x, y)`

A raw (not type-checking) private method calculating the inner product of two space elements `x` and `y`.

Parameters:

x,y [*LinearSpaceVector*] Vectors whose inner product to calculate

Returns:

inner [`float` or `complex`] The inner product of `x` and `y`. If *LinearSpace.field* is the set of real numbers, `inner` is a `float`, otherwise `complex`.

Requirements:

- `_inner(x, y) == _inner(y, x)^*` with '*' = complex conjugation
- `_inner(s * x, y) == s * _inner(x, y)` for `s` scalar
- `_inner(x + z, y) == _inner(x, y) + _inner(z, y)`
- `_inner(x, x) == 0` (approx.) if and only if `x == 0` (approx.)

Pointwise multiplication (optional)

`_multiply(x1, x2, out)`

A raw (not type-checking) private method multiplying two vectors `x1` and `x2` element-wise and storing the result in `out`.

Parameters:

x1, x2 [*LinearSpaceVector*] Vectors whose element-wise product to calculate

out [*LinearSpaceVector*] Vector to store the result

Returns: `None`

Requirements:

- `_multiply(x, y, out) <==> _multiply(y, x, out)`
- **`_multiply(s * x, y, out) <==> _multiply(x, y, out); out *= s <==>`** `_multiply(x, s * y, out)` for any scalar `s`
- There is a space element `one` with `out` after `_multiply(one, x, out)` or `_multiply(x, one, out)` equals `x`.

Notes

- A normed space is automatically a metric space with the distance function `_dist(x, y) = _norm(x - y)`.
- A Hilbert space (inner product space) is automatically a normed space with the norm function `_norm(x) = sqrt(_inner(x, x))`.
- The conditions on the pointwise multiplication constitute a *unital commutative algebra* in the mathematical sense.

References

See Wikipedia's mathematical overview articles Vector space, Algebra.

1.2.3 Vectorized functions

This section is intended as a small guideline on how to write functions which work with the vectorization machinery by Numpy which is used internally in ODL.

What is vectorization?

In general, *vectorization* means that a function can be evaluated on a whole array of values at once instead of looping over individual entries. This is very important for performance in an interpreted language like python, since loops are usually very slow compared to compiled languages.

Technically, vectorization in Numpy works through the Universal functions (ufunc) interface. It is fast because all loops over data are implemented in C, and the resulting implementations are exposed to Python for each function individually.

How to use Numpy's ufuncs?

The easiest way to write fast custom mathematical functions in Python is to use the available ufuncs and compose them to a new function:

```
def gaussian(x):
    # Negation, powers and scaling are vectorized, of course.
    return np.exp(-x ** 2 / 2)

def step(x):
    # np.where checks the condition in the first argument and
    # returns the second for `True`, otherwise the third. The
    # last two arguments can be arrays, too.
    # Note that also the comparison operation is vectorized.
    return np.where(x[0] <= 0, 0, 1)
```

This should cover a very large range of useful functions already (basic arithmetic is vectorized, too!). An even larger list of special functions are available in the Scipy package.

Usage in ODL

Python functions are in most cases used as input to a discretization process. For example, we may want to discretize a two-dimensional Gaussian function:

```
def gaussian2(x):
    return np.exp(-(x[0] ** 2 + x[1] ** 2) / 2)
```

on the rectangle [-5, 5] x [-5, 5] with 100 pixels in each dimension. The code for this is simply:

```
# Note that the minimum and maxiumum coordinates are given as
# vectors, not one interval at a time.
discr = odl.uniform_discr([-5, -5], [5, 5], (100, 100))

# This creates an element in the discretized space ``discr``
gaussian_discr = discr.element(gaussian2)
```

What happens behind the scenes is that `discr` creates a *discretization* object which has a built-in method `element` to turn continuous functions into discrete arrays by evaluating them at a set of grid points. In the example above, this grid is a uniform sampling of the rectangle by 100 points per dimension.

To make this process fast, `element` assumes that the function is written in a way that not only supports vectorization, but also guarantees that the output has the correct shape. The function receives a *meshgrid* tuple as input, in the above case consisting of two vectors:

```
>>> mesh = discr.meshgrid()
>>> mesh[0].shape
(100, 1)
>>> mesh[1].shape
(1, 100)
```

When inserted into the function, the final shape of the output is determined by Numpy's broadcasting rules. For the Gaussian function, Numpy will conclude that the output shape must be `(100, 100)` since the arrays in `mesh` are added after squaring. This size is the same as expected by the discretization.

If, however, the function does not use all components of its input, the shape will be different:

```
>>> def gaussian_const_x0_bad(x):
...     return np.exp(-x[1] ** 2 / 2)  # no x[0] -> no broadcasting
```

```
>>> gaussian_const_x0_bad(mesh).shape
(1, 100)
```

This array is too small for the discretization, and an exception will be raised, stating that this function cannot be discretized.

The solution to this issue is rather simple: just make sure that all components are used such that the broadcasting rules are triggered:

```
>>> def gaussian_const_x0_good(x):
...     return np.exp(-x[1] ** 2 / 2) + 0 * x[0]  # broadcasting

>>> gaussian_const_x0_good(mesh).shape
(100, 100)
```

Further reading

Scipy Lecture notes on Numpy

CHAPTER 2

Mathematical Background

This section explains the mathematical concepts on which ODL is built.

2.1 Discretizations

2.1.1 Mathematical background

In mathematics, the term *discretization* stands for the transition from abstract, continuous, often infinite-dimensional objects to concrete, discrete, finite-dimensional counterparts. We define discretizations as tuples encompassing all necessary aspects involved in this transition. Let $\mathcal{X}$ be an arbitrary set, $\mathbb{F}^n$ be the set of n-tuples where each component lies in $\mathbb{F}$. We define two mappings

$$\mathcal{R}_\mathcal{X} : \mathcal{X} \to \mathbb{F}^n,$$
$$\mathcal{E}_\mathcal{X} : \mathbb{F}^n \to \mathcal{X},$$

which we call *restriction* and *extension*, respectively. Then, the discretization of $\mathcal{X}$ with respect to $\mathbb{F}^n$ and the above operators is defined as the tuple

$$\mathcal{D}(\mathcal{X}) = (\mathcal{X}, \mathbb{F}^n, \mathcal{R}_\mathcal{X}, \mathcal{E}_\mathcal{X}).$$

The following abstract diagram visualizes a discretization:

TODO: write up in more detail

2.1.2 Example

Let $\mathcal{X} = C([0, 1])$ be the space of real-valued continuous functions on the interval $[0, 1]$, and let $x_1 < \cdots < x_n$ be ordered sampling points in $[0, 1]$.

Restriction operator:

We define the *grid collocation operator* as

$$\mathcal{C} : \mathcal{X} \to \mathbb{R}^n,$$
$$\mathcal{C}(f) := \big(f(x_1), \ldots, f(x_n)\big).$$

The abstract object in this case is the input function f, and the operator evaluates this function at the given points, resulting in a vector in $\mathbb{R}^n$.

This operator is implemented as `PointCollocation`.

Extension operator:

Let discrete values $\bar{f} \in \mathbb{R}^n$ be given. Consider the linear interpolation of those values at a point $x \in [0, 1]$:

$$I(\bar{f}; x) := (1 - \lambda(x))f_i + \lambda(x)f_{i+1},$$
$$\lambda(x) = \frac{x - x_i}{x_{i+1} - x_i},$$

where i is the index such that $x \in [x_i, x_{i+1})$.

Then we can define the linear interpolation operator as

$$\mathcal{L} : \mathbb{R}^n \to C([0, 1]),$$
$$\mathcal{L}(\bar{f}) := I(\bar{f}; \cdot),$$

where $I(\bar{f}; \cdot)$ stands for the function $x \mapsto I(\bar{f}; x)$.

Hence, this operator maps the finite array $\bar{f} \in \mathbb{R}^n$ to the abstract interpolating function $I(\bar{f}; \cdot)$.

This interpolation scheme is implemented in the `LinearInterpolation` operator.

2.1.3 Useful Wikipedia articles

- Discretization

2.2 Transformations

This section contains the mathematical descriptions of (integral) transforms implemented in ODL.

2.2.1 Fourier Transform

Background

Definition and basic properties

The Fourier Transform (FT) of a function f belonging to the Lebesgue Space $L^1(\mathbb{R})$ is defined as

$$\widehat{f}(\xi) = \mathcal{F}(f)(\xi) = (2\pi)^{-\frac{1}{2}} \int_{\mathbb{R}} f(x)\, e^{-ix\xi}\, \mathrm{d}x. \tag{2.1}$$

By unique continuation, the bounded FT operator can be extended to $L^p(\mathbb{R})$ for $p \in [1, 2]$, yielding a mapping

$$\mathcal{F} : L^p(\mathbb{R}) \longrightarrow L^q(\mathbb{R}), \quad q = \frac{p}{p - 1},$$

where q is the conjugate exponent of p (for $p = 1$ one sets $q = \infty$). Finite exponents larger than 2 also allow the extension of the operator but require the notion of Distributions to characterize its range. See *[SW1971]* for further details.

The inverse of $\mathcal{F}$ on its range is given by the formula

$$\widetilde{\phi}(x) = \mathcal{F}^{-1}(\phi)(x) = (2\pi)^{-\frac{1}{2}} \int_{\mathbb{R}} \phi(\xi)\, e^{i\xi x}\, \mathrm{d}\xi. \tag{2.2}$$

For $p = 2$, the conjugate exponent is $q = 2$, and the FT is a unitary operator on $L`2(\mathbb{R})$ according to Parseval's Identity

$$\int_{\mathbb{R}} |f(x)|^2 \,\mathrm{d}x = \int_{\mathbb{R}} |\widetilde{f}(\xi)|^2 \,\mathrm{d}\xi,$$

which implies that its adjoint is its inverse, $\mathcal{F}^* = \mathcal{F}^{-1}$.

Further Properties

$$\begin{aligned}
\mathcal{F}^{-\infty}(\phi) = \mathcal{F}(\check{\phi}) = \mathcal{F}(\phi)(-\cdot) = \overline{\mathcal{F}(\overline{\phi})} = \mathcal{F}^3(\phi), \quad \check{\phi}(x) = \phi(-x), \\
\mathcal{F}\big(f(\cdot - b)\big)(\xi) = e^{-ib\xi}\widehat{f}(\xi), \\
\mathcal{F}\big(f(a\cdot)\big)(\xi) = a^{-1}\widehat{f}(a^{-1}\xi), \\
\frac{\mathrm{d}}{\mathrm{d}\xi}\widehat{f}(\xi) = \mathcal{F}(-ixf)(\xi) \\
\mathcal{F}(f')(\xi) = i\xi\widehat{f}(\xi).
\end{aligned} \tag{2.3}$$

The first identity implies in particular that for real-valued f, it is $\overline{\mathcal{F}(\phi)}(\xi) = \mathcal{F}(\phi)(-\xi)$, i.e. the FT is completely known already from the its values in a half-space only. This property is later exploited to reduce storage.

In d dimensions, the FT is defined as

$$\mathcal{F}(f)(\xi) = (2\pi)^{-\frac{d}{2}} \int_{\mathbb{R}^d} f(x)\, e^{-ix^{\mathrm{T}}\xi} \,\mathrm{d}x$$

with the usual inner product $x^{\mathrm{T}}\xi = \sum_{k=1}^{d} x_k\xi_k$ in $\mathbb{R}^d$. The identities (2.3) also hold in this case with obvious modifications.

Discretized Fourier Transform

General case

The approach taken in ODL for the discretization of the FT follows immediately from the way *Discretizations* are defined, but the original inspiration for it came from the book *[Pre+2007]*, Section 13.9 "Computing Fourier Integrals Using the FFT".

Discretization of the Fourier transform operator means evaluating the Fourier integral (2.1) on a discretized function

$$f(x) = \sum_{k=0}^{n-1} f_k \phi_k(x) \tag{2.4}$$

with coefficients $\bar{f} = (f_0, \ldots, f_{n-1}) \in \mathbb{C}^n$ and functions $\phi_0, \ldots, \phi_{n-1}$. This approach follows from the way , but can be We consider in particular functions generated from a single kernel ϕ via

$$\phi_k(x) = \phi\left(\frac{x - x_k}{s_k}\right),$$

where $x_0 < \cdots < x_{n-1}$ are sampling points and $s_k > 0$ scaling factors. Using the shift and scaling properties in (2.3) yields

$$\widehat{f}(\xi) = \sum_{k=0}^{n-1} f_k \widehat{\phi_k}(\xi) = \sum_{k=0}^{n-1} f_k\, s_k \widehat{\phi}(s_k\xi) e^{-ix_k\xi}. \tag{2.5}$$

There exist methods for the fast approximation of such sums for a general choice of frequency samples ξ_m, e.g. NFFT.

Regular grids

For regular grids

$$x_k = x_0 + ks, \quad \xi_j = \xi_0 + j\sigma, \tag{2.6}$$

the evaluation of the integral can be written in the form which uses trigonometric sums as computed in FFTW or in Numpy:

$$\hat{f}_j = \sum_{k=0}^{n-1} f_k e^{-i2\pi jk/n}. \tag{2.7}$$

Hence, the Fourier integral evaluation can be built around established libraries with simple pre- and post-processing steps.

With regular grids, the discretized integral (2.5) evaluated at $\xi = \xi_j$, can be expanded to

$$\widehat{f}(\xi_j) = s\widehat{\phi}(s\xi_j)e^{-ix_0\xi_j} \sum_{k=0}^{n-1} f_k \, e^{-iks\xi_0} \, e^{-ijks\sigma}$$

To reach the form (2.7), the factor depending on both indices j and k must agree with the corresponding factor in the FFT sum. This is achieved by setting

$$\sigma = \frac{2\pi}{ns}, \tag{2.8}$$

finally yielding the representation

$$\hat{f}_j = \widehat{f}(\xi_j) = s\widehat{\phi}(s\xi_j)e^{-ix_0\xi_j} \sum_{k=0}^{n-1} f_k \, e^{-iks\xi_0} \, e^{-i2\pi jk/n}. \tag{2.9}$$

Choice of ξ_0

There is a certain degree of freedom in the choice of the most negative frequency ξ_0. Usually one wants to center the Fourier space grid around zero since most information is typically concentrated there. Point-symmetric grids are the standard choice, however sometimes one explicitly wants to include (for even n) or exclude (for odd n) the zero frequency from the grid, which is achieved by shifting the frequency xi_0 by $-\sigma/2$. This results in two possible choices

$$\xi_{0,\mathrm{n}} = -\frac{\pi}{s} + \frac{\pi}{sn} \quad \text{(no shift)},$$
$$\xi_{0,\mathrm{s}} = -\frac{\pi}{s} \quad \text{(shift)}.$$

For the shifted frequency, the pre-processing factor in the sum in (2.9) can be simplified to

$$e^{-iks\xi_0} = e^{ik\pi} = (-1)^k,$$

which is favorable for real-valued input $\bar{f}$ since this first operation preserves this property. For half-complex transforms, shifting is required.

The factor $\widehat{\phi}(s\xi_j)$

In (2.9), the FT of the kernel ϕ appears as post-processing factor. We give the explicit formulas for the two standard discretizations currently used in ODL, which are nearest neighbor interpolation

$$\phi_{\mathrm{nn}}(x) = \begin{cases} 1, & \text{if } -1/2 \leq x < 1/2, \\ 0, & \text{else}, \end{cases}$$

and linear interpolation

$$\phi_{\text{lin}}(x) = \begin{cases} 1 - |x|, & \text{if } -1 \leq x \leq 1, \\ 0, & \text{else.} \end{cases}$$

Their Fourier transforms are given by

$$\widehat{\phi_{\text{nn}}}(\xi) = (2\pi)^{-1/2}\text{sinc}(\xi/2),$$
$$\widehat{\phi_{\text{lin}}}(\xi) = (2\pi)^{-1/2}\text{sinc}^2(\xi/2).$$

Since their arguments $s\xi_j = s\xi_0 + 2\pi/n$ lie between $-\pi$ and π, these functions introduce only a slight taper towards higher frequencies given the fact that the first zeros lie at $\pm 2\pi$.

Inverse transform

According to (2.2), the inverse of the continuous Fourier transform is given by the same formula as the forward transform (2.1), except for a switched sign in the complex exponential. Hence, this operator can rather be viewed as a variation of the forward FT, and it is implemented via a `sign` parameter in *`FourierTransform`*.

The inverse of the discretized formula (2.9) is instead gained directly using the identity

$$\begin{aligned} \sum_{j=0}^{N-1} e^{i2\pi\frac{(l-k)j}{N}} &= \sum_{j=0}^{N-1} \left(e^{i2\pi\frac{(l-k)}{N}}\right)^j = \begin{cases} N, & \text{if } l = k, \\ \frac{1-e^{i2\pi(l-k)}}{1-e^{i2\pi(l-k)/N}} = 0, & \text{else} \end{cases} \\ &= N\,\delta_{l,k}. \end{aligned} \tag{2.10}$$

By dividing (2.9) with the factor

$$\alpha_j = s\widehat{\psi}(s\xi_j)\, e^{-ix_0\xi_j}$$

before the sum, multiplying with the exponential factor $e^{i2\pi\frac{lj}{N}}$ and summing over j, the coefficients f_k can be recovered:

$$\begin{aligned} \sum_{j=0}^{N-1} \hat{f}_j \frac{1}{\alpha_j} e^{i2\pi\frac{lj}{N}} &= \sum_{j=0}^{N-1}\sum_{k=0}^{N-1} \bar{f}_k\, e^{-i2\pi\frac{jk}{N}} e^{i2\pi\frac{lj}{N}} \\ &= \sum_{k=0}^{N-1} \bar{f}_k\, N\delta_{l,k} \\ &= N\,\bar{f}_l. \end{aligned}$$

Hence, the inversion formula for the discretized FT reads as

$$f_k = e^{iks\xi_0}\,\frac{1}{N}\sum_{j=0}^{N-1} \hat{f}_j\,\frac{1}{s\widehat{\psi}(s\xi_j)}\, e^{ix_0\xi_j}\, e^{i2\pi\frac{kj}{N}}, \tag{2.11}$$

which can be calculated in the same manner as the forward FT, basically by switching the roles of pre- and post-processing steps and flipping the sign in the complex exponentials.

Useful Wikipedia articles

- Fourier Transform
- Lebesgue Space
- Distributions
- Parseval's Identity

CHAPTER 3

Contributing to ODL

3.1 How to document

ODL is documented using sphinx and a modified version of numpydoc. An example documentation is given below.

```
class MyClass(object):

    """Calculate important things.

    The first line summarizes the class, after that comes a blank
    line followed by a more detailed description (both optional).
    Confine the docstring to 72 characters per line. In general, try
    to follow `PEP257`_ in the docstring style.

    Docstrings can have sections with headers, signalized by a
    single-dash underline, e.g. "References". Check out
    `Numpydoc`_ for the recognized section labels.

    References
    ----------
    .. _PEP257: https://www.python.org/dev/peps/pep-0257/
    .. _Numpydoc: https://github.com/numpy/numpy/blob/master/doc/\
HOWTO_DOCUMENT.rst.txt
    """

    def __init__(self, c, parameter=None):
        """Initializer doc goes here.

        Parameters
        ----------
        c : `float`
            Constant to scale by
        parameter : `float`, optional
            Some extra parameter
        """
        self.c = c
        self.parameter = parameter

    def my_method(self, x, y):
        """Calculate ``c * (x + y)``.

        The first row is a summary, after that comes
        a more detailed description.
```

```
        Parameters
        ----------
        x : `float`
            First summand
        y : `float`
            Second summand

        Returns
        -------
        scaled_sum : `float`
            Result of ``c * (x + y)``

        Examples
        --------
        Examples should be working pieces of code and are checked with
        ``doctest`` for consistent output.

        >>> obj = MyClass(5)
        >>> obj(3, 5)
        8.0
        """
        return self.c * (x + y)
```

Some short tips

- Text within backticks: `` `some_target` `` will create a link to the target.
- Make sure that the first line is short and descriptive.
- Examples are often better than long descriptions.

3.1.1 Quick summary of PEP257

- Write docstrings always with triple double quotes `"""`, even one-liners
- Class docstrings are separated from the class definition line by a blank line, functions and methods begin directly in the next line.
- Use imperative style ("Calculate", not "Calculates") in the summary (=first) line and end it with a full stop. Do not add a space after the opening triple quotes.
- For one-liners: put the closing quotes on the same line. Otherwise: make a new line for the closing quotes.
- Document at least all *public* methods and attributes.

Advanced

This section covers advanced topics for developers that need to change how the doc works.

3.1.2 Re-generating the doc

The HTML documentation is generated by running `make html` in the `doc/` folder. Autosummary currently does not support nested modules, so to handle this, we auto-generate `.rst` files for each module. This is done in each invocation of `make html`. If results are inconsistent after changing code (or switching branches), e.g. warnings about missing modules appear, run `make clean` an build the docs from scratch with `make html`.

3.1.3 Modifications to numpydoc

Numpydoc has been modified in the following ways:

- The numpy sphinx domain has been removed.
- More `extra_public_methods` has been added.
- `:autoclass:` summaries now link to full name, which allows subclassing between packages.

3.2 Working with *ODL* source code

Contents:

3.2.1 Introduction

These pages describe a git and github workflow for the ODL project.

There are several different workflows here, for different ways of working with *ODL*.

This is not a comprehensive git reference, it's just a workflow for our own project. It's tailored to the github hosting service. You may well find better or quicker ways of getting stuff done with git, but these should get you started.

For general resources for learning git, see *git resources*.

3.2.2 Install git

Overview

Debian / Ubuntu	`sudo apt-get install git`
Fedora	`sudo yum install git`
Windows	Download and install msysGit
OS X	Use the git-osx-installer

In detail

See the git page for the most recent information.

Have a look at the github install help pages available from github help

There are good instructions here: http://git-scm.com/book/en/v2/Getting-Started-Installing-Git

3.2.3 Following the latest source

These are the instructions if you just want to follow the latest *ODL* source, but you don't need to do any development for now.

The steps are:

- *Install git*
- get local copy of the ODL github git repository
- update local copy from time to time

Get the local copy of the code

From the command line:

```
git clone git://github.com/odlgroup/odl.git
```

You now have a copy of the code tree in the new `odl` directory.

Updating the code

From time to time you may want to pull down the latest code. Do this with:

```
cd odl
git pull
```

The tree in `odl` will now have the latest changes from the initial repository.

3.2.4 Making a patch

You've discovered a bug or something else you want to change in ODL .. — excellent!

You've worked out a way to fix it — even better!

You want to tell us about it — best of all!

The easiest way is to make a *patch* or set of patches. Here we explain how. Making a patch is the simplest and quickest, but if you're going to be doing anything more than simple quick things, please consider following the *Git for development* model instead.

Making patches

Overview

```
# tell git who you are
git config --global user.email you@yourdomain.example.com
git config --global user.name "Your Name Comes Here"
# get the repository if you don't have it
git clone git://github.com/odlgroup/odl.git
# make a branch for your patching
cd odl
git branch the-fix-im-thinking-of
git checkout the-fix-im-thinking-of
# hack, hack, hack
# Tell git about any new files you've made
git add somewhere/tests/test_my_bug.py
# commit work in progress as you go
git commit -am 'BF - added tests for Funny bug'
# hack hack, hack
git commit -am 'BF - added fix for Funny bug'
# make the patch files
git format-patch -M -C master
```

Then, send the generated patch files to the ODL mailing list — where we will thank you warmly.

In detail

1. Tell git who you are so it can label the commits you've made:

```
git config --global user.email you@yourdomain.example.com
git config --global user.name "Your Name Comes Here"
```

2. If you don't already have one, clone a copy of the ODL repository:

```
git clone git://github.com/odlgroup/odl.git
cd odl
```

3. Make a 'feature branch'. This will be where you work on your bug fix. It's nice and safe and leaves you with access to an unmodified copy of the code in the main branch:

```
git branch the-fix-im-thinking-of
git checkout the-fix-im-thinking-of
```

4. Do some edits, and commit them as you go:

```
# hack, hack, hack
# Tell git about any new files you've made
git add somewhere/tests/test_my_bug.py
# commit work in progress as you go
git commit -am 'BF - added tests for Funny bug'
# hack hack, hack
git commit -am 'BF - added fix for Funny bug'
```

   Note the `-am` options to `commit`. The `m` flag just signals that you're going to type a message on the command line. The `a` flag — you can just take on faith — or see why the -a flag?.

5. When you have finished, check you have committed all your changes:

```
git status
```

6. Finally, make your commits into patches. You want all the commits since you branched from the `master` branch:

```
git format-patch -M -C master
```

   You will now have several files named for the commits:

```
0001-BF-added-tests-for-Funny-bug.patch
0002-BF-added-fix-for-Funny-bug.patch
```

   Send these files to the ODL mailing list.

When you are done, to switch back to the main copy of the code, just return to the `master` branch:

```
git checkout master
```

Moving from patching to development

If you find you have done some patches, and you have one or more feature branches, you will probably want to switch to development mode. You can do this with the repository you have.

Fork the ODL repository on github — *Making your own copy (fork) of ODL*. Then:

```
# checkout and refresh master branch from main repo
git checkout master
git pull origin master
# rename pointer to main repository to 'upstream'
git remote rename origin upstream
# point your repo to default read / write to your fork on github
git remote add origin git@github.com:your-user-name/odl.git
# push up any branches you've made and want to keep
git push origin the-fix-im-thinking-of
```

Then you can, if you want, follow the *Development workflow*.

3.2.5 Git for development

Contents:

Making your own copy (fork) of ODL

You need to do this only once. The instructions here are very similar to the instructions at http://help.github.com/forking/ — please see that page for more detail. We're repeating some of it here just to give the specifics for the ODL project, and to suggest some default names.

Set up and configure a github account

If you don't have a github account, go to the github page, and make one.

You then need to configure your account to allow write access — see the `Generating SSH keys` help on github help.

Create your own forked copy of ODL

1. Log into your github account.
2. Go to the ODL github home at ODL github.
3. Click on the *fork* button:

Now, after a short pause and some 'Hardcore forking action', you should find yourself at the home page for your own forked copy of ODL.

Set up your fork

First you follow the instructions for *Making your own copy (fork) of ODL*.

Overview

```
git clone git@github.com:your-user-name/odl.git
cd odl
git remote add upstream git://github.com/odlgroup/odl.git
```

In detail

Clone your fork

1. Clone your fork to the local computer with `git clone git@github.com:your-user-name/odl.git`
2. Investigate. Change directory to your new repo: `cd odl`. Then `git branch -a` to show you all branches. You'll get something like:

```
* master
remotes/origin/master
```

   This tells you that you are currently on the `master` branch, and that you also have a `remote` connection to `origin/master`. What remote repository is `remote/origin`? Try `git remote -v` to see the URLs for the remote. They will point to your github fork.

   Now you want to connect to the upstream ODL github repository, so you can merge in changes from trunk.

Linking your repository to the upstream repo

```
cd odl
git remote add upstream git://github.com/odlgroup/odl.git
```

`upstream` here is just the arbitrary name we're using to refer to the main ODL repository at ODL github.

Note that we've used `git://` for the URL rather than `git@`. The `git://` URL is read only. This means we that we can't accidentally (or deliberately) write to the upstream repo, and we are only going to use it to merge into our own code.

Just for your own satisfaction, show yourself that you now have a new 'remote', with `git remote -v show`, giving you something like:

```
upstream     git://github.com/odlgroup/odl.git (fetch)
upstream     git://github.com/odlgroup/odl.git (push)
origin       git@github.com:your-user-name/odl.git (fetch)
origin       git@github.com:your-user-name/odl.git (push)
```

Configure git

Overview

Your personal git configurations are saved in the `.gitconfig` file in your home directory.

Here is an example `.gitconfig` file:

```
[user]
        name = Your Name
        email = you@yourdomain.example.com

[alias]
        ci = commit -a
```

```
        co = checkout
        st = status
        stat = status
        br = branch
        wdiff = diff --color-words

[core]
        editor = vim

[merge]
        summary = true
```

You can edit this file directly or you can use the `git config --global` command:

```
git config --global user.name "Your Name"
git config --global user.email you@yourdomain.example.com
git config --global alias.ci "commit -a"
git config --global alias.co checkout
git config --global alias.st "status -a"
git config --global alias.stat "status -a"
git config --global alias.br branch
git config --global alias.wdiff "diff --color-words"
git config --global core.editor vim
git config --global merge.summary true
```

To set up on another computer, you can copy your `~/.gitconfig` file, or run the commands above.

In detail

user.name and user.email It is good practice to tell git who you are, for labeling any changes you make to the code. The simplest way to do this is from the command line:

```
git config --global user.name "Your Name"
git config --global user.email you@yourdomain.example.com
```

This will write the settings into your git configuration file, which should now contain a user section with your name and email:

```
[user]
      name = Your Name
      email = you@yourdomain.example.com
```

Of course you'll need to replace `Your Name` and `you@yourdomain.example.com` with your actual name and email address.

Aliases You might well benefit from some aliases to common commands.

For example, you might well want to be able to shorten `git checkout` to `git co`. Or you may want to alias `git diff --color-words` (which gives a nicely formatted output of the diff) to `git wdiff`

The following `git config --global` commands:

```
git config --global alias.ci "commit -a"
git config --global alias.co checkout
git config --global alias.st "status -a"
git config --global alias.stat "status -a"
git config --global alias.br branch
git config --global alias.wdiff "diff --color-words"
```

will create an `alias` section in your `.gitconfig` file with contents like this:

```
[alias]
        ci = commit -a
        co = checkout
        st = status -a
        stat = status -a
        br = branch
        wdiff = diff --color-words
```

Editor You may also want to make sure that your editor of choice is used

```
git config --global core.editor vim
```

Merging To enforce summaries when doing merges (`~/.gitconfig` file again):

```
[merge]
   log = true
```

Or from the command line:

```
git config --global merge.log true
```

Fancy log output This is a very nice alias to get a fancy log output; it should go in the `alias` section of your `.gitconfig` file:

```
lg = log --graph --pretty=format:'%Cred%h%Creset -%C(yellow)%d%Creset %s %Cgreen(%cr) %C(bold blue)[%
```

You use the alias with:

```
git lg
```

and it gives graph / text output something like this (but with color!):

```
* 6d8e1ee - (HEAD, origin/my-fancy-feature, my-fancy-feature) NF - a fancy file (45 minutes ago) [Mat
*   d304a73 - (origin/placeholder, placeholder) Merge pull request #48 from hhuuggoo/master (2 weeks
|\
| * 4aff2a8 - fixed bug 35, and added a test in test_bugfixes (2 weeks ago) [Hugo]
|/
* a7ff2e5 - Added notes on discussion/proposal made during Data Array Summit. (2 weeks ago) [Corran W
* 68f6752 - Initial implimentation of AxisIndexer - uses 'index_by' which needs to be changed to a ca
*   376adbd - Merge pull request #46 from terhorst/master (2 weeks ago) [Jonathan Terhorst]
|\
| * b605216 - updated joshu example to current api (3 weeks ago) [Jonathan Terhorst]
| * 2e991e8 - add testing for outer ufunc (3 weeks ago) [Jonathan Terhorst]
| * 7beda5a - prevent axis from throwing an exception if testing equality with non-axis object (3 wee
| * 65af65e - convert unit testing code to assertions (3 weeks ago) [Jonathan Terhorst]
| *   956fbab - Merge remote-tracking branch 'upstream/master' (3 weeks ago) [Jonathan Terhorst]
| |\
| |/
```

Thanks to Yury V. Zaytsev for posting it.

Development workflow

You already have your own forked copy of the ODL repository, by following *Making your own copy (fork) of ODL*. You have *Set up your fork*. You have configured git by following *Configure git*. Now you are ready for some real work.

Workflow summary

In what follows we'll refer to the upstream ODL `master` branch, as "trunk".

- Don't use your `master` branch for anything. Consider deleting it.
- When you are starting a new set of changes, fetch any changes from trunk, and start a new *feature branch* from that.
- Make a new branch for each separable set of changes — "one task, one branch" (ipython git workflow).
- Name your branch for the purpose of the changes - e.g. `bugfix-for-issue-14` or `refactor-database-code`.
- If you can possibly avoid it, avoid merging trunk or any other branches into your feature branch while you are working.
- If you do find yourself merging from trunk, consider *Rebasing on trunk*
- Ask on the ODL mailing list if you get stuck.
- Ask for code review!

This way of working helps to keep work well organized, with readable history. This in turn makes it easier for project maintainers (that might be you) to see what you've done, and why you did it.

See linux git workflow and ipython git workflow for some explanation.

Consider deleting your master branch

It may sound strange, but deleting your own `master` branch can help reduce confusion about which branch you are on. See deleting master on github for details.

Update the mirror of trunk

First make sure you have done *Linking your repository to the upstream repo*.

From time to time you should fetch the upstream (trunk) changes from github:

```
git fetch upstream
```

This will pull down any commits you don't have, and set the remote branches to point to the right commit. For example, 'trunk' is the branch referred to by (remote/branchname) `upstream/master` - and if there have been commits since you last checked, `upstream/master` will change after you do the fetch.

Make a new feature branch

When you are ready to make some changes to the code, you should start a new branch. Branches that are for a collection of related edits are often called 'feature branches'.

Making an new branch for each set of related changes will make it easier for someone reviewing your branch to see what you are doing.

Choose an informative name for the branch to remind yourself and the rest of us what the changes in the branch are for. For example `add-ability-to-fly`, or `buxfix-for-issue-42`.

```
# Update the mirror of trunk
git fetch upstream
# Make new feature branch starting at current trunk
git branch my-new-feature upstream/master
git checkout my-new-feature
```

Generally, you will want to keep your feature branches on your public github fork of ODL. To do this, you git push this new branch up to your github repo. Generally (if you followed the instructions in these pages, and by default), git will have a link to your github repo, called `origin`. You push up to your own repo on github with:

```
git push origin my-new-feature
```

In git >= 1.7 you can ensure that the link is correctly set by using the `--set-upstream` option:

```
git push --set-upstream origin my-new-feature
```

From now on git will know that `my-new-feature` is related to the `my-new-feature` branch in the github repo.

The editing workflow

Overview

```
# hack hack
git add my_new_file
git commit -am 'NF - some message'
git push
```

In more detail

1. Make some changes
2. See which files have changed with `git status` (see git status). You'll see a listing like this one:

```
# On branch ny-new-feature
# Changed but not updated:
#   (use "git add <file>..." to update what will be committed)
#   (use "git checkout -- <file>..." to discard changes in working directory)
#
#  modified:   README
#
# Untracked files:
#   (use "git add <file>..." to include in what will be committed)
#
#  INSTALL
no changes added to commit (use "git add" and/or "git commit -a")
```

3. Check what the actual changes are with `git diff` (git diff).
4. Add any new files to version control `git add new_file_name` (see git add).
5. To commit all modified files into the local copy of your repo,, do `git commit -am 'A commit message'`. Note the `-am` options to `commit`. The `m` flag just signals that you're going to type a message on the command line. The `a` flag — you can just take on faith — or see why the -a flag? — and the helpful use-case description in the tangled working copy problem. The git commit manual page might also be useful.

6. To push the changes up to your forked repo on github, do a `git push` (see git push).

The commit message Bear in mind that the commit message will be part of the history of the repository, shown by typing `git log`, so good messages will make the history searchable. Don't see the commit message as an annoyance, but rather as an important part of your contribution.

We appreciate if you follow the following style:

1. Start your commit with an acronym, e.g., `BUG`, `TST` or `STY` to indicate what kind of modification you make.
2. Write a one-line summary of your modification no longer than 50 characters. If you have a hard time summarizing you changes, maybe you need to split up the commit into parts.

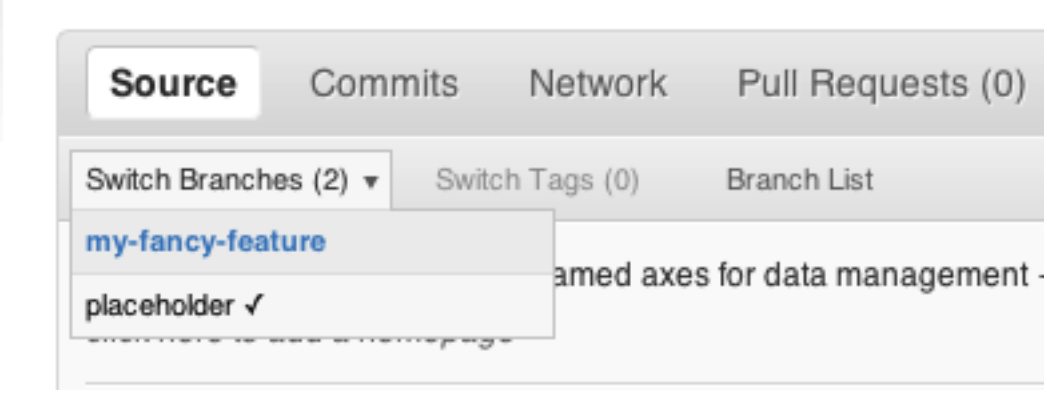
   Use imperative style, i.e. write `add super feature` or `fix horrific bug` rather than `added`, `fixed` .... This saves two characters for something else.

   Don't use markdown. You can refer to issues by writing `#12`. You can even close an issue by writing `closes #12`, but do that only if you are sure.
3. (optional) Write an extended summary. Describe why these changes are necessary and what the new code does better than the old one. You can use markdown here, i.e. create lists, tables, ...

Ask for your changes to be reviewed or merged

When you are ready to ask for someone to review your code and consider a merge:

1. Go to the URL of your forked repo, say `http://github.com/your-user-name/odl`.
2. Use the 'Switch Branches' dropdown menu near the top left of the page to select the branch with your changes:



3. Click on the 'Pull request' button:

Enter a title for the set of changes, and some explanation of what you've done. Say if there is anything you'd like particular attention for - like a complicated change or some code you are not happy with.

If you don't think your request is ready to be merged, just say so in your pull request message. This is still a good way of getting some preliminary code review.

Some other things you might want to do

Delete a branch on github

```
git checkout master
# delete branch locally
git branch -D my-unwanted-branch
# delete branch on github
git push origin :my-unwanted-branch
```

(Note the colon `:` before `test-branch`. See also: http://github.com/guides/remove-a-remote-branch

Several people sharing a single repository If you want to work on some stuff with other people, where you are all committing into the same repository, or even the same branch, then just share it via github.

First fork ODL into your account, as from *Making your own copy (fork) of ODL*.

Then, go to your forked repository github page, say `http://github.com/your-user-name/odl`

Click on the 'Admin' button, and add anyone else to the repo as a collaborator:

Now all those people can do:

```
git clone git@githhub.com:your-user-name/odl.git
```

Remember that links starting with `git@` use the ssh protocol and are read-write; links starting with `git://` are read-only.

Your collaborators can then commit directly into that repo with the usual:

```
git commit -am 'ENH - much better code'
git push origin master # pushes directly into your repo
```

Explore your repository To see a graphical representation of the repository branches and commits:

```
gitk --all
```

To see a linear list of commits for this branch:

```
git log
```

You can also look at the network graph visualizer for your github repo.

Finally the *Fancy log output* `lg` alias will give you a reasonable text-based graph of the repository.

Rebasing on trunk Let's say you thought of some work you'd like to do. You *Update the mirror of trunk* and *Make a new feature branch* called `cool-feature`. At this stage trunk is at some commit, let's call it E. Now you make some new commits on your `cool-feature` branch, let's call them A, B, C. Maybe your changes take a while, or you come back to them after a while. In the meantime, trunk has progressed from commit E to commit (say) G:

```
      A---B---C cool-feature
     /
D---E---F---G trunk
```

At this stage you consider merging trunk into your feature branch, and you remember that this here page sternly advises you not to do that, because the history will get messy. Most of the time you can just ask for a review, and not worry that trunk has got a little ahead. But sometimes, the changes in trunk might affect your changes, and you need to harmonize them. In this situation you may prefer to do a rebase.

rebase takes your changes (A, B, C) and replays them as if they had been made to the current state of `trunk`. In other words, in this case, it takes the changes represented by A, B, C and replays them on top of G. After the rebase, your history will look like this:

```
              A'--B'--C' cool-feature
             /
D---E---F---G trunk
```

See rebase without tears for more detail.

To do a rebase on trunk:

```
# Update the mirror of trunk
git fetch upstream
# go to the feature branch
git checkout cool-feature
# make a backup in case you mess up
git branch tmp cool-feature
# rebase cool-feature onto trunk
git rebase --onto upstream/master upstream/master cool-feature
```

In this situation, where you are already on branch `cool-feature`, the last command can be written more succinctly as:

```
git rebase upstream/master
```

When all looks good you can delete your backup branch:

```
git branch -D tmp
```

If it doesn't look good you may need to have a look at *Recovering from mess-ups*.

If you have made changes to files that have also changed in trunk, this may generate merge conflicts that you need to resolve - see the git rebase man page for some instructions at the end of the "Description" section. There is some related help on merging in the git user manual - see resolving a merge.

Recovering from mess-ups Sometimes, you mess up merges or rebases. Luckily, in git it is relatively straightforward to recover from such mistakes.

If you mess up during a rebase:

```
git rebase --abort
```

If you notice you messed up after the rebase:

```
# reset branch back to the saved point
git reset --hard tmp
```

If you forgot to make a backup branch:

```
# look at the reflog of the branch
git reflog show cool-feature

8630830 cool-feature@{0}: commit: BUG: io: close file handles immediately
278dd2a cool-feature@{1}: rebase finished: refs/heads/my-feature-branch onto 11ee694744f2552d
26aa21a cool-feature@{2}: commit: BUG: lib: make seek_gzip_factory not leak gzip obj
...

# reset the branch to where it was before the botched rebase
git reset --hard cool-feature@{2}
```

Rewriting commit history

Note: Do this only for your own feature branches.

There's an embarrassing typo in a commit you made? Or perhaps the you made several false starts you would like the posterity not to see.

This can be done via *interactive rebasing*.

Suppose that the commit history looks like this:

```
git log --oneline
eadc391 Fix some remaining bugs
a815645 Modify it so that it works
2dec1ac Fix a few bugs + disable
13d7934 First implementation
6ad92e5 * masked is now an instance of a new object, MaskedConstant
29001ed Add pre-nep for a copule of structured_array_extensions.
...
```

and `6ad92e5` is the last commit in the `cool-feature` branch. Suppose we want to make the following changes:

- Rewrite the commit message for `13d7934` to something more sensible.
- Combine the commits `2dec1ac`, `a815645`, `eadc391` into a single one.

We do as follows:

```
# make a backup of the current state
git branch tmp HEAD
# interactive rebase
git rebase -i 6ad92e5
```

This will open an editor with the following text in it:

```
pick 13d7934 First implementation
pick 2dec1ac Fix a few bugs + disable
pick a815645 Modify it so that it works
pick eadc391 Fix some remaining bugs

# Rebase 6ad92e5..eadc391 onto 6ad92e5
#
# Commands:
#  p, pick = use commit
```

```
#  r, reword = use commit, but edit the commit message
#  e, edit = use commit, but stop for amending
#  s, squash = use commit, but meld into previous commit
#  f, fixup = like "squash", but discard this commit's log message
#
# If you remove a line here THAT COMMIT WILL BE LOST.
# However, if you remove everything, the rebase will be aborted.
#
```

To achieve what we want, we will make the following changes to it:

```
r 13d7934 First implementation
pick 2dec1ac Fix a few bugs + disable
f a815645 Modify it so that it works
f eadc391 Fix some remaining bugs
```

This means that (i) we want to edit the commit message for `13d7934`, and (ii) collapse the last three commits into one. Now we save and quit the editor.

Git will then immediately bring up an editor for editing the commit message. After revising it, we get the output:

```
[detached HEAD 721fc64] FOO: First implementation
 2 files changed, 199 insertions(+), 66 deletions(-)
[detached HEAD 0f22701] Fix a few bugs + disable
 1 files changed, 79 insertions(+), 61 deletions(-)
Successfully rebased and updated refs/heads/my-feature-branch.
```

and the history looks now like this:

```
0f22701 Fix a few bugs + disable
721fc64 ENH: Sophisticated feature
6ad92e5 * masked is now an instance of a new object, MaskedConstant
```

If it went wrong, recovery is again possible as explained *above*.

Maintainer workflow

This page is for maintainers — those of us who merge our own or other peoples' changes into the upstream repository.

Being as how you're a maintainer, you are completely on top of the basic stuff in *Development workflow*.

The instructions in *Linking your repository to the upstream repo* add a remote that has read-only access to the upstream repo. Being a maintainer, you've got read-write access.

It's good to have your upstream remote have a scary name, to remind you that it's a read-write remote:

```
git remote add upstream-rw git@github.com:odlgroup/odl.git
git fetch upstream-rw
```

Integrating changes

Let's say you have some changes that need to go into trunk (`upstream-rw/master`).

The changes are in some branch that you are currently on. For example, you are looking at someone's changes like this:

```
git remote add someone git://github.com/someone/odl.git
git fetch someone
git branch cool-feature --track someone/cool-feature
git checkout cool-feature
```

So now you are on the branch with the changes to be incorporated upstream. The rest of this section assumes you are on this branch.

A few commits If there are only a few commits, consider rebasing to upstream:

```
# Fetch upstream changes
git fetch upstream-rw
# rebase
git rebase upstream-rw/master
```

Remember that, if you do a rebase, and push that, you'll have to close any github pull requests manually, because github will not be able to detect the changes have already been merged.

A long series of commits If there are a longer series of related commits, consider a merge instead:

```
git fetch upstream-rw
git merge --no-ff upstream-rw/master
```

The merge will be detected by github, and should close any related pull requests automatically.

Note the `--no-ff` above. This forces git to make a merge commit, rather than doing a fast-forward, so that these set of commits branch off trunk then rejoin the main history with a merge, rather than appearing to have been made directly on top of trunk.

Check the history Now, in either case, you should check that the history is sensible and you have the right commits:

```
git log --oneline --graph
git log -p upstream-rw/master..
```

The first line above just shows the history in a compact way, with a text representation of the history graph. The second line shows the log of commits excluding those that can be reached from trunk (`upstream-rw/master`), and including those that can be reached from current HEAD (implied with the `..` at the end). So, it shows the commits unique to this branch compared to trunk. The `-p` option shows the diff for these commits in patch form.

Push to trunk

```
git push upstream-rw my-new-feature:master
```

This pushes the `my-new-feature` branch in this repository to the `master` branch in the `upstream-rw` repository.

3.2.6 git resources

Tutorials and summaries

- github help has an excellent series of how-to guides.
- learn.github has an excellent series of tutorials
- The pro git book is a good in-depth book on git.

- A git cheat sheet is a page giving summaries of common commands.
- The git user manual
- The git tutorial
- The git community book
- git ready — a nice series of tutorials
- git casts — video snippets giving git how-tos.
- git magic — extended introduction with intermediate detail
- The git parable is an easy read explaining the concepts behind git.
- git foundation expands on the git parable.
- Fernando Perez' git page — Fernando's git page — many links and tips
- A good but technical page on git concepts
- git svn crash course: git for those of us used to subversion

Advanced git workflow

There are many ways of working with git; here are some posts on the rules of thumb that other projects have come up with:

- Linus Torvalds on git management
- Linus Torvalds on linux git workflow . Summary; use the git tools to make the history of your edits as clean as possible; merge from upstream edits as little as possible in branches where you are doing active development.

Manual pages online

You can get these on your own machine with (e.g) `git help push` or (same thing) `git push --help`, but, for convenience, here are the online manual pages for some common commands:

- git add
- git branch
- git checkout
- git clone
- git commit
- git config
- git diff
- git log
- git pull
- git push
- git remote
- git status

CHAPTER 4

Frequently asked questions

Abbreviations: **Q** uestion – **P** roblem – **S** olution

4.1 General errors

1. **Q:** When importing `odl`, the following error is shown:

```
File "/path/to/odl/odl/__init__.py", line 36

  from . import diagnostics

  ImportError: cannot import diagnostics
```

   P: When you for the first time import (=execute) a module or execute a script, a bytecode file is created, basically to speed up execution next time. If you installed `odl` with `pip -e` (`--editable`), these files can interfere with changes to your codebase.

   S: Delete the bytecode files. In a standard GNU/Linux shell, you can simply invoke (in your `odl` working directory)

```
find . -name *.pyc | xargs rm
```

2. **Q:** When adding two vectors, the following error is shown:

```
TypeError: unsupported operand type(s) for -: 'DiscreteLpVector' and 'DiscreteLpVector'
```

   P: The vectors you are trying to add are not in the same space, for example the following code gives the error

```
>>> x = odl.uniform_discr(0, 1, 10).one()
>>> y = odl.uniform_discr(0, 1, 11).one()
>>> x - y
```

   In this case, the problem is that the vectors have a different number of elements. Other possible issues include that they are discretizations of different sets, have different data types (*dtype*), or implementation (for example cuda/cpu).

   S: The vectors need to somehow be cast to the same space. How to do this depends on the problem at hand. To find what the issue is, inspect the `space` properties of both vectors. For example in the above we see that the issue lies in the number of discretization points

```
>>> x.space
odl.uniform_discr(0, 1, 10)
```

```
>>> y.space
odl.uniform_discr(0, 1, 11)
```

- In the case of spaces being discretizations of different underlying spaces, a transformation of some kind has to be applied (for example by using an operator). In general, errors like this indicates a conceptual issue with the code, for example a "we identify X with Y" step has been omitted.
- If the `dtype` or `impl` do not match, they need to be cast to each one of the others. The most simple way to do this is by using the `DiscreteLpVector.astype` method.

3. **Q:** I have installed ODL with the `pip install --editable` option, but I still get an `AttributeError` when I try to use a function/class I just implemented. The use-without-reinstall thing does not seem to work. What am I doing wrong?

   P: You probably use an IDE like Spyder with integrated editor, console, etc. While your installation of the ODL *package* sees the changes immediately, the console still sees the version of the package *before the changes since it was opened*.

   S: Simply close the current console and open a new one.

4.2 Errors related to Python 2/3

1. **Q:** I follow your recommendation to call `super().__init__(dom, ran)` in the `__init__()` method of `MyOperator`, but I get the following error:

```
File <...>, line ..., in __init__
        super().__init__(dom, ran)

TypeError: super() takes at least 1 argument (0 given)
```

   P: The `super()` function in Python 2 has to be called with a type as first argument, whereas in Python 3, the type argument is optional and usually not needed.

   S: We recommend to include `from builtins import super` in your module to backport the new Py3 `super()` function. This way, your code will run in both Python 2 and 3.

4.3 Usage

1. **Q:** I want to write an *Operator* with two input arguments, for example

$$op(x, y) := x + y$$

   However, ODL only supports single arguments. How do I do this?

   P: Mathematically, such an operator is defined as

$$\mathcal{A} : \mathcal{X}_1 \times \mathcal{X}_2 \to \mathcal{Z}$$

   ODL adhers to the strict definition of this and hence only takes one parameter $x \in \mathcal{X}_1 \times \mathcal{X}_2$. This product space element x is then a tuple of elements $x = (x_1, x_2), x_1 \in \mathcal{X}_1, x_2 \in \mathcal{X}_2$.

   S: Make the domain of the operator a *ProductSpace* if $\mathcal{X}_1$ and $\mathcal{X}_2$ are *LinearSpace*'s, or a *CartesianProduct* if they are mere *Set*'s. Mathematically, this corresponds to

$$op([x, y]) := x + y$$

   Of course, a number of input arguments larger than 2 can be treated analogously.

CHAPTER 5

Glossary

array-like Any data structure which can be converted into a `numpy.ndarray` by the `numpy.array` constructor. Includes all *`NtuplesBaseVector`* based classes.

dtype Short for data type, indicates the way data is represented internally. For example `float32` means 32-bit floating point numbers. See numpy dtype for more details.

discretization Structure to handle the mapping between abstract objects (e.g. functions) and concrete, finite realization. It encompasses an abstract *`Set`*, a finite data container (*`NtuplesBaseVector`* in general) and the mappings between them, *restriction* and *extension*.

domain Set of elements to which an operator can be applied.

element Saying that `x` is an element of a given *`Set`* `my_set` means that `x in my_set` evaluates to `True`. The term is typically used as "element of <set>" or "<set>" element. When referring to a *`LinearSpace`* like, e.g., *`DiscreteLp`*, an element is of the corresponding type *`LinearSpaceVector`*, i.e. *`DiscreteLpVector`* in the above example. Elements of a set can be created by the *`Set.element`* method.

element-like Any data structure which can be converted into an *element* of a *`Set`* by the *`Set.element`* method. For example, an `Rn(3) element-like` is any *array-like* object with 3 real entries.

Example: `'DiscreteLp' element-like` means that *`DiscreteLp.element`* can create a *`DiscreteLpVector`* from the input.

extension Operator in a *discretization* mapping a concrete (finite-dimensional) object to an abstract (infinite-dimensional) one. Example: *`LinearInterpolation`*.

in-place evaluation Operator evaluation method which uses an existing data container to store the result. Usually more efficient than *out-of-place evaluation* since no new memory is allocated and no data is copied.

meshgrid Tuple of arrays defining a tensor grid by all possible combinations of entries, one from each array. In 2 dimensions, for example, the arrays `[1, 2]` and `[-1, 0, 1]` define the grid points `(1, -1), (1, 0), (1, 1), (2, -1), (2, 0), (2, 1)`.

operator Mathematical notion for a mapping between arbitrary vector spaces. This includes the important special case of an operator taking a (discretized) function as an input and returning another function. For example, the Fourier Transform maps a function to its transformed version. Operators of this type are the most prominent use case in ODL. See *the in-depth guide on operators* for details on their implementation.

order Ordering of the axes in a multi-dimensional array with linear (one-dimensional) storage. For C ordering (`'C'`), the last axis has smallest stride (varies fastest), and the first axis has largest stride (varies slowest). Fortran ordering (`'F'`) is the exact opposite.

out-of-place evaluation Operator evaluation method which creates a new data container to store the result. Usually less efficient than *in-place evaluation* since new memory is allocated and data needs to be copied.

range Set of elements to which an operator maps, i.e. in which the result of an operator evaluation lies.

restriction Operator in a *discretization* mapping an abstract (infinite-dimensional) object to a concrete (finite-dimensional) one. Example: `PointCollocation`.

vectorization Ability of a function to be evaluated on a grid in a single call rather than looping over the grid points. Vectorized evaluation gives a huge performance boost compared to Python loops (at least if there is no JIT) since loops are implemented in optimized C code.

The vectorization concept in ODL differs slightly from the one in NumPy in that arguments have to be passed as a single tuple rather than a number of (positional) arguments. See numpy vectorization for more details.

CHAPTER 6

Release Notes

6.1 ODL 0.2.2 Release Notes (2016-03-11)

From this release on, ODL can be installed through `pip` directly from the Python package index.

6.2 ODL 0.2.1 Release Notes (2016-03-11)

Fix for the version number in setup.py.

6.3 ODL 0.2 Release Notes (2016-03-11)

This release adds the functionality of the **Fourier Transform** in arbitrary dimensions. The operator comes in two different flavors: the "bare", trigonometric-sum-only Discrete Fourier Transform and the discretization of the continuous Fourier Transform.

6.3.1 New Features

Fourier Transform (FT)

The FT is an *operator* mapping a function to its transformed version (shown for 1d):

$$\widehat{f}(\xi) = \mathcal{F}(f)(\xi) = (2\pi)^{-\frac{1}{2}} \int_{\mathbb{R}} f(x)\, e^{-ix\xi}\, \mathrm{d}x, \quad \xi \in \mathbb{R}.$$

This implementation acts on discretized functions and accounts for scaling and shift of the underlying grid as well as the type of discretization used. Supported backends are Numpy's FFTPACK based transform and pyFFTW (Python wrapper for FFTW). The implementation has full support for the wrapped backends, including

- Forward and backward transforms,
- Half-complex transfroms, i.e. real-to-complex transforms where roughly only half of the coefficients need to be stored,
- Partial transforms along selected axes,
- Computation of efficient FFT plans (pyFFTW only).

Discrete Fourier Transform (DFT)

This operator merely calculates the trigonometric sum

$$\hat{f}_j = \sum_{k=0}^{n-1} f_k \, e^{-i2\pi jk/n}, \quad j = 0, \dots, n-1$$

without accounting for shift and scaling of the underlying grid. It supports the same features of the wrapped backends as the FT.

Further additions

- The `weighting` attribute in *`FnBase`* is now public and can be used to initialize a new space.
- The *`FnBase`* classes now have a `default_dtype` static method.
- A *`discr_sequence_space`* has been added as a simple implementation of finite sequences with multi-indexing.
- *`DiscreteLp`* and *`FunctionSpace`* elements now have `real` and `imag` with setters as well as a `conj()` method.
- *`FunctionSpace`* explicitly handles output data type and allows this attribute to be chosen during initialization.
- *`FunctionSpace`*, *`FnBase`* and *`DiscreteLp`* spaces support creation of a copy with different data type via the `astype()` method.
- New `conj_exponent()` utility to get the conjugate of a given exponent.

6.3.2 Improvements

- Handle some not-so-unlikely corner cases where vectorized functions don't behave as they should. The main issue was the way Python 2 treats comparisons of tuples against scalars (Python 3 raises an exception which is correctly handled by the subsequent code). In Python 2, the following happens:

```
>>> t = ()
>>> t > 0
True
>>> t = (-1,)
>>> t > 0
True
```

  This is especially unfortunate if used as `t[t > 0]` in 1d functions, when `t` is a *meshgrid* sequence (of 1 element). In this case, `t > 0` evaluates to `True`, which is treated as `1` in the index expression, which in turn will raise an `IndexError` since the sequence has only length one. This situation is now properly caught.

- `x ** 0` evaluates to the `one()` space element if implemented.

6.3.3 Changes

- Move *`fast_1d_tensor_mult`* to the `numerics.py` module.

6.4 ODL 0.1 Release Notes (2016-03-08)

First official release.

CHAPTER 7

References

CHAPTER 8

odl

ODL is a functional analysis library with a focus on discretization.

ODL suppors abstract sets, linear vector spaces defined on such and Operators/Functionals defined on these sets. It is intended to be used to write general code and faciliate code reuse.

Modules

8.1 diagnostics

Automated tests for ODL.

Modules

8.1.1 examples

Functions for generating standardized examples in spaces.

Functions

samples(*sets)	Generate some samples from the given sets.
scalar_examples(field)	Generate example scalars in `field`.
vector_examples(space)	Generate example vectors in `space`.

samples

odl.diagnostics.examples.**samples**(**sets*)

Generate some samples from the given sets.

Currently supports vectors according to *vector_examples* and scalars according to *scalar_examples*.

Parameters*sets : *Set* instance(s)

Returnssamples : `generator`

Generator that yields tuples of examples from the sets.

scalar_examples

odl.diagnostics.examples.**scalar_examples**(*field*)
Generate example scalars in `field`.

Parametersfield : *Field*

The field to generate examples from

Returnsexamples : `generator`

Yields elements in `field`

vector_examples

odl.diagnostics.examples.**vector_examples**(*space*)
Generate example vectors in `space`.

Parametersspace : *LinearSpace*

The space to generate examples from

Returnsexamples : `generator`

Yields tuples (`string`, *LinearSpaceVector*) where `string` is a short description of the vector

8.1.2 operator

Standardized tests for *Operator*'s.

Classes

OperatorTest(operator[, operator_norm])	Automated tests for *Operator* implementations.

OperatorTest

class odl.diagnostics.operator.**OperatorTest**(*operator*, *operator_norm=None*)
Bases: `object`

Automated tests for *Operator* implementations.

This class allows users to automatically test various features of an Operator such as linearity and the adjoint definition.

Methods

`__eq__`	Return self==value.
adjoint()	Verify that *Operator.adjoint* works appropriately.
derivative([step])	Verify that *Operator.derivative* works appropriately.
linear()	Verify that the operator is actually linear.
norm()	Estimate the operator norm of the operator.

Continued on next page

Table 8.3 – continued from previous page

run_tests()	Run all tests on this operator.
self_adjoint()	Verify (Ax, y) = (x, Ay)

OperatorTest.adjoint

OperatorTest.**adjoint**()
Verify that *Operator.adjoint* works appropriately.

References

Wikipedia article on Adjoint.

OperatorTest.derivative

OperatorTest.**derivative**(*step=0.0001*)
Verify that *Operator.derivative* works appropriately.

References

Wikipedia article on Derivative. Wikipedia article on Frechet derivative.

OperatorTest.linear

OperatorTest.**linear**()
Verify that the operator is actually linear.

OperatorTest.norm

OperatorTest.**norm**()
Estimate the operator norm of the operator.

The norm is estimated by calculating

```
A(x).norm() / x.norm()
```

for some nonzero `x`

Returnsnorm : `float`

Estimate of operator norm

References

Wikipedia article on Operator norm.

OperatorTest.run_tests

OperatorTest.**run_tests**()
Run all tests on this operator.

OperatorTest.self_adjoint

OperatorTest.**self_adjoint**()
Verify (Ax, y) = (x, Ay)

__init__(*operator*, *operator_norm=None*)
Create a new instance

Parametersoperator : *Operator*

The operator to run tests on

operator_norm : float

The norm of the operator, used for error estimates can be estimated otherwise.

8.1.3 space

Standardized tests for *LinearSpace*'s.

Classes

SpaceTest(space[, eps])	Automated tests for *LinearSpace* instances.

SpaceTest

class odl.diagnostics.space.**SpaceTest**(*space*, *eps=1e-05*)
Bases: object

Automated tests for *LinearSpace* instances.

This class allows users to automatically test various features of an LinearSpace such as linearity and the various operators.

Methods

__eq__	Return self==value.
_lincomb()	Check linear combination.
contains()	Verify *LinearSpace.__contains__*.
dist()	Verify *LinearSpace.dist*.
element()	Verify *LinearSpace.element*
equals()	Verify *LinearSpace.__eq__*.
field()	Verify *LinearSpace.field*
inner()	Verify *LinearSpace.inner*.
linearity()	Verify the linear space properties by examples.
multiply()	Verify *LinearSpace.multiply*.
norm()	Verify *LinearSpace.norm*.
run_tests()	Run all tests on this space.
vector()	Verify *LinearSpaceVector*.
vector_assign()	Verify *LinearSpaceVector.assign*.
vector_copy()	Verify *LinearSpaceVector.copy*.

Continued on next page

Table 8.5 – continued from previous page

vector_equals()	Verify *LinearSpaceVector.__eq__*.
vector_set_zero()	Verify *LinearSpaceVector.set_zero*.
vector_space()	Verify *LinearSpaceVector.space*.

SpaceTest._lincomb

SpaceTest.**_lincomb**()
Check linear combination.

SpaceTest.contains

SpaceTest.**contains**()
Verify *LinearSpace.__contains__*.

SpaceTest.dist

SpaceTest.**dist**()
Verify *LinearSpace.dist*.

The dist satisfies properties

positivity `d(x, y) >= 0`

coincidence `d(x, y) = 0` iff `x = y`

symmetry `d(x, y) = d(y, x)`

triangle inequality `d(x, z) = d(x, y) + d(y, z)`

References

Wikipedia article on metric

SpaceTest.element

SpaceTest.**element**()
Verify *LinearSpace.element*

SpaceTest.equals

SpaceTest.**equals**()
Verify *LinearSpace.__eq__*.

SpaceTest.field

SpaceTest.**field**()
Verify *LinearSpace.field*

SpaceTest.inner

SpaceTest.**inner**()

Verify *LinearSpace.inner*.

The inner product satisfies properties such as

conjugate symmetry `(x, y) = (y, x)^*` (^* complex conjugate)

linearity `(a * x, y) = a * (x, y) (x + y, z) = (x, z) + (y, z)`

positivity `(x, x) >= 0`

References

Wikipedia article on inner product.

SpaceTest.linearity

SpaceTest.**linearity**()

Verify the linear space properties by examples.

These properties include things such as associativity

`x + y = y + x`

and identity of the *LinearSpace.zero* element

`x + 0 = x`

References

Wikipedia article on Vector space.

SpaceTest.multiply

SpaceTest.**multiply**()

Verify *LinearSpace.multiply*.

Multiplication satisfies

Zero element `0 * x = 0`

Commutativity `x * y = y * x`

Associativity `x * (y * z) = (x * y) * z`

Distributivity `a * (x + y) = a * x + a * y x * (y + z) = x * y + x * z`

SpaceTest.norm

SpaceTest.**norm**()

Verify *LinearSpace.norm*.

The norm satisfies properties

linearity `||a * x|| = |a| * ||x||`

triangle inequality `||x + y|| = ||x|| + ||y||`

separation `||x|| = 0` iff `x = 0`

positivity `||x|| >= 0`

References

Wikipedia article on norm.

SpaceTest.run_tests

`SpaceTest.`**`run_tests`**`()`
Run all tests on this space.

SpaceTest.vector

`SpaceTest.`**`vector`**`()`
Verify *LinearSpaceVector*.

SpaceTest.vector_assign

`SpaceTest.`**`vector_assign`**`()`
Verify *LinearSpaceVector.assign*.

SpaceTest.vector_copy

`SpaceTest.`**`vector_copy`**`()`
Verify *LinearSpaceVector.copy*.

SpaceTest.vector_equals

`SpaceTest.`**`vector_equals`**`()`
Verify *LinearSpaceVector.__eq__*.

SpaceTest.vector_set_zero

`SpaceTest.`**`vector_set_zero`**`()`
Verify *LinearSpaceVector.set_zero*.

SpaceTest.vector_space

`SpaceTest.`**`vector_space`**`()`
Verify *LinearSpaceVector.space*.

`__init__`(*space*, *eps=1e-05*)
Initialize a new instance.

Parameters
space : *LinearSpace*

The space that should be tested

eps : `float`, optional

Precision of the tests.

8.2 discr

Discretizations in ODL.

Modules

8.2.1 discr_mappings

Mappings between abstract (continuous) and discrete sets.

Includes grid evaluation (collocation) and various interpolation operators.

Classes

FunctionSetMapping(map_type, fset, ...[, linear])	Abstract base class for function set discretization mappings.
LinearInterpolation(fspace, partition, ...)	Linear interpolation interpolation as an *Operator*.
NearestInterpolation(fset, partition, ...)	Nearest neighbor interpolation as an *Operator*.
PerAxisInterpolation(fspace, partition, ...)	Interpolation scheme set for each axis individually.
PointCollocation(ip_fset, partition, dspace, ...)	Function evaluation at grid points.

FunctionSetMapping

class `odl.discr.discr_mappings.`**`FunctionSetMapping`**(*map_type*, *fset*, *partition*, *dspace*, *linear=False*, ***kwargs*)

Bases: *odl.operator.operator.Operator*

Abstract base class for function set discretization mappings.

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
grid	The sampling grid.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
order	Axis ordering in the data storage.
partition	The underlying domain partition.
range	Set in which the result of an evaluation of this operator lies.

FunctionSetMapping.adjoint

FunctionSetMapping.**adjoint**
The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

FunctionSetMapping.domain

FunctionSetMapping.**domain**
Set of objects on which this operator can be evaluated.

FunctionSetMapping.grid

FunctionSetMapping.**grid**
The sampling grid.

FunctionSetMapping.inverse

FunctionSetMapping.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

FunctionSetMapping.is_functional

FunctionSetMapping.**is_functional**
`True` if the this operator's range is a *Field*.

FunctionSetMapping.is_linear

FunctionSetMapping.**is_linear**
`True` if this operator is linear.

FunctionSetMapping.order

FunctionSetMapping.**order**
Axis ordering in the data storage.

FunctionSetMapping.partition

FunctionSetMapping.**partition**
The underlying domain partition.

FunctionSetMapping.range

`FunctionSetMapping.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__(other)	
_call(x[, out])	Implementation of the operator evaluation.
derivative(point)	Return the operator derivative at `point`.

FunctionSetMapping.__call__

`FunctionSetMapping.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

FunctionSetMapping.__eq__

`FunctionSetMapping.__eq__(other)`

FunctionSetMapping._call

`FunctionSetMapping._call(x, out=None, **kwargs)`

Implementation of the operator evaluation.

This method is the private backend for the evaluation of an operator. It needs to match certain signature conventions, and its implementation type is inferred from its signature.

The following signatures are allowed:

Python 2 and 3:

- `_call(self, x)` –> out-of-place evaluation
- `_call(self, vec, out)` –> in-place evaluation
- `_call(self, x, out=None)` –> both

Python 3 only:

- `_call(self, x, *, out=None)` (`out` as keyword-only argument) –> both

For disambiguation, the instance name (the first argument) **must** be 'self'.

The name of the `out` argument **must** be 'out', the second argument may have any name.

Additional variable `**kwargs` and keyword-only arguments (Python 3 only) are also allowed.

Parametersx : *Operator.domain element-like*

Element to which the operator is applied

out : *Operator.range element*, optional

Element to which the result is written

Returnsout : *Operator.range element-like*

Result of the evaluation. If `out` was provided, the returned object is a reference to it.

Notes

Some general advice on how to implement operator evaluation:

- If you just write a quick implementation or are not too worried about efficiency, it may be easiest to write the evaluation *out of place*.
- We recommend advanced and performance-aware users to implement the *in-place* pattern if the wrapped code supports it. In-place evaluation is usually significantly faster since it avoids the allocation of new memory and a copy compared to out-of-place evaluation.

- If there is a significant performance gain from implementing an out-of-place method separately, use the pattern for both (`out` optional) and decide according to the given `out` parameter which one to use.
- If your evaluation code does not support in-place evaluation, use the out-of-place pattern.

Note that the public call pattern `op()` using `op.__call__` provides a default implementation of the underlying in-place or out-of-place call even if you choose the respective other pattern.

See the documentation for more info on in-place vs. out-of-place evaluation.

FunctionSetMapping.derivative

`FunctionSetMapping.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*map_type*, *fset*, *partition*, *dspace*, *linear=False*, ***kwargs*)

Initialize a new instance.

Parametersmap_type : {'restriction', 'extension'}

The type of operator

fset : *FunctionSet*

The non-discretized (abstract) set of functions to be discretized

partition : *RectPartition*

Partition of (a subset of) `fset.domain` based on a *TensorGrid*

dspace : *NtuplesBase*

Data space providing containers for the values of a discretized object. Its *NtuplesBase.size* must be equal to the total number of grid points.

linear : bool

Create a linear operator if `True`, otherwise a non-linear operator.

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

LinearInterpolation

class `odl.discr.discr_mappings.`**`LinearInterpolation`**(*fspace*, *partition*, *dspace*, ***kwargs*)

Bases: *odl.discr.discr_mappings.FunctionSetMapping*

Linear interpolation interpolation as an *Operator*.

Attributes

adjoint	The operator adjoint (abstract).

Continued on next page

Table 8.9 – continued from previous page

domain	Set of objects on which this operator can be evaluated.
grid	The sampling grid.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
order	Axis ordering in the data storage.
partition	The underlying domain partition.
range	Set in which the result of an evaluation of this operator lies.

LinearInterpolation.adjoint

`LinearInterpolation.`**`adjoint`**
The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

LinearInterpolation.domain

`LinearInterpolation.`**`domain`**
Set of objects on which this operator can be evaluated.

LinearInterpolation.grid

`LinearInterpolation.`**`grid`**
The sampling grid.

LinearInterpolation.inverse

`LinearInterpolation.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

LinearInterpolation.is_functional

`LinearInterpolation.`**`is_functional`**
`True` if the this operator's range is a *Field*.

LinearInterpolation.is_linear

`LinearInterpolation.`**`is_linear`**
`True` if this operator is linear.

LinearInterpolation.order

`LinearInterpolation.`**`order`**
Axis ordering in the data storage.

LinearInterpolation.partition

`LinearInterpolation.`**`partition`**
The underlying domain partition.

LinearInterpolation.range

`LinearInterpolation.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__(other)	
_call(x[, out])	Create an interpolator from grid values `x`.
derivative(point)	Return the operator derivative at `point`.

LinearInterpolation.__call__

`LinearInterpolation.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

LinearInterpolation.__eq__

LinearInterpolation.**__eq__**(*other*)

LinearInterpolation._call

LinearInterpolation.**_call**(*x*, *out=None*)

Create an interpolator from grid values `x`.

Parametersx : *FnBaseVector*

The array of values to be interpolated

out : *FunctionSpaceVector*, optional

Vector in which to store the interpolator

Returnsout : *FunctionSpaceVector*

Linear interpolator for the grid of this operator. If `out` was provided, the returned object is a reference to it.

LinearInterpolation.derivative

LinearInterpolation.**derivative**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*fspace*, *partition*, *dspace*, ***kwargs*)

Initialize a new instance.

Parametersfspace : *FunctionSpace*

The undiscretized (abstract) space of functions to be discretized. Its field must be the same as that of data space. The function domain must provide a *Set.contains_set* method.

partition : *RectPartition*

Partition of (a subset of) `fspace.domain` based on a *TensorGrid*

dspace : *FnBase*

Data space providing containers for the values of a discretized object. Its *NtuplesBase.size* must be equal to the total number of grid points, and its *FnBase.field* must be the same as that of the function space.

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

NearestInterpolation

class `odl.discr.discr_mappings.`**`NearestInterpolation`**(*fset*, *partition*, *dspace*, ***kwargs*)

Bases: *odl.discr.discr_mappings.FunctionSetMapping*

Nearest neighbor interpolation as an *Operator*.

Given points `x1 < x2 < ... < xN`, and values `f1, ..., fN`, nearest neighbor interpolation at `x` is defined by:

```
I(x) = fj  with j such that |x - xj| is minimal.
```

The ambiguity at the midpoints is resolved by preferring one of the neighbors. For higher dimensions, this rule is applied per component.

The nearest neighbor interpolation operator is defined as the mapping from the values `f1, ..., fN` to the function `I(x)` (as a whole).

In higher dimensions, this principle is applied per axis, the only difference being the additional information about the ordering of the axes in the flat storage array (C- vs. Fortran ordering).

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
grid	The sampling grid.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
order	Axis ordering in the data storage.
partition	The underlying domain partition.
range	Set in which the result of an evaluation of this operator lies.

NearestInterpolation.adjoint

`NearestInterpolation.`**`adjoint`**

The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

NearestInterpolation.domain

`NearestInterpolation.`**`domain`**
Set of objects on which this operator can be evaluated.

NearestInterpolation.grid

`NearestInterpolation.`**`grid`**
The sampling grid.

NearestInterpolation.inverse

`NearestInterpolation.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

NearestInterpolation.is_functional

`NearestInterpolation.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

NearestInterpolation.is_linear

`NearestInterpolation.`**`is_linear`**
`True` if this operator is linear.

NearestInterpolation.order

`NearestInterpolation.`**`order`**
Axis ordering in the data storage.

NearestInterpolation.partition

`NearestInterpolation.`**`partition`**
The underlying domain partition.

NearestInterpolation.range

`NearestInterpolation.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__(other)	
_call(x[, out])	Create an interpolator from grid values `x`.
derivative(point)	Return the operator derivative at `point`.

NearestInterpolation.__call__

`NearestInterpolation.`**`__call__`**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

NearestInterpolation.__eq__

NearestInterpolation.**__eq__**(*other*)

NearestInterpolation._call

NearestInterpolation.**_call**(*x*, *out=None*)

Create an interpolator from grid values `x`.

Parametersx : *NtuplesVector*

The array of values to be interpolated

out : *FunctionSetVector*, optional

Vector in which to store the interpolator

Returnsout : *FunctionSetVector*

Nearest-neighbor interpolator for the grid of this operator. If `out` was provided, the returned object is a reference to it.

See also:

LinearInterpolation(bi-/tri-/...)linear interpolation

Notes

Important: if called on a point array, the points are assumed to be sorted in ascending order in each dimension for efficiency reasons.

Nearest neighbor interpolation is the only scheme which works with data of non-scalar type since it does not involve any arithmetic operations on the values.

Examples

We test nearest neighbor interpolation with a non-scalar data type in 2d:

```
>>> import numpy as np
>>> from odl import Rectangle, Strings, FunctionSet
>>> rect = Rectangle([0, 0], [1, 1])
>>> strings = Strings(1)  # 1-char strings
>>> space = FunctionSet(rect, strings)
```

Partitioning the domain uniformly with no nodes on the boundary (will shift the grid points):

```
>>> from odl import uniform_partition_fromintv, Ntuples
>>> part = uniform_partition_fromintv(rect, [4, 2],
...                                   nodes_on_bdry=False)
>>> part.grid.coord_vectors
(array([ 0.125,  0.375,  0.625,  0.875]), array([ 0.25,  0.75]))
```

```
>>> dspace = Ntuples(part.size, dtype='U1')
```

Now we initialize the operator and test it with some points:

```
>>> interp_op = NearestInterpolation(space, part, dspace)
>>> values = np.array([c for c in 'mystring'])
>>> function = interp_op(values)
>>> print(function([0.3, 0.6]))  # closest to index (1, 1) -> 3
t
>>> out = np.empty(2, dtype='U1')
>>> pts = np.array([[0.3, 0.6],
...                 [1.0, 1.0]])
>>> out = function(pts.T, out=out)  # returns original out
>>> all(out == ['t', 'g'])
True
```

NearestInterpolation.derivative

NearestInterpolation.**derivative**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*fset*, *partition*, *dspace*, ***kwargs*)

Initialize a new instance.

Parametersfset : *FunctionSet*

The undiscretized (abstract) set of functions to be discretized. The function domain must provide a *Set.contains_set* method.

partition : *RectPartition*

Partition of (a subset of) `ip_fset.domain` based on a spatial grid

dspace : *NtuplesBase*

Data space providing containers for the values of a discretized object. Its *NtuplesBase.size* must be equal to the total number of grid points.

variant : {'left', 'right'}, optional

Behavior variant at midpoint between neighbors

'left' : favor left neighbor (default)

'right' : favor right neighbor

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

Notes

The distinction between 'left' and 'right' variants is currently made by changing <= to < at one place. This difference may not be noticable in some situations due to rounding errors.

PerAxisInterpolation

class odl.discr.discr_mappings.**PerAxisInterpolation**(*fspace*, *partition*, *dspace*, *schemes*, ***kwargs*)

Bases: *odl.discr.discr_mappings.FunctionSetMapping*

Interpolation scheme set for each axis individually.

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
grid	The sampling grid.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
nn_variants	List of nearest neighbor variants, one for each axis.
order	Axis ordering in the data storage.
partition	The underlying domain partition.
range	Set in which the result of an evaluation of this operator lies.
schemes	List of interpolation schemes, one for each axis.

PerAxisInterpolation.adjoint

PerAxisInterpolation.**adjoint**

The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

PerAxisInterpolation.domain

PerAxisInterpolation.**domain**

Set of objects on which this operator can be evaluated.

PerAxisInterpolation.grid

PerAxisInterpolation.**grid**

The sampling grid.

PerAxisInterpolation.inverse

PerAxisInterpolation.**inverse**

Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

PerAxisInterpolation.is_functional

PerAxisInterpolation.**is_functional**
`True` if the this operator's range is a *Field*.

PerAxisInterpolation.is_linear

PerAxisInterpolation.**is_linear**
`True` if this operator is linear.

PerAxisInterpolation.nn_variants

PerAxisInterpolation.**nn_variants**
List of nearest neighbor variants, one for each axis.

PerAxisInterpolation.order

PerAxisInterpolation.**order**
Axis ordering in the data storage.

PerAxisInterpolation.partition

PerAxisInterpolation.**partition**
The underlying domain partition.

PerAxisInterpolation.range

PerAxisInterpolation.**range**
Set in which the result of an evaluation of this operator lies.

PerAxisInterpolation.schemes

PerAxisInterpolation.**schemes**
List of interpolation schemes, one for each axis.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__(other)	
_call(x[, out])	Create an interpolator from grid values `x`.
derivative(point)	Return the operator derivative at `point`.

PerAxisInterpolation.__call__

PerAxisInterpolation.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

PerAxisInterpolation.__eq__

`PerAxisInterpolation.__eq__(other)`

PerAxisInterpolation._call

`PerAxisInterpolation._call(x, out=None)`

Create an interpolator from grid values `x`.

Parametersx : *FnBaseVector*

The array of values to be interpolated

out : *FunctionSpaceVector*, optional

Vector in which to store the interpolator

Returnsout : *FunctionSpaceVector*

Per-axis interpolator for the grid of this operator. If `out` was provided, the returned object is a reference to it.

PerAxisInterpolation.derivative

`PerAxisInterpolation.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*fspace*, *partition*, *dspace*, *schemes*, ***kwargs*)

Initialize a new instance.

Parametersfspace : *FunctionSpace*

The undiscretized (abstract) space of functions to be discretized. Its field must be the same as that of data space. The function domain must provide a *Set.contains_set* method.

partition : *RectPartition*

Partition of (a subset of) `fspace.domain` based on a *TensorGrid*

dspace : *FnBase*

Data space providing containers for the values of a discretized object. Its *NtuplesBase.size* must be equal to the total number of grid points, and its *FnBase.field* must be the same as that of the function space.

schemes : `str` or `sequence` of `str`

Indicates which interpolation scheme to use for which axis. A single string is interpreted as a global scheme for all axes.

nn_variants : `str` or `sequence` of `str`, optional

Which variant ('left' or 'right') to use in nearest neighbor interpolation for which axis. A single string is interpreted as a global variant for all axes. This option has no effect for schemes other than nearest neighbor. Default: 'left'

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

PointCollocation

class `odl.discr.discr_mappings.`**`PointCollocation`**(*ip_fset*, *partition*, *dspace*, ***kwargs*)

Bases: *odl.discr.discr_mappings.FunctionSetMapping*

Function evaluation at grid points.

This operator evaluates a given function in a set of points. These points are given as the sampling grid of a partition of the function domain. The result of this evaluation is an array of function values at these points.

If, for example, a function is defined on the interval [0, 1], and a partition divides the interval into `N` subintervals, the resulting array will have length `N`. The sampling points are defined by the partition, usually they are the midpoints of the subintervals.

In higher dimensions, the same principle is applied, with the only difference being the additional information about the ordering of the axes in the flat storage array (C- vs. Fortran ordering).

This operator is the default 'restriction' used by all core discretization classes.

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
grid	The sampling grid.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
order	Axis ordering in the data storage.
partition	The underlying domain partition.
range	Set in which the result of an evaluation of this operator lies.

PointCollocation.adjoint

PointCollocation.**adjoint**
The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

PointCollocation.domain

PointCollocation.**domain**
Set of objects on which this operator can be evaluated.

PointCollocation.grid

PointCollocation.**grid**
The sampling grid.

PointCollocation.inverse

PointCollocation.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

PointCollocation.is_functional

PointCollocation.**is_functional**
`True` if the this operator's range is a *Field*.

PointCollocation.is_linear

PointCollocation.**is_linear**
`True` if this operator is linear.

PointCollocation.order

PointCollocation.**order**
Axis ordering in the data storage.

PointCollocation.partition

PointCollocation.**partition**
The underlying domain partition.

PointCollocation.range

PointCollocation.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__(other)	
_call(func[, out])	Evaluate `func` at the grid of this operator.
derivative(point)	Return the operator derivative at `point`.

PointCollocation.__call__

PointCollocation.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_call Implementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

PointCollocation.__eq__

`PointCollocation.__eq__(other)`

PointCollocation._call

`PointCollocation._call(func, out=None)`

Evaluate `func` at the grid of this operator.

Parametersfunc : *FunctionSetVector*

The function to be evaluated

out : *NtuplesBaseVector*, optional

Array to which the values are written. Its shape must be `(N,)`, where N is the total number of grid points. The data type must be the same as in the `dspace` of this mapping.

Returnsout : *NtuplesBaseVector*, optional

The function values at the grid points. If `out` was provided, the returned object is a reference to it.

See also:

odl.discr.grid.TensorGrid.meshgrid, numpy.meshgrid

Notes

This operator expects its input functions to be written in a vectorization-conforming manner to ensure fast evaluation. See the vectorization guide for a detailed introduction.

Examples

Define a set of functions from the rectangle [1, 3] x [2, 5] to the real numbers:

```
>>> from odl import FunctionSpace, Rectangle
>>> rect = Rectangle([1, 3], [2, 5])
>>> funcset = FunctionSpace(rect)
```

Partition the rectangle by a tensor grid:

```
>>> from odl import TensorGrid, Rectangle, RectPartition, Rn
>>> rect = Rectangle([1, 3], [2, 5])
>>> grid = TensorGrid([1, 2], [3, 4, 5])
>>> partition = RectPartition(rect, grid)
>>> rn = Rn(grid.size)
```

Finally create the operator and test it on a function:

```
>>> coll_op = PointCollocation(funcset, partition, rn)
...
... # Properly vectorized function
>>> func_elem = funcset.element(lambda x: x[0] - x[1])
>>> coll_op(func_elem)
Rn(6).element([-2.0, -3.0, -4.0, -1.0, -2.0, -3.0])
>>> coll_op(lambda x: x[0] - x[1])  # Works directly
Rn(6).element([-2.0, -3.0, -4.0, -1.0, -2.0, -3.0])
>>> out = Rn(6).element()
>>> coll_op(func_elem, out=out)  # In-place
Rn(6).element([-2.0, -3.0, -4.0, -1.0, -2.0, -3.0])
```

Fortran ordering:

```
>>> coll_op = PointCollocation(funcset, partition, rn, order='F')
>>> coll_op(func_elem)
Rn(6).element([-2.0, -1.0, -3.0, -2.0, -4.0, -3.0])
```

PointCollocation.derivative

PointCollocation.**derivative**(*point*)

Return the operator derivative at point.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*ip_fset*, *partition*, *dspace*, ***kwargs*)

Initialize a new instance.

Parametersfset : *FunctionSet*

The non-discretized (abstract) set of functions to be discretized. The function domain must provide a *Set.contains_set* method.

partition : *RectPartition*

Partition of (a subset of) `ip_fset.domain` based on a *TensorGrid*

dspace : *NtuplesBase*

Data space providing containers for the values of a discretized object. Its *NtuplesBase.size* must be equal to the total number of grid points.

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

8.2.2 discr_ops

Operators defined on *DiscreteLp*.

Classes

Divergence(space[, method])	Divergence operator for *DiscreteLp* spaces.
Gradient(space[, method])	Spatial gradient operator for *DiscreteLp* spaces.
Laplacian(space)	Spatial Laplacian operator for *DiscreteLp* spaces.
PartialDerivative(space[, axis, method, ...])	Calculate the discrete partial derivative along a given axis.

Divergence

class `odl.discr.discr_ops.`**`Divergence`**(*space*, *method='forward'*)

Bases: *odl.operator.operator.Operator*

Divergence operator for *DiscreteLp* spaces.

Calls helper function *finite_diff* for each component of the input product space vector. For the adjoint of the *Divergence* operator to match the negative *Gradient* operator implicit zero is assumed.

Attributes

adjoint	Return the adjoint operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

Divergence.adjoint

`Divergence.`**`adjoint`**

Return the adjoint operator.

Assuming implicit zero padding, the adjoint operator is given by the negative of the *Gradient* operator.

Divergence.domain

Divergence.**domain**
Set of objects on which this operator can be evaluated.

Divergence.inverse

Divergence.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

Divergence.is_functional

Divergence.**is_functional**
`True` if the this operator's range is a *Field*.

Divergence.is_linear

Divergence.**is_linear**
`True` if this operator is linear.

Divergence.range

Divergence.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Calculate the divergence of `x`.
derivative(point)	Return the operator derivative at `point`.

Divergence.__call__

Divergence.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is

treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

Divergence._call

`Divergence.`**`_call`**(*x*, *out=None*)

Calculate the divergence of `x`.

Parametersx : `domain` *element*

ProductSpaceVector to which the divergence operator is applied

out : `range` *element*, optional

Output vector to which the result is written

Returnsout : `range` *element*

Result of the evaluation. If `out` is provided, the returned object is a reference to it.

Examples

```
>>> from odl import uniform_discr
>>> data = np.array([[0., 1., 2., 3., 4.],
...                  [1., 2., 3., 4., 5.],
...                  [2., 3., 4., 5., 6.]])
>>> space = uniform_discr([0, 0], [3, 5], data.shape)
>>> div = Divergence(space)
>>> f = div.domain.element([data, data])
>>> div_f = div(f)
>>> print(div_f)
[[2.0, 2.0, 2.0, 2.0, -3.0],
 [2.0, 2.0, 2.0, 2.0, -4.0],
 [-1.0, -2.0, -3.0, -4.0, -12.0]]
```

Verify adjoint:

```
>>> g = div.range.element(data ** 2)
>>> adj_div_g = div.adjoint(g)
>>> g.inner(div_f) / f.inner(adj_div_g)
1.0
```

Divergence.derivative

Divergence.**derivative**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*space*, *method='forward'*)

Initialize a *Divergence* operator instance.

Zero padding is assumed for the adjoint of the *Divergence* operator to match negative *Gradient* operator.

Parametersspace : *DiscreteLp*

The space of elements which the operator is acting on

method : {'central', 'forward', 'backward'}, optional

Finite difference method to be used

Gradient

class odl.discr.discr_ops.**Gradient**(*space*, *method='forward'*)

Bases: *odl.operator.operator.Operator*

Spatial gradient operator for *DiscreteLp* spaces.

Calls helper function *finite_diff* to calculate each component of the resulting product space vector. For the adjoint of the *Gradient* operator, zero padding is assumed to match the negative *Divergence* operator

Attributes

adjoint	Return the adjoint operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

Gradient.adjoint

`Gradient.`**`adjoint`**
Return the adjoint operator.

Assuming implicit zero padding, the adjoint operator is given by the negative of the *Divergence* operator.

The Divergence is constructed from a `space` as a product space operator `space^n --> space`, hence we need to provide the domain of this operator.

Gradient.domain

`Gradient.`**`domain`**
Set of objects on which this operator can be evaluated.

Gradient.inverse

`Gradient.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

Gradient.is_functional

`Gradient.`**`is_functional`**
`True` if the this operator's range is a *Field*.

Gradient.is_linear

`Gradient.`**`is_linear`**
`True` if this operator is linear.

Gradient.range

`Gradient.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Calculate the spatial gradient of `x`.
derivative(point)	Return the operator derivative at `point`.

Gradient.__call__

`Gradient.`**`__call__`**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

Gradient._call

`Gradient.__call__`(*x*, *out=None*)

Calculate the spatial gradient of `x`.

Parametersx : `domain` *element*

Input vector to which the *Gradient* operator is applied

out : `range` *element*, optional

Output vector to which the result is written

Returnsout : `range` *element*

Result of the evaluation. If `out` is provided, the returned object is a reference to it.

Examples

```
>>> from odl import uniform_discr
>>> data = np.array([[ 0., 1., 2., 3., 4.],
...                  [ 0., 2., 4., 6., 8.]])
>>> discr = uniform_discr([0, 0], [2, 5], data.shape)
>>> f = discr.element(data)
>>> grad = Gradient(discr)
>>> grad_f = grad(f)
>>> print(grad_f[0])
[[0.0, 1.0, 2.0, 3.0, 4.0],
 [0.0, -2.0, -4.0, -6.0, -8.0]]
>>> print(grad_f[1])
[[1.0, 1.0, 1.0, 1.0, -4.0],
 [2.0, 2.0, 2.0, 2.0, -8.0]]
```

Verify adjoint:

```
>>> g = grad.range.element((data, data ** 2))
>>> adj_g = grad.adjoint(g)
>>> print(adj_g)
[[0.0, -2.0, -5.0, -8.0, -11.0],
 [0.0, -5.0, -14.0, -23.0, -32.0]]
>>> g.inner(grad_f) / f.inner(adj_g)
1.0
```

Gradient.derivative

`Gradient.derivative`(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*space*, *method='forward'*)

Initialize a *Gradient* operator instance.

Zero padding is assumed for the adjoint of the *Gradient* operator to match negative *Divergence* operator.

Parametersspace : *DiscreteLp*

The space of elements which the operator is acting on.

method : {'central', 'forward', 'backward'}, optional

Finite difference method to be used

Laplacian

class odl.discr.discr_ops.**Laplacian**(*space*)

Bases: *odl.operator.operator.Operator*

Spatial Laplacian operator for *DiscreteLp* spaces.

Calls helper function *finite_diff* to calculate each component of the resulting product space vector.

Outside the domain zero padding is assumed.

Attributes

adjoint	Return the adjoint operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

Laplacian.adjoint

Laplacian.**adjoint**

Return the adjoint operator.

The laplacian is self-adjoint, so this returns `self`.

Laplacian.domain

Laplacian.**domain**

Set of objects on which this operator can be evaluated.

Laplacian.inverse

Laplacian.**inverse**

Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

Laplacian.is_functional

Laplacian.**is_functional**

`True` if the this operator's range is a *Field*.

Laplacian.is_linear

`Laplacian.`**`is_linear`**
`True` if this operator is linear.

Laplacian.range

`Laplacian.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Calculate the spatial Laplacian of `x`.
derivative(point)	Return the operator derivative at `point`.

Laplacian.__call__

`Laplacian.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

Laplacian._call

Laplacian.**_call**(*x*, *out=None*)

Calculate the spatial Laplacian of `x`.

Parameters

x : `domain` *element*

Input vector to which the *Laplacian* operator is applied

out : `range` *element*, optional

Output vector to which the result is written

Returns

out : `range` *element*

Result of the evaluation. If `out` is provided, the returned object is a reference to it.

Examples

```
>>> from odl import uniform_discr
>>> data = np.array([[ 0., 0., 0.],
...                  [ 0., 1., 0.],
...                  [ 0., 0., 0.]])
>>> space = uniform_discr([0, 0], [3, 3], data.shape)
>>> f = space.element(data)
>>> lap = Laplacian(space)
>>> print(lap(f))
[[0.0, 1.0, 0.0],
 [1.0, -4.0, 1.0],
 [0.0, 1.0, 0.0]]
```

Laplacian.derivative

Laplacian.**derivative**(*point*)

Return the operator derivative at `point`.

Raises

OpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*space*)

Initialize a *Laplacian* operator instance.

Parameters

space : *DiscreteLp*

The space of elements which the operator is acting on

PartialDerivative

class odl.discr.discr_ops.**PartialDerivative**(*space*, *axis=0*, *method='forward'*, *padding_method=None*, *padding_value=0*, *edge_order=None*)

Bases: *odl.operator.operator.Operator*

Calculate the discrete partial derivative along a given axis.

Calls helper function *finite_diff* to calculate finite difference. Preserves the shape of the underlying grid.

Attributes

adjoint	Return the adjoint operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

PartialDerivative.adjoint

PartialDerivative.**adjoint**

Return the adjoint operator.

PartialDerivative.domain

PartialDerivative.**domain**

Set of objects on which this operator can be evaluated.

PartialDerivative.inverse

PartialDerivative.**inverse**

Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

PartialDerivative.is_functional

PartialDerivative.**is_functional**

`True` if the this operator's range is a *Field*.

PartialDerivative.is_linear

PartialDerivative.**is_linear**

`True` if this operator is linear.

PartialDerivative.range

`PartialDerivative.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Apply gradient operator to `x` and store result in `out`.
derivative(point)	Return the operator derivative at `point`.

PartialDerivative.__call__

`PartialDerivative.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

PartialDerivative._call

`PartialDerivative.__call__`(*x*, *out=None*)

Apply gradient operator to `x` and store result in `out`.

Parametersx : `domain` *element*

Input vector to which the operator is applied to

out : `range` element, optional

Output vector to which the result is written

Returnsout : `range` *element*

Result of the evaluation. If `out` is provided, the returned object is a reference to it.

Examples

```
>>> from odl import uniform_discr
>>> data = np.array([[ 0.,  1.,  2.,  3.,  4.],
...                  [ 0.,  2.,  4.,  6.,  8.]])
>>> discr = uniform_discr([0, 0], [2, 1], data.shape)
>>> par_deriv = PartialDerivative(discr)
>>> f = par_deriv.domain.element(data)
>>> par_div_f = par_deriv(f)
>>> print(par_div_f)
[[0.0, 1.0, 2.0, 3.0, 4.0],
 [0.0, 1.0, 2.0, 3.0, 4.0]]
```

PartialDerivative.derivative

`PartialDerivative.derivative`(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*space*, *axis=0*, *method='forward'*, *padding_method=None*, *padding_value=0*, *edge_order=None*)

Initialize an operator instance.

Parametersspace : *DiscreteLp*

The space of elements which the operator is acting on

axis : `int`, optional

The axis along which the partial derivative is evaluated

method : {'central', 'forward', 'backward'}, optional

Finite difference method which is used in the interior of the domain of `f`

padding_method : {'constant', 'symmetric'}, optional

'constant' : Pads values outside the domain of `f` with a constant value given by `padding_value`

'symmetric' : Pads with the reflection of the vector mirrored along the edge of the array

If `None` is given, one-sided forward or backward differences are used at the boundary

padding_value : `float`, optional

If `padding_method` is 'constant' `f` assumes `padding_value` for indices outside the domain of `f`

edge_order : {1, 2}, optional

Edge-order accuracy at the boundaries if no padding is used. If `None` the edge-order accuracy at endpoints corresponds to the accuracy in the interior.

Functions

finite_diff(f[, axis, dx, method, out])	Calculate the partial derivative of `f` along a given `axis`.

finite_diff

odl.discr.discr_ops.**finite_diff**(*f*, *axis=0*, *dx=1.0*, *method='forward'*, *out=None*, ***kwargs*)

Calculate the partial derivative of `f` along a given `axis`.

In the interior of the domain of f, the partial derivative is computed using first-order accurate forward or backward difference or second-order accurate central differences.

With padding the same method and thus accuracy is used on endpoints as in the interior i.e. forward and backward differences use first-order accuracy on edges while central differences use second-order accuracy at edges.

Without padding one-sided forward or backward differences are used at the boundaries. The accuracy at the endpoints can then also be triggered by the edge order.

The returned array has the same shape as the input array `f`.

Per default forward difference with dx=1 and no padding is used.

Parametersf : *array-like*

An N-dimensional array

axis : `int`, optional

The axis along which the partial derivative is evaluated

dx : `float`, optional

Scalar specifying the distance between sampling points along `axis`

method : {'central', 'forward', 'backward'}, optional

Finite difference method which is used in the interior of the domainof `f`.

padding_method : {'constant', 'symmetric'}, optional

'constant' : Pads values outside the domain of `f` with a constant value given by `padding_value`

'symmetric' : Pads with the reflection of the vector mirrored along the edge of the array

If `None` is given, one-sided forward or backward differences are used at the boundary.

padding_value : `float`, optional

If `padding_method` is 'constant' `f` assumes `padding_value` for indices outside the domain of `f`

edge_order : {1, 2}, optional

Edge-order accuracy at the boundaries if no padding is used. If `None` the edge-order accuracy at endpoints corresponds to the accuracy in the interior. Default: `None`

out : `numpy.ndarray`, optional

An N-dimensional array to which the output is written. Has to have the same shape as the input array `f`. Default: `None`

Returnsout : `numpy.ndarray`

N-dimensional array of the same shape as `f`. If `out` is provided, the returned object is a reference to it.

Notes

Without padding the use of second-order accurate edges requires at least three elements.

Central differences with padding cannot be used with first-order accurate edges.

Forward and backward differences with padding use the first-order accuracy on edges (as in the interior).

An edge-order accuracy different from the interior can only be triggered without padding i.e. when one-sided differences are used at the edges.

Examples

```
>>> f = np.array([ 0., 1., 2., 3., 4., 5., 6., 7., 8., 9.])
```

```
>>> finite_diff(f)
array([ 1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.])
```

Without arguments the above defaults to:

```
>>> finite_diff(f, axis=0, dx=1.0, method='forward', padding_method=None,
... edge_order=None)
array([ 1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.])
```

```
>>> finite_diff(f, dx=0.5)
array([ 2.,  2.,  2.,  2.,  2.,  2.,  2.,  2.,  2.,  2.])
>>> finite_diff(f, padding_method='constant')
array([ 1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1., -9.])
```

Central differences and different edge orders:

```
>>> finite_diff(1/2*f**2, method='central')
array([-0.,  1.,  2.,  3.,  4.,  5.,  6.,  7.,  8.,  9.])
>>> finite_diff(1/2*f**2, method='central', edge_order=1)
array([ 0.5,  1. ,  2. ,  3. ,  4. ,  5. ,  6. ,  7. ,  8. ,  8.5])
```

In-place evaluation:

```
>>> out = f.copy()
>>> out is finite_diff(f, out=out)
True
```

8.2.3 discretization

Base classes for discretization.

Classes

Discretization(uspace, dspace[, restr, ext])	Abstract class for discretizations of linear vector spaces.
DiscretizationVector(space, data)	Representation of a *Discretization* element.
RawDiscretization(uspace, dspace[, restr, ext])	Abstract raw discretization class.
RawDiscretizationVector(space, ntuple)	Representation of a *RawDiscretization* element.

Discretization

class odl.discr.discretization.**Discretization**(*uspace*, *dspace*, *restr=None*, *ext=None*)
Bases: *odl.discr.discretization.RawDiscretization*, *odl.space.base_ntuples.FnBase*

Abstract class for discretizations of linear vector spaces.

This variant of *RawDiscretization* adds linear structure to all its members. The *RawDiscretization.uspace* is a *LinearSpace*, the *RawDiscretization.dspace* for the data representation is an implementation of $\mathbb{F}^n$, where $\mathbb{F}$ is some *Field*, and both *RawDiscretization.restriction* and *RawDiscretization.extension* are linear *Operator*'s.

Attributes

domain	The domain of the continuous space.
dspace	The data space.
dspace_type	Data space type of this discretization.
dtype	The data type of each entry.
element_type	*DiscretizationVector*
extension	The operator mapping an n-tuple to a *uspace* element.
field	The field of this vector space.
is_cn	Return True if the space represents C^n, i.e.
is_rn	Return True if the space represents R^n, i.e.
is_weighted	Return True if the dspace is weighted.
restriction	The operator mapping a *uspace* element to an n-tuple.
shape	The shape of this space.

Continued on next page

Table 8.28 – continued from previous page

size	The number of entries per tuple.
uspace	The undiscretized space.
weighting	This space's weighting scheme.

Discretization.domain

Discretization.**domain**
The domain of the continuous space.

Discretization.dspace

Discretization.**dspace**
The data space.

Discretization.dspace_type

Discretization.**dspace_type**
Data space type of this discretization.

Discretization.dtype

Discretization.**dtype**
The data type of each entry.

Discretization.element_type

Discretization.**element_type**
DiscretizationVector

Discretization.extension

Discretization.**extension**
The operator mapping an n-tuple to a *uspace* element.

Discretization.field

Discretization.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

Discretization.is_cn

Discretization.**is_cn**
Return `True` if the space represents C^n, i.e. complex tuples.

Discretization.is_rn

Discretization.**is_rn**
Return `True` if the space represents R^n, i.e. real tuples.

Discretization.is_weighted

Discretization.**is_weighted**
Return `True` if the `dspace` is weighted.

Discretization.restriction

Discretization.**restriction**
The operator mapping a *uspace* element to an n-tuple.

Discretization.shape

Discretization.**shape**
The shape of this space.

Discretization.size

Discretization.**size**
The number of entries per tuple.

Discretization.uspace

Discretization.**uspace**
The undiscretized space.

Discretization.weighting

Discretization.**weighting**
This space's weighting scheme.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.

Continued on next page

Table 8.29 – continued from previous page

_dist(x1, x2)	Raw distance between two vectors.
_divide(x1, x2, out)	Raw pointwise multiplication of two vectors.
_inner(x1, x2)	Raw inner product of two vectors.
_lincomb(a, x1, b, x2, out)	Raw linear combination.
_multiply(x1, x2, out)	Raw pointwise multiplication of two vectors.
_norm(x)	Raw norm of a vector.
astype(dtype)	Return a copy of this space with new `dtype`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp])	Create an element from `inp` or from scratch.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	Create a vector of ones.
zero()	Create a vector of zeros.

Discretization.__contains__

Discretization.**__contains__**(*other*)

Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *NtuplesBaseVector* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

Discretization.__eq__

Discretization.**__eq__**(*other*)

Return `self == other`.

Returnsequals : `bool`

`True` if `other` is a *RawDiscretization* instance and all attributes *uspace*, *dspace*, *RawDiscretization.restriction* and *RawDiscretization.extension* of `other` and this discretization are equal, `False` otherwise.

Discretization._dist

Discretization.**_dist**(*x1*, *x2*)
Raw distance between two vectors.

Discretization._divide

Discretization.**_divide**(*x1*, *x2*, *out*)
Raw pointwise multiplication of two vectors.

Discretization._inner

Discretization.**_inner**(*x1*, *x2*)
Raw inner product of two vectors.

Discretization._lincomb

Discretization.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)
Raw linear combination.

Discretization._multiply

Discretization.**_multiply**(*x1*, *x2*, *out*)
Raw pointwise multiplication of two vectors.

Discretization._norm

Discretization.**_norm**(*x*)
Raw norm of a vector.

Discretization.astype

Discretization.**astype**(*dtype*)
Return a copy of this space with new `dtype`.

Parametersdtype :

Data type of the returned space. Can be given in any way `numpy.dtype` understands, e.g. as string ('complex64') or data type (`complex`).

Returnsnewspace : *FnBase*

The version of this space with given data type

Discretization.contains_all

Discretization.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

Discretization.contains_set

Discretization.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

Discretization.dist

Discretization.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

Discretization.divide

Discretization.**divide**(*x1*, *x2*, *out=None*)
Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

Discretization.element

Discretization.**element**(*inp=None*)
Create an element from `inp` or from scratch.

Parametersinp : `object`, optional

The input data to create an element from. Must be recognizable by the *LinearSpace.element* method of either *dspace* or *uspace*.

Returnselement : *RawDiscretizationVector*

The discretized element, calculated as `dspace.element(inp)` or `restriction(uspace.element(inp))`, tried in this order.

Discretization.inner

Discretization.**inner**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

Discretization.lincomb

Discretization.**lincomb**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

Discretization.multiply

Discretization.**multiply**(*x1*, *x2*, *out=None*)
Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

Discretization.norm

Discretization.**norm**(*x*)
Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

Discretization.one

Discretization.**one**()
Create a vector of ones.

Discretization.zero

Discretization.**zero**()
Create a vector of zeros.

__init__(*uspace*, *dspace*, *restr=None*, *ext=None*)
Abstract initialization method.

Intended to be called by subclasses for proper type checking and setting of attributes.

Parametersuspace : *LinearSpace*

The (abstract) space to be discretized

dspace : *FnBase*

Data space providing containers for the values of a discretized object. Its *FnBase.field* attribute must be the same as `uspace.field`.

restr : *Operator*, linear, optional

Operator mapping a *RawDiscretization.uspace* element to a *RawDiscretization.dspace* element. Must satisfy `restr.domain == uspace`, `restr.range == dspace`

ext : *Operator*, linear, optional

Operator mapping a *RawDiscretization.dspace* element to a *RawDiscretization.uspace* element. Must satisfy `ext.domain == dspace`, `ext.range == uspace`.

DiscretizationVector

class `odl.discr.discretization.`**`DiscretizationVector`**(*space*, *data*)

Bases: *odl.discr.discretization.RawDiscretizationVector*, *odl.space.base_ntuples.FnBaseVector*

Representation of a *Discretization* element.

Attributes

T	The transpose of a vector, the functional given by (.
dtype	type of data storage.
extension	The extension operator associated with this vector.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions, always 1.
ntuple	Structure for data storage.
shape	Number of entries per axis, equals (size,) for linear storage.
size	size of data storage.
space	Space to which this vector.
ufunc	*NtuplesBaseUFuncs*, access to numpy style ufuncs.

DiscretizationVector.T

`DiscretizationVector.`**`T`**

The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

DiscretizationVector.dtype

DiscretizationVector.**dtype**
type of data storage.

DiscretizationVector.extension

DiscretizationVector.**extension**
The extension operator associated with this vector.

Returnsextension_op : *FunctionSetMapping*

Operatior representing a continuous extension of this vector.

See also:

RawDiscretization.extensionFor full description

Examples

```
>>> import odl
>>> import numpy as np
```

Create continuous extension of 1d function with nearest neighbour

```
>>> X = odl.uniform_discr(0, 1, 3, nodes_on_bdry=True)
>>> x = X.element([0, 1, 0])
>>> x.extension(np.array([0.24, 0.26]))
array([ 0.,  1.])
```

Create continuous extension of 1d function wiht linear interpolation

```
>>> X = odl.uniform_discr(0, 1, 3, nodes_on_bdry=True, interp='linear')
>>> x = X.element([0, 1, 0])
>>> x.extension(np.array([0.24, 0.26]))
array([ 0.48,  0.52])
```

DiscretizationVector.itemsize

DiscretizationVector.**itemsize**
The size in bytes on one element of this type.

DiscretizationVector.nbytes

DiscretizationVector.**nbytes**
The number of bytes this vector uses in memory.

DiscretizationVector.ndim

DiscretizationVector.**ndim**
Number of dimensions, always 1.

DiscretizationVector.ntuple

DiscretizationVector.**ntuple**
Structure for data storage.

DiscretizationVector.shape

DiscretizationVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

DiscretizationVector.size

DiscretizationVector.**size**
size of data storage.

DiscretizationVector.space

DiscretizationVector.**space**
Space to which this vector.

DiscretizationVector.ufunc

DiscretizationVector.**ufunc**
NtuplesBaseUFuncs, access to numpy style ufuncs.

These are always available, but may or may not be optimized for the specific space in use.

Methods

__eq__(other)	Return `vec == other`.
__getitem__(indices)	Return `self[indices]`.
__setitem__(indices, values)	Implement `self[indices] = values`.
asarray([out])	Extract the data of this array as a numpy array.
assign(other)	Assign the values of `other` to self.
copy()	Create an identical (deep) copy of this vector.
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
restriction(ufunc)	Restrict a continuous function and assign to this vector
set_zero()	Set this vector to zero.
show([title, method, show, fig])	Display the function graphically.

DiscretizationVector.__eq__

DiscretizationVector.**__eq__**(*other*)
Return `vec == other`.

Returnsequals : `bool`

`True` if all entries of `other` are equal to this vector's entries, `False` otherwise.

DiscretizationVector.__getitem__

DiscretizationVector.**__getitem__**(*indices*)
Return `self[indices]`.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : *NtuplesBaseVector*

The value(s) at the index (indices)

DiscretizationVector.__setitem__

DiscretizationVector.**__setitem__**(*indices*, *values*)
Implement `self[indices] = values`.

Parametersindices : `int` or `slice`

The position(s) that should be set

values : scalar, *array-like* or *NtuplesBaseVector*

The value(s) that are to be assigned.

If `index` is an `int`, `value` must be single value.

If `index` is a `slice`, `value` must be broadcastable to the size of the slice (same size, shape (1,) or single value).

DiscretizationVector.asarray

DiscretizationVector.**asarray**(*out=None*)
Extract the data of this array as a numpy array.

Parametersout : `numpy.ndarray`, optional

Array in which the result should be written in-place. Has to be contiguous and of the correct dtype.

DiscretizationVector.assign

DiscretizationVector.**assign**(*other*)
Assign the values of `other` to self.

DiscretizationVector.copy

DiscretizationVector.**copy**()
Create an identical (deep) copy of this vector.

DiscretizationVector.dist

DiscretizationVector.**dist**(*other*)
Distance to `other`.

LinearSpace.dist

DiscretizationVector.divide

DiscretizationVector.**divide**(*x*, *y*)
Divide by `other` inplace.

LinearSpace.divide

DiscretizationVector.inner

DiscretizationVector.**inner**(*other*)
Inner product with `other`.

LinearSpace.inner

DiscretizationVector.lincomb

DiscretizationVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

DiscretizationVector.multiply

DiscretizationVector.**multiply**(*x*, *y*)
Multiply by `other` inplace.

LinearSpace.multiply

DiscretizationVector.norm

DiscretizationVector.**norm**()
Norm of vector

LinearSpace.norm

DiscretizationVector.restriction

DiscretizationVector.**restriction**(*ufunc*)

Restrict a continuous function and assign to this vector

Parametersufunc : `self.space.uspace` element

The continuous function that should be restricted.

See also:

RawDiscretization.restrictionFor full description

Examples

```
>>> import odl
>>> import numpy as np
```

Create discretization

```
>>> X = odl.uniform_discr(0, 1, 5)
>>> x = X.element()
```

Assign x according to continuous vector

```
>>> x.restriction(lambda x: x)
>>> print(x) # Print values at gridpoints (which are centered)
[0.1, 0.3, 0.5, 0.7, 0.9]
```

DiscretizationVector.set_zero

DiscretizationVector.**set_zero**()

Set this vector to zero.

LinearSpace.zero

DiscretizationVector.show

DiscretizationVector.**show**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)

Display the function graphically.

Parameterstitle : `str`, optional

Set the title of the figure

method : `str`, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : `bool`, optional

If the plot should be showed now or deferred until later.

fig : `matplotlib.figure.Figure`

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that `fig` is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : `matplotlib.figure.Figure`

The resulting figure. It is also shown to the user.

See also:

odl.util.graphics.show_discrete_data Underlying implementation

__init__ (*space*, *data*)
Initialize a new instance.

RawDiscretization

class odl.discr.discretization.**RawDiscretization**(*uspace*, *dspace*, *restr=None*, *ext=None*)
Bases: *odl.space.base_ntuples.NtuplesBase*

Abstract raw discretization class.

A discretization in ODL is a way to encode the transition from an arbitrary set to a set of n-tuples explicitly representable in a computer. The most common use case is the discretization of an infinite-dimensional vector space of functions by means of storing coefficients in a finite basis.

The minimal information required to create a discretization is the set to be discretized ("undiscretized space") and a backend for storage and processing of the n-tuples ("data space" or "discretized space").

As additional information, two mappings can be provided. The first one is an explicit way to map an (abstract) element from the source set to an `n`-tuple. This mapping is called **restriction** in ODL. The second one encodes the converse way of mapping an `n`-tuple to an element of the original set. This mapping is called **extension**.

Attributes

domain	The domain of the continuous space.
dspace	The data space.
dspace_type	Data space type of this discretization.
dtype	The data type of each entry.
element_type	*RawDiscretizationVector*
extension	The operator mapping an n-tuple to a *uspace* element.
restriction	The operator mapping a *uspace* element to an n-tuple.
shape	The shape of this space.
size	The number of entries per tuple.
uspace	The undiscretized space.

RawDiscretization.domain

RawDiscretization.**domain**
The domain of the continuous space.

RawDiscretization.dspace

RawDiscretization.**dspace**
The data space.

RawDiscretization.dspace_type

RawDiscretization.**dspace_type**
Data space type of this discretization.

RawDiscretization.dtype

RawDiscretization.**dtype**
The data type of each entry.

RawDiscretization.element_type

RawDiscretization.**element_type**
RawDiscretizationVector

RawDiscretization.extension

RawDiscretization.**extension**
The operator mapping an n-tuple to a *uspace* element.

RawDiscretization.restriction

RawDiscretization.**restriction**
The operator mapping a *uspace* element to an n-tuple.

RawDiscretization.shape

RawDiscretization.**shape**
The shape of this space.

RawDiscretization.size

RawDiscretization.**size**
The number of entries per tuple.

RawDiscretization.uspace

RawDiscretization.**uspace**
The undiscretized space.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([inp])	Create an element from `inp` or from scratch.

RawDiscretization.__contains__

RawDiscretization.**__contains__**(*other*)

Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *NtuplesBaseVector* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

RawDiscretization.__eq__

RawDiscretization.**__eq__**(*other*)

Return `self == other`.

Returnsequals : `bool`

`True` if `other` is a *RawDiscretization* instance and all attributes *uspace*, *dspace*, *RawDiscretization.restriction* and *RawDiscretization.extension* of `other` and this discretization are equal, `False` otherwise.

RawDiscretization.contains_all

RawDiscretization.**contains_all**(*other*)

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

RawDiscretization.contains_set

RawDiscretization.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

RawDiscretization.element

RawDiscretization.**element**(*inp=None*)
Create an element from `inp` or from scratch.

Parametersinp : `object`, optional

The input data to create an element from. Must be recognizable by the *LinearSpace.element* method of either *dspace* or *uspace*.

Returnselement : *RawDiscretizationVector*

The discretized element, calculated as `dspace.element(inp)` or `restriction(uspace.element(inp))`, tried in this order.

__init__(*uspace*, *dspace*, *restr=None*, *ext=None*)
Abstract initialization method.

Intended to be called by subclasses for proper type checking and setting of attributes.

Parametersuspace : *Set*

The undiscretized (abstract) set to be discretized

dspace : *NtuplesBase*

Data space providing containers for the values of a discretized object

restr : *Operator*, optional

Operator mapping a *uspace* element to a *dspace* element. Must satisfy `restr.domain == uspace`, `restr.range == dspace`.

ext : *Operator*, optional

Operator mapping a *dspace* element to a *uspace* element. Must satisfy `ext.domain == dspace`, `ext.range == uspace`.

RawDiscretizationVector

class odl.discr.discretization.**RawDiscretizationVector**(*space*, *ntuple*)
Bases: *odl.space.base_ntuples.NtuplesBaseVector*

Representation of a *RawDiscretization* element.

Basically only a wrapper class for dspace's vector class.

Attributes

dtype	type of data storage.
extension	The extension operator associated with this vector.

Continued on next page

Table 8.34 – continued from previous page

itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions, always 1.
ntuple	Structure for data storage.
shape	Number of entries per axis, equals (size,) for linear storage.
size	size of data storage.
space	Space to which this vector.
ufunc	*NtuplesBaseUFuncs*, access to numpy style ufuncs.

RawDiscretizationVector.dtype

RawDiscretizationVector.**dtype**
type of data storage.

RawDiscretizationVector.extension

RawDiscretizationVector.**extension**
The extension operator associated with this vector.

Returnsextension_op : *FunctionSetMapping*

Operatior representing a continuous extension of this vector.

See also:

RawDiscretization.extensionFor full description

Examples

```
>>> import odl
>>> import numpy as np
```

Create continuous extension of 1d function with nearest neighbour

```
>>> X = odl.uniform_discr(0, 1, 3, nodes_on_bdry=True)
>>> x = X.element([0, 1, 0])
>>> x.extension(np.array([0.24, 0.26]))
array([ 0.,  1.])
```

Create continuous extension of 1d function wiht linear interpolation

```
>>> X = odl.uniform_discr(0, 1, 3, nodes_on_bdry=True, interp='linear')
>>> x = X.element([0, 1, 0])
>>> x.extension(np.array([0.24, 0.26]))
array([ 0.48,  0.52])
```

RawDiscretizationVector.itemsize

RawDiscretizationVector.**itemsize**
The size in bytes on one element of this type.

RawDiscretizationVector.nbytes

RawDiscretizationVector.**nbytes**
The number of bytes this vector uses in memory.

RawDiscretizationVector.ndim

RawDiscretizationVector.**ndim**
Number of dimensions, always 1.

RawDiscretizationVector.ntuple

RawDiscretizationVector.**ntuple**
Structure for data storage.

RawDiscretizationVector.shape

RawDiscretizationVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

RawDiscretizationVector.size

RawDiscretizationVector.**size**
size of data storage.

RawDiscretizationVector.space

RawDiscretizationVector.**space**
Space to which this vector.

RawDiscretizationVector.ufunc

RawDiscretizationVector.**ufunc**
NtuplesBaseUFuncs, access to numpy style ufuncs.

These are always available, but may or may not be optimized for the specific space in use.

Methods

__eq__(other)	Return `vec == other`.
__getitem__(indices)	Return `self[indices]`.
__setitem__(indices, values)	Implement `self[indices] = values`.
asarray([out])	Extract the data of this array as a numpy array.
copy()	Create an identical (deep) copy of this vector.
restriction(ufunc)	Restrict a continuous function and assign to this vector
show([title, method, show, fig])	Display the function graphically.

RawDiscretizationVector.__eq__

RawDiscretizationVector.**__eq__**(*other*)
Return `vec == other`.

Returnsequals : `bool`

`True` if all entries of `other` are equal to this vector's entries, `False` otherwise.

RawDiscretizationVector.__getitem__

RawDiscretizationVector.**__getitem__**(*indices*)
Return `self[indices]`.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : *NtuplesBaseVector*

The value(s) at the index (indices)

RawDiscretizationVector.__setitem__

RawDiscretizationVector.**__setitem__**(*indices*, *values*)
Implement `self[indices] = values`.

Parametersindices : `int` or `slice`

The position(s) that should be set

values : scalar, *array-like* or *NtuplesBaseVector*

The value(s) that are to be assigned.

If `index` is an `int`, `value` must be single value.

If `index` is a `slice`, `value` must be broadcastable to the size of the slice (same size, shape (1,) or single value).

RawDiscretizationVector.asarray

RawDiscretizationVector.**asarray**(*out=None*)
Extract the data of this array as a numpy array.

Parametersout : `numpy.ndarray`, optional

Array in which the result should be written in-place. Has to be contiguous and of the correct dtype.

RawDiscretizationVector.copy

RawDiscretizationVector.**copy**()
Create an identical (deep) copy of this vector.

RawDiscretizationVector.restriction

RawDiscretizationVector.**restriction**(*ufunc*)

Restrict a continuous function and assign to this vector

Parametersufunc : `self.space.uspace` element

The continuous function that should be restricted.

See also:

RawDiscretization.restriction For full description

Examples

```
>>> import odl
>>> import numpy as np
```

Create discretization

```
>>> X = odl.uniform_discr(0, 1, 5)
>>> x = X.element()
```

Assign x according to continuous vector

```
>>> x.restriction(lambda x: x)
>>> print(x) # Print values at gridpoints (which are centered)
[0.1, 0.3, 0.5, 0.7, 0.9]
```

RawDiscretizationVector.show

RawDiscretizationVector.**show**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)

Display the function graphically.

Parameterstitle : `str`, optional

Set the title of the figure

method : `str`, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : `bool`, optional

If the plot should be showed now or deferred until later.

fig : `matplotlib.figure.Figure`

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that `fig` is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : `matplotlib.figure.Figure`

The resulting figure. It is also shown to the user.

See also:

odl.util.graphics.show_discrete_data Underlying implementation

__init__(*space*, *ntuple*)
Initialize a new instance.

Functions

dspace_type(space, impl[, dtype])	Select the correct corresponding n-tuples space.

dspace_type

odl.discr.discretization.**dspace_type**(*space*, *impl*, *dtype=None*)
Select the correct corresponding n-tuples space.

Parameterspace :

Template space from which to infer an adequate data space. If it has a *LinearSpace.field* attribute, `dtype` must be consistent with it.

impl : {'numpy', 'cuda'}

Implementation backend for the data space

dtype : `type`, optional

Data type which the space is supposed to use. If `None`, the space type is purely determined from `space` and `impl`. If given, it must be compatible with the field of `space`.

Returnstype : `type`

Space type selected after the space's field, the backend and the data type

8.2.4 grid

Sparse implementations of n-dimensional sampling grids.

Sampling grids are collections of points in an n-dimensional coordinate space with a certain structure which is exploited to minimize storage.

Classes

RegularGrid(min_pt, max_pt, shape)	An n-dimensional tensor grid with equidistant coordinates.
TensorGrid(*coord_vectors)	An n-dimensional tensor grid.

RegularGrid

class odl.discr.grid.**RegularGrid**(*min_pt*, *max_pt*, *shape*)
Bases: *odl.discr.grid.TensorGrid*

An n-dimensional tensor grid with equidistant coordinates.

This is a sparse representation of an n-dimensional grid defined as the tensor product of n coordinate vectors with equidistant nodes. The grid points are calculated according to the rule:

```
x_j = min_pt + j * (max_pt - min_pt) / (shape - 1)
```

with elementwise addition and multiplication.

Attributes

center	The center of the grid.
coord_vectors	The coordinate vectors of the grid.
max_pt	Vector containing the maximal grid coordinates per axis.
meshgrid	A grid suitable for function evaluation.
min_pt	Vector containing the minimal grid coordinates per axis.
ndim	The number of dimensions of the grid.
shape	The number of grid points per axis.
size	The total number of grid points.
stride	The step per axis between two neighboring grid points.

RegularGrid.center

RegularGrid.**center**

The center of the grid. Not necessarily a grid point.

Examples

```
>>> rg = RegularGrid([-1.5, -1], [-0.5, 3], (2, 3))
>>> rg.center
array([-1.,  1.])
```

RegularGrid.coord_vectors

RegularGrid.**coord_vectors**

The coordinate vectors of the grid.

Returnscoord_vectors : tuple of `numpy.ndarray`'s

See also:

meshgrid Same result but with nd arrays

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> x, y = g.coord_vectors
>>> x
array([ 0.,  1.])
>>> y
array([-1.,  0.,  2.])
```

RegularGrid.max_pt

RegularGrid.**max_pt**
Vector containing the maximal grid coordinates per axis.

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.max_pt
array([ 5.,  2.])
```

RegularGrid.meshgrid

RegularGrid.**meshgrid**
A grid suitable for function evaluation.

Returnsmeshgrid : `tuple` of `numpy.ndarray`

Function evaluation grid with `ndim` axes

See also:

numpy.meshgrid Coordinate matrices from coordinate vectors. We use `indexing='ij'` and `copy=True`

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> x, y = g.meshgrid
>>> x
array([[ 0.],
       [ 1.]])
>>> y
array([[-1.,  0.,  2.]])
```

Easy function evaluation via broadcasting:

```
>>> x**2 - y**2
array([[-1.,  0., -4.],
       [ 0.,  1., -3.]])
```

RegularGrid.min_pt

RegularGrid.**min_pt**
Vector containing the minimal grid coordinates per axis.

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.min_pt
array([ 1., -2.])
```

RegularGrid.ndim

RegularGrid.**ndim**
The number of dimensions of the grid.

RegularGrid.shape

RegularGrid.**shape**
The number of grid points per axis.

RegularGrid.size

RegularGrid.**size**
The total number of grid points.

RegularGrid.stride

RegularGrid.**stride**
The step per axis between two neighboring grid points.

Examples

```
>>> rg = RegularGrid([-1.5, -1], [-0.5, 3], (2, 3))
>>> rg.stride
array([ 1.,  2.])
```

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
__getitem__(slc)	self[slc] implementation.
append(other)	Insert grid `other` at the end.
approx_contains(other, atol)	Test if `other` belongs to this grid up to a tolerance.
approx_equals(other, atol)	Test if this grid is equal to another grid.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
convex_hull()	Return the smallest *IntervalProd* containing this grid.
corner_grid()	Return a grid with only the corner points.
corners([order])	The corner points of the grid in a single array.
element()	An arbitrary element, the minimum coordinates.
extent()	Return the edge lengths of this grid's minimal bounding box.
insert(index, other)	Insert another regular grid before the given index.
is_subgrid(other[, atol])	Test if this grid is contained in another grid.
max(**kwargs)	Return *max_pt*.
min(**kwargs)	Return *min_pt*.
points([order])	All grid points in a single array.
squeeze()	Return the grid with removed degenerate dimensions.

RegularGrid.__contains__

RegularGrid.**__contains__**(*other*)
Return `other in self`.

RegularGrid.__eq__

RegularGrid.**__eq__**(*other*)
Return `self == other`.

RegularGrid.__getitem__

RegularGrid.**__getitem__**(*slc*)
self[slc] implementation.

Parametersslc : `int` or slice

Negative indices and `None` (new axis) are not supported.

Examples

```
>>> g = RegularGrid([-1.5, -3, -1], [-0.5, 7, 4], (2, 3, 6))
>>> g[0, 0, 0]
array([-1.5, -3. , -1. ])
>>> g[:, 0, 0]
RegularGrid([-1.5, -3.0, -1.0], [-0.5, -3.0, -1.0], (2, 1, 1))
```

Ellipsis can be used, too:

```
>>> g[..., ::3]
RegularGrid([-1.5, -3.0, -1.0], [-0.5, 7.0, 2.0], (2, 3, 2))
```

RegularGrid.append

RegularGrid.**append**(*other*)
Insert grid `other` at the end.

Parametersother : *IntervalProd*, `float` or *array-like*

The set to be inserted. A `float` or array a is treated as an `IntervalProd(a, a)`.

See also:

insert

Examples

```
>>> g1 = TensorGrid([0, 1], [-1, 2])
>>> g2 = TensorGrid([1], [-6, 15])
>>> g1.append(g2)
TensorGrid([0.0, 1.0], [-1.0, 2.0], [1.0], [-6.0, 15.0])
```

RegularGrid.approx_contains

RegularGrid.**approx_contains**(*other*, *atol*)

Test if `other` belongs to this grid up to a tolerance.

Parametersother : *array-like* or `float`

The object to test for membership in this grid

atol : `float`

Allow deviations up to this number in absolute value per vector entry.

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.approx_contains([0, 0], atol=0.0)
True
>>> [0, 0] in g  # equivalent
True
>>> g.approx_contains([0.1, -0.1], atol=0.0)
False
>>> g.approx_contains([0.1, -0.1], atol=0.15)
True
```

RegularGrid.approx_equals

RegularGrid.**approx_equals**(*other*, *atol*)

Test if this grid is equal to another grid.

Parametersother : `object`

Object to be tested

atol : `float`

Allow deviations up to this number in absolute value per vector entry.

Returnsequals : `bool`

`True` if `other` is a *TensorGrid* instance with all coordinate vectors equal (up to the given tolerance), to the ones of this grid, otherwise `False`.

Examples

```
>>> g1 = TensorGrid([0, 1], [-1, 0, 2])
>>> g2 = TensorGrid([-0.1, 1.1], [-1, 0.1, 2])
>>> g1.approx_equals(g2, atol=0)
False
>>> g1.approx_equals(g2, atol=0.15)
True
```

RegularGrid.contains_all

RegularGrid.**contains_all**(*other*)

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

RegularGrid.contains_set

RegularGrid.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

RegularGrid.convex_hull

RegularGrid.**convex_hull**()
Return the smallest *IntervalProd* containing this grid.

The convex hull of a set is the union of all line segments between points in the set. For a tensor grid, it is the interval product given by the extremal coordinates.

Returnschull : *IntervalProd*

Interval product defined by the minimum and maximum of the grid

Examples

```
>>> g = TensorGrid([-1, 0, 3], [2, 4], [5], [2, 4, 7])
>>> g.convex_hull()
IntervalProd([-1.0, 2.0, 5.0, 2.0], [3.0, 4.0, 5.0, 7.0])
```

RegularGrid.corner_grid

RegularGrid.**corner_grid**()
Return a grid with only the corner points.

Returnscgrid : *TensorGrid*

Grid with size 2 in non-degenerate dimensions and 1 in degenerate ones

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.corner_grid()
TensorGrid([0.0, 1.0], [-1.0, 2.0])
```

RegularGrid.corners

RegularGrid.**corners**(*order='C'*)
The corner points of the grid in a single array.

Parametersorder : {'C', 'F'}

Axis ordering in the resulting point array

Returnscorners : `numpy.ndarray`

The size of the array is 2^m x ndim, where m is the number of non-degenerate axes, i.e. the corners are stored as rows.

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.corners()
array([[ 0., -1.],
       [ 0.,  2.],
       [ 1., -1.],
       [ 1.,  2.]])
>>> g.corners(order='F')
array([[ 0., -1.],
       [ 1., -1.],
       [ 0.,  2.],
       [ 1.,  2.]])
```

RegularGrid.element

RegularGrid.**element**()
An arbitrary element, the minimum coordinates.

RegularGrid.extent

RegularGrid.**extent**()
Return the edge lengths of this grid's minimal bounding box.

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.extent()
array([ 4.,  4.])
```

RegularGrid.insert

RegularGrid.**insert**(*index*, *other*)
Insert another regular grid before the given index.

The given grid (`m` dimensions) is inserted into the current one (`n` dimensions) before the given index, resulting in a new *RegularGrid* with `n + m` dimensions. Note that no changes are made in-place.

Parametersindex : `int`

Index of the dimension before which `other` is to be inserted. Negative indices count backwards from `self.ndim`.

other : *TensorGrid*

Grid to be inserted. If a *RegularGrid* is given, the output will be a *RegularGrid*.

Returnsnewgrid : *TensorGrid* or *RegularGrid*

The enlarged grid. If the inserted grid is a *RegularGrid*, so is the return value.

Examples

```
>>> rg1 = RegularGrid([-1.5, -1], [-0.5, 3], (2, 3))
>>> rg2 = RegularGrid(-3, 7, 6)
>>> rg1.insert(1, rg2)
RegularGrid([-1.5, -3.0, -1.0], [-0.5, 7.0, 3.0], (2, 6, 3))
```

If other is a TensorGrid, so is the result:

```
>>> tg = TensorGrid([0, 1, 2])
>>> rg1.insert(2, tg)
TensorGrid([-1.5, -0.5], [-1.0, 1.0, 3.0], [0.0, 1.0, 2.0])
```

RegularGrid.is_subgrid

`RegularGrid.`**`is_subgrid`**(*other*, *atol=0.0*)

Test if this grid is contained in another grid.

Parametersother :

Check if this object is a subgrid

atol : `float`

Allow deviations up to this number in absolute value per coordinate vector entry.

Examples

```
>>> rg = RegularGrid([-2, -2], [0, 4], (3, 4))
>>> rg.coord_vectors
(array([-2., -1.,  0.]), array([-2.,  0.,  2.,  4.]))
>>> rg_sub = RegularGrid([-1, 2], [0, 4], (2, 2))
>>> rg_sub.coord_vectors
(array([-1.,  0.]), array([ 2.,  4.]))
>>> rg_sub.is_subgrid(rg)
True
```

Fuzzy check is also possible. Note that the tolerance still applies to the coordinate vectors.

```
>>> rg_sub = RegularGrid([-1.015, 2], [0, 3.99], (2, 2))
>>> rg_sub.is_subgrid(rg, atol=0.01)
False
>>> rg_sub.is_subgrid(rg, atol=0.02)
True
```

RegularGrid.max

`RegularGrid.`**`max`**(***kwargs*)

Return *max_pt*.

Parameterskwargs

For duck-typing with `numpy.amax`

See also:

min, *odl.set.domain.IntervalProd.max*

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.max()
array([ 5.,  2.])
```

Also works with numpy

```
>>> import numpy
>>> numpy.max(g)
array([ 5.,  2.])
```

RegularGrid.min

RegularGrid.**min**(***kwargs*)

Return *min_pt*.

Parameterskwargs

For duck-typing with `numpy.amin`

See also:

max, *odl.set.domain.IntervalProd.min*

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.min()
array([ 1., -2.])
```

Also works with numpy

```
>>> import numpy
>>> numpy.min(g)
array([ 1., -2.])
```

RegularGrid.points

RegularGrid.**points**(*order='C'*)

All grid points in a single array.

Parametersorder : {'C', 'F'}

Axis ordering in the resulting point array

Returnspoints : `numpy.ndarray`

The shape of the array is `size x ndim`, i.e. the points are stored as rows.

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.points()
array([[ 0., -1.],
       [ 0.,  0.],
       [ 0.,  2.],
       [ 1., -1.],
       [ 1.,  0.],
       [ 1.,  2.]])
>>> g.points(order='F')
array([[ 0., -1.],
       [ 1., -1.],
       [ 0.,  0.],
       [ 1.,  0.],
       [ 0.,  2.],
       [ 1.,  2.]])
```

RegularGrid.squeeze

RegularGrid.**squeeze**()

Return the grid with removed degenerate dimensions.

Returnssqueezed : *RegularGrid*

The squeezed grid

Examples

```
>>> g = RegularGrid([0, 0, 0], [1, 0, 1], (5, 1, 5))
>>> g.squeeze()
RegularGrid([0.0, 0.0], [1.0, 1.0], (5, 5))
```

__init__(*min_pt*, *max_pt*, *shape*)

Initialize a new instance.

Parametersmin_pt : *array-like* or `float`

Grid point with minimum coordinates, can be a single float for 1D grids

max_pt : *array-like* or `float`

Grid point with maximum coordinates, can be a single float for 1D grids

shape : *array-like* or `int`

The number of grid points per axis, can be an integer for 1D grids

Examples

```
>>> rg = RegularGrid([-1.5, -1], [-0.5, 3], (2, 3))
>>> rg
RegularGrid([-1.5, -1.0], [-0.5, 3.0], (2, 3))
>>> rg.coord_vectors
(array([-1.5, -0.5]), array([-1.,  1.,  3.]))
>>> rg.ndim, rg.size
(2, 6)
```

TensorGrid

class odl.discr.grid.**TensorGrid**(**coord_vectors*)
Bases: *odl.set.sets.Set*

An n-dimensional tensor grid.

A tensor grid is the set of points defined by all possible combination of coordinates taken from fixed coordinate vectors.

In 2 dimensions, for example, given two coordinate vectors:

```
coord_vec1 = [0, 1]
coord_vec2 = [-1, 0, 2]
```

the corresponding tensor grid is the set of all 2d points whose first component is from `coord_vec1` and the second component from `coord_vec2`. The total number of such points is 2 * 3 = 6:

```
points = [[0, -1], [0, 0], [0, 2],
          [1, -1], [1, 0], [1, 2]]
```

Note that this is the standard 'C' ordering where the first axis (`coord_vec1`) varies slowest. Ordering is only relevant when the point array is actually created; the grid itself is independent of this ordering.

The storage need for a tensor grid is only the sum of the lengths of the coordinate vectors, while the total number of points is the product of these lengths. This class makes use of this sparse storage.

Attributes

coord_vectors	The coordinate vectors of the grid.
max_pt	Vector containing the maximal grid coordinates per axis.
meshgrid	A grid suitable for function evaluation.
min_pt	Vector containing the minimal grid coordinates per axis.
ndim	The number of dimensions of the grid.
shape	The number of grid points per axis.
size	The total number of grid points.

TensorGrid.coord_vectors

TensorGrid.**coord_vectors**
The coordinate vectors of the grid.

Returnscoord_vectors : tuple of `numpy.ndarray`'s

See also:

meshgrid Same result but with nd arrays

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> x, y = g.coord_vectors
>>> x
array([ 0.,  1.])
```

```
>>> y
array([-1.,  0.,  2.])
```

TensorGrid.max_pt

TensorGrid.**max_pt**
Vector containing the maximal grid coordinates per axis.

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.max_pt
array([ 5.,  2.])
```

TensorGrid.meshgrid

TensorGrid.**meshgrid**
A grid suitable for function evaluation.

Returnsmeshgrid : tuple of numpy.ndarray

Function evaluation grid with ndim axes

See also:

numpy.meshgrid Coordinate matrices from coordinate vectors. We use indexing='ij' and copy=True

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> x, y = g.meshgrid
>>> x
array([[ 0.],
       [ 1.]])
>>> y
array([[-1.,  0.,  2.]])
```

Easy function evaluation via broadcasting:

```
>>> x**2 - y**2
array([[-1.,  0., -4.],
       [ 0.,  1., -3.]])
```

TensorGrid.min_pt

TensorGrid.**min_pt**
Vector containing the minimal grid coordinates per axis.

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.min_pt
array([ 1., -2.])
```

TensorGrid.ndim

TensorGrid.**ndim**
The number of dimensions of the grid.

TensorGrid.shape

TensorGrid.**shape**
The number of grid points per axis.

TensorGrid.size

TensorGrid.**size**
The total number of grid points.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
__getitem__(slc)	Return `self[slc]`.
append(other)	Insert grid `other` at the end.
approx_contains(other, atol)	Test if `other` belongs to this grid up to a tolerance.
approx_equals(other, atol)	Test if this grid is equal to another grid.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
convex_hull()	Return the smallest *IntervalProd* containing this grid.
corner_grid()	Return a grid with only the corner points.
corners([order])	The corner points of the grid in a single array.
element()	An arbitrary element, the minimum coordinates.
extent()	Return the edge lengths of this grid's minimal bounding box.
insert(index, other)	Return a copy with `other` inserted before `index`.
is_subgrid(other[, atol])	Test if this grid is contained in another grid.
max(**kwargs)	Return *max_pt*.
min(**kwargs)	Return *min_pt*.
points([order])	All grid points in a single array.
squeeze()	Return the grid with removed degenerate (length 1) dimensions.

TensorGrid.__contains__

TensorGrid.**__contains__**(*other*)
Return `other in self`.

TensorGrid.__eq__

TensorGrid.**__eq__**(*other*)
Return `self == other`.

TensorGrid.__getitem__

TensorGrid.**__getitem__**(*slc*)
Return `self[slc]`.

Parameterslc : `int` or slice

Negative indices and `None` (new axis) are not supported.

Examples

```
>>> g = TensorGrid([-1, 0, 3], [2, 4], [5], [2, 4, 7])
>>> g[0, 0, 0, 0]
array([-1.,  2.,  5.,  2.])
>>> g[:, 0, 0, 0]
TensorGrid([-1.0, 0.0, 3.0], [2.0], [5.0], [2.0])
>>> g[0, ..., 1:]
TensorGrid([-1.0], [2.0, 4.0], [5.0], [4.0, 7.0])
>>> g[::2, ..., ::2]
TensorGrid([-1.0, 3.0], [2.0, 4.0], [5.0], [2.0, 7.0])
```

TensorGrid.append

TensorGrid.**append**(*other*)
Insert grid `other` at the end.

Parametersother : *IntervalProd*, `float` or *array-like*

The set to be inserted. A `float` or array a is treated as an `IntervalProd(a, a)`.

See also:

insert

Examples

```
>>> g1 = TensorGrid([0, 1], [-1, 2])
>>> g2 = TensorGrid([1], [-6, 15])
>>> g1.append(g2)
TensorGrid([0.0, 1.0], [-1.0, 2.0], [1.0], [-6.0, 15.0])
```

TensorGrid.approx_contains

TensorGrid.**approx_contains**(*other*, *atol*)
Test if `other` belongs to this grid up to a tolerance.

Parametersother : *array-like* or `float`

The object to test for membership in this grid

atol : `float`

Allow deviations up to this number in absolute value per vector entry.

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.approx_contains([0, 0], atol=0.0)
True
>>> [0, 0] in g  # equivalent
True
>>> g.approx_contains([0.1, -0.1], atol=0.0)
False
>>> g.approx_contains([0.1, -0.1], atol=0.15)
True
```

TensorGrid.approx_equals

`TensorGrid.`**`approx_equals`**(*other*, *atol*)

Test if this grid is equal to another grid.

Parametersother : `object`

Object to be tested

atol : `float`

Allow deviations up to this number in absolute value per vector entry.

Returnsequals : `bool`

`True` if `other` is a *TensorGrid* instance with all coordinate vectors equal (up to the given tolerance), to the ones of this grid, otherwise `False`.

Examples

```
>>> g1 = TensorGrid([0, 1], [-1, 0, 2])
>>> g2 = TensorGrid([-0.1, 1.1], [-1, 0.1, 2])
>>> g1.approx_equals(g2, atol=0)
False
>>> g1.approx_equals(g2, atol=0.15)
True
```

TensorGrid.contains_all

`TensorGrid.`**`contains_all`**(*other*)

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

TensorGrid.contains_set

TensorGrid.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

TensorGrid.convex_hull

TensorGrid.**convex_hull**()
Return the smallest *IntervalProd* containing this grid.

The convex hull of a set is the union of all line segments between points in the set. For a tensor grid, it is the interval product given by the extremal coordinates.

Returnschull : *IntervalProd*

Interval product defined by the minimum and maximum of the grid

Examples

```
>>> g = TensorGrid([-1, 0, 3], [2, 4], [5], [2, 4, 7])
>>> g.convex_hull()
IntervalProd([-1.0, 2.0, 5.0, 2.0], [3.0, 4.0, 5.0, 7.0])
```

TensorGrid.corner_grid

TensorGrid.**corner_grid**()
Return a grid with only the corner points.

Returnscgrid : *TensorGrid*

Grid with size 2 in non-degenerate dimensions and 1 in degenerate ones

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.corner_grid()
TensorGrid([0.0, 1.0], [-1.0, 2.0])
```

TensorGrid.corners

TensorGrid.**corners**(*order='C'*)
The corner points of the grid in a single array.

Parametersorder : {'C', 'F'}

Axis ordering in the resulting point array

Returnscorners : `numpy.ndarray`

The size of the array is 2^m x ndim, where m is the number of non-degenerate axes, i.e. the corners are stored as rows.

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.corners()
array([[ 0., -1.],
       [ 0.,  2.],
       [ 1., -1.],
       [ 1.,  2.]])
>>> g.corners(order='F')
array([[ 0., -1.],
       [ 1., -1.],
       [ 0.,  2.],
       [ 1.,  2.]])
```

TensorGrid.element

TensorGrid.**element**()

An arbitrary element, the minimum coordinates.

TensorGrid.extent

TensorGrid.**extent**()

Return the edge lengths of this grid's minimal bounding box.

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.extent()
array([ 4.,  4.])
```

TensorGrid.insert

TensorGrid.**insert**(*index*, *other*)

Return a copy with `other` inserted before `index`.

The given grid (`m` dimensions) is inserted into the current one (`n` dimensions) before the given index, resulting in a new *TensorGrid* with `n + m` dimensions. Note that no changes are made in-place.

Parametersindex : `int`

The index of the dimension before which `other` is to be inserted. Negative indices count backwards from `self.ndim`.

other : *TensorGrid*, `float` or *array-like*

The grid to be inserted

Returnsnewgrid : *TensorGrid*

The enlarged grid

See also:

append

Examples

```
>>> g1 = TensorGrid([0, 1], [-1, 2])
>>> g2 = TensorGrid([1], [-6, 15])
>>> g1.insert(1, g2)
TensorGrid([0.0, 1.0], [1.0], [-6.0, 15.0], [-1.0, 2.0])
```

TensorGrid.is_subgrid

TensorGrid.**is_subgrid**(*other*, *atol=0.0*)

Test if this grid is contained in another grid.

Parametersother : *TensorGrid*

The other grid which is supposed to contain this grid

atol : float

Allow deviations up to this number in absolute value per coordinate vector entry.

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g_sub = TensorGrid([0], [-1, 2])
>>> g_sub.is_subgrid(g)
True
>>> g_sub = TensorGrid([0.1], [-1.05, 2.1])
>>> g_sub.is_subgrid(g)
False
>>> g_sub.is_subgrid(g, atol=0.15)
True
```

TensorGrid.max

TensorGrid.**max**(***kwargs*)

Return *max_pt*.

Parameterskwargs

For duck-typing with numpy.amax

See also:

min, *odl.set.domain.IntervalProd.max*

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.max()
array([ 5.,  2.])
```

Also works with numpy

```
>>> import numpy
>>> numpy.max(g)
array([ 5.,  2.])
```

TensorGrid.min

TensorGrid.**min**(***kwargs*)

Return *min_pt*.

Parameterskwargs

For duck-typing with `numpy.amin`

See also:

max, *odl.set.domain.IntervalProd.min*

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g.min()
array([ 1., -2.])
```

Also works with numpy

```
>>> import numpy
>>> numpy.min(g)
array([ 1., -2.])
```

TensorGrid.points

TensorGrid.**points**(*order='C'*)

All grid points in a single array.

Parametersorder : {'C', 'F'}

Axis ordering in the resulting point array

Returnspoints : `numpy.ndarray`

The shape of the array is `size x ndim`, i.e. the points are stored as rows.

Examples

```
>>> g = TensorGrid([0, 1], [-1, 0, 2])
>>> g.points()
array([[ 0., -1.],
       [ 0.,  0.],
       [ 0.,  2.],
       [ 1., -1.],
       [ 1.,  0.],
       [ 1.,  2.]])
>>> g.points(order='F')
array([[ 0., -1.],
       [ 1., -1.],
```

```
               [ 0.,  0.],
               [ 1.,  0.],
               [ 0.,  2.],
               [ 1.,  2.]])
```

TensorGrid.squeeze

TensorGrid.**squeeze**()

Return the grid with removed degenerate (length 1) dimensions.

Returnssqueezed : *TensorGrid*

The squeezed grid

Examples

```
>>> g = TensorGrid([0, 1], [-1], [-1, 0, 2])
>>> g.squeeze()
TensorGrid([0.0, 1.0], [-1.0, 0.0, 2.0])
```

__init__(**coord_vectors*)

Initialize a TensorGrid instance.

Parametersvec1,...,vecN : *array-like*

The coordinate vectors defining the grid points. They must be sorted in ascending order and may not contain duplicates. Empty vectors are not allowed.

Examples

```
>>> g = TensorGrid([1, 2, 5], [-2, 1.5, 2])
>>> g
TensorGrid([1.0, 2.0, 5.0], [-2.0, 1.5, 2.0])
>>> print(g)
grid [1.0, 2.0, 5.0] x [-2.0, 1.5, 2.0]
>>> g.ndim  # number of axes
2
>>> g.shape  # points per axis
(3, 3)
>>> g.size  # total number of points
9
```

Grid points can be extracted with index notation (NOTE: This is slow, do not loop over the grid using indices!):

```
>>> g = TensorGrid([-1, 0, 3], [2, 4], [5], [2, 4, 7])
>>> g[0, 0, 0, 0]
array([-1.,  2.,  5.,  2.])
```

Slices and ellipsis are also supported:

```
>>> g[:, 0, 0, 0]
TensorGrid([-1.0, 0.0, 3.0], [2.0], [5.0], [2.0])
>>> g[0, ..., 1:]
TensorGrid([-1.0], [2.0, 4.0], [5.0], [4.0, 7.0])
```

Functions

sparse_meshgrid(*x)	Make a sparse *meshgrid* by adding empty dimensions.
uniform_sampling(begin, end, num_nodes[, ...])	Sample an implicitly defined interval product uniformly.
uniform_sampling_fromintv(intv_prod, num_nodes)	Sample an interval product uniformly.

sparse_meshgrid

odl.discr.grid.**sparse_meshgrid**(**x*)

Make a sparse *meshgrid* by adding empty dimensions.

Parametersx1,...,xN : *array-like*

Input arrays to turn into sparse meshgrid vectors

Returnsmeshgrid : `tuple` of `numpy.ndarray`

Sparse coordinate vectors representing an N-dimensional grid

See also:

numpy.meshgriddense or sparse meshgrids

Examples

```
>>> x, y = [0, 1], [2, 3, 4]
>>> mesh = sparse_meshgrid(x, y)
>>> sum(xi for xi in mesh).ravel()  # first axis slowest
array([2, 3, 4, 3, 4, 5])
```

uniform_sampling

odl.discr.grid.**uniform_sampling**(*begin*, *end*, *num_nodes*, *nodes_on_bdry=True*)

Sample an implicitly defined interval product uniformly.

Parametersbegin : *array-like* or `float`

The lower ends of the intervals in the product

end : *array-like* or `float`

The upper ends of the intervals in the product

num_nodes : `int` or `tuple` of `int`

Number of nodes per axis. For dimension >= 2, a `tuple` is required. All entries must be positive. Entries corresponding to degenerate axes must be equal to 1.

nodes_on_bdry : `bool` or `sequence`, optional

If a sequence is provided, it determines per axis whether to place the last grid point on the boundary (True) or shift it by half a cell size into the interior (False). In each axis, an entry may consist in a single `bool` or a 2-tuple of `bool`. In the latter case, the first tuple entry decides for the left, the second for the right boundary. The length of the sequence must be `array.ndim`.

A single boolean is interpreted as a global choice for all boundaries.

See also:

uniform_sampling_fromintvsample a given interval product

odl.discr.partition.uniform_partitiondivide implicitly defined interval product into equally sized subsets

Examples

```
>>> grid = uniform_sampling([-1.5, 2], [-0.5, 3], (3, 3))
>>> grid.coord_vectors
(array([-1.5, -1. , -0.5]), array([ 2. ,  2.5,  3. ]))
```

To have the nodes in the "middle", use nodes_on_bdry=False

```
>>> grid = uniform_sampling([-1.5, 2], [-0.5, 3], (2, 2),
...                         nodes_on_bdry=False)
>>> grid.coord_vectors
(array([-1.25, -0.75]), array([ 2.25,  2.75]))
```

uniform_sampling_fromintv

odl.discr.grid.**uniform_sampling_fromintv**(*intv_prod*, *num_nodes*, *nodes_on_bdry=True*)

Sample an interval product uniformly.

The resulting grid will include `begin` and `end` of `intv_prod` as grid points. If you want a subdivision into equally sized cells with grid points in the middle, use *uniform_partition* instead.

Parametersintv_prod : *IntervalProd*

Set to be sampled

num_nodes : `int` or `tuple` of `int`

Number of nodes per axis. For dimension >= 2, a `tuple` is required. All entries must be positive. Entries corresponding to degenerate axes must be equal to 1.

nodes_on_bdry : `bool` or `sequence`, optional

If a sequence is provided, it determines per axis whether to place the last grid point on the boundary (True) or shift it by half a cell size into the interior (False). In each axis, an entry may consist in a single `bool` or a 2-tuple of `bool`. In the latter case, the first tuple entry decides for the left, the second for the right boundary. The length of the sequence must be `array.ndim`.

A single boolean is interpreted as a global choice for all boundaries.

Returnssampling : *RegularGrid*

Uniform sampling grid for the interval product

See also:

uniform_samplingSample an implicitly created *IntervalProd*

Examples

```
>>> from odl import IntervalProd
>>> rbox = IntervalProd([-1.5, 2], [-0.5, 3])
>>> grid = uniform_sampling_fromintv(rbox, (3, 3))
>>> grid.coord_vectors
(array([-1.5, -1. , -0.5]), array([ 2. ,  2.5,  3. ]))
```

To have the nodes in the "middle", use nodes_on_bdry=False

```
>>> grid = uniform_sampling_fromintv(rbox, (2, 2), nodes_on_bdry=False)
>>> grid.coord_vectors
(array([-1.25, -0.75]), array([ 2.25,  2.75]))
```

8.2.5 lp_discr

L^p type discretizations of function spaces.

Classes

DiscreteLp(fspace, partition, dspace[, ...])	Discretization of a Lebesgue L^p space.
DiscreteLpVector(space, data)	Representation of a *DiscreteLp* element.

DiscreteLp

class odl.discr.lp_discr.**DiscreteLp**(*fspace*, *partition*, *dspace*, *exponent=2.0*, *interp='nearest'*, ***kwargs*)

Bases: *odl.discr.discretization.Discretization*

Discretization of a Lebesgue L^p space.

Attributes

cell_sides	Side lengths of a cell in an underlying *uniform* partition.
cell_volume	Cell volume of an underlying regular partition.
domain	The domain of the continuous space.
dspace	The data space.
dspace_type	Data space type of this discretization.
dtype	The data type of each entry.
element_type	*DiscreteLpVector*
exponent	The exponent p in L^p.
extension	The operator mapping an n-tuple to a *uspace* element.
field	The field of this vector space.
grid	Sampling grid of the discretization mappings.
interp	Interpolation type of this discretization.
is_cn	Return True if the space represents C^n, i.e.
is_rn	Return True if the space represents R^n, i.e.
is_weighted	Return True if the dspace is weighted.
meshgrid	All sampling points in the partition as a sparse meshgrid.

Continued on next page

Table 8.44 – continued from previous page

ndim	Number of dimensions.
order	Axis ordering for array flattening.
partition	The *RectPartition* of the domain.
restriction	The operator mapping a *uspace* element to an n-tuple.
shape	Shape of the underlying partition.
size	Total number of underlying partition cells.
uspace	The undiscretized space.
weighting	This space's weighting scheme.

DiscreteLp.cell_sides

DiscreteLp.**cell_sides**
Side lengths of a cell in an underlying *uniform* partition.

DiscreteLp.cell_volume

DiscreteLp.**cell_volume**
Cell volume of an underlying regular partition.

DiscreteLp.domain

DiscreteLp.**domain**
The domain of the continuous space.

DiscreteLp.dspace

DiscreteLp.**dspace**
The data space.

DiscreteLp.dspace_type

DiscreteLp.**dspace_type**
Data space type of this discretization.

DiscreteLp.dtype

DiscreteLp.**dtype**
The data type of each entry.

DiscreteLp.element_type

DiscreteLp.**element_type**
DiscreteLpVector

DiscreteLp.exponent

DiscreteLp.**exponent**
The exponent p in L^p.

DiscreteLp.extension

DiscreteLp.**extension**
The operator mapping an n-tuple to a *uspace* element.

DiscreteLp.field

DiscreteLp.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

DiscreteLp.grid

DiscreteLp.**grid**
Sampling grid of the discretization mappings.

DiscreteLp.interp

DiscreteLp.**interp**
Interpolation type of this discretization.

DiscreteLp.is_cn

DiscreteLp.**is_cn**
Return True if the space represents C^n, i.e. complex tuples.

DiscreteLp.is_rn

DiscreteLp.**is_rn**
Return True if the space represents R^n, i.e. real tuples.

DiscreteLp.is_weighted

DiscreteLp.**is_weighted**
Return True if the dspace is weighted.

DiscreteLp.meshgrid

DiscreteLp.**meshgrid**
All sampling points in the partition as a sparse meshgrid.

DiscreteLp.ndim

DiscreteLp.**ndim**
Number of dimensions.

DiscreteLp.order

DiscreteLp.**order**
Axis ordering for array flattening.

DiscreteLp.partition

DiscreteLp.**partition**
The *RectPartition* of the domain.

DiscreteLp.restriction

DiscreteLp.**restriction**
The operator mapping a *uspace* element to an n-tuple.

DiscreteLp.shape

DiscreteLp.**shape**
Shape of the underlying partition.

DiscreteLp.size

DiscreteLp.**size**
Total number of underlying partition cells.

DiscreteLp.uspace

DiscreteLp.**uspace**
The undiscretized space.

DiscreteLp.weighting

DiscreteLp.**weighting**
This space's weighting scheme.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
_dist(x, y)	Return `self.dist(x, y)`.
_divide(x1, x2, out)	Raw pointwise multiplication of two vectors.
_inner(x, y)	Return `self.inner(x, y)`.
_lincomb(a, x1, b, x2, out)	Raw linear combination.
_multiply(x1, x2, out)	Raw pointwise multiplication of two vectors.
_norm(x)	Return `self.norm(x)`.
astype(dtype)	Return a copy of this space with new `dtype`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp])	Create an element from `inp` or from scratch.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	Create a vector of ones.
points()	All sampling points in the partition.
zero()	Create a vector of zeros.

DiscreteLp.__contains__

DiscreteLp.**__contains__**(*other*)

Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *NtuplesBaseVector* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

DiscreteLp.__eq__

DiscreteLp.**__eq__**(*other*)

Return `self == other`.

Returnsequals : `bool`

True if other is a *RawDiscretization* instance and all attributes *uspace*, *dspace*, *RawDiscretization.restriction* and *RawDiscretization.extension* of other and this discretization are equal, False otherwise.

DiscreteLp._dist

DiscreteLp.**_dist**(*x*, *y*)
Return self.dist(x, y).

DiscreteLp._divide

DiscreteLp.**_divide**(*x1*, *x2*, *out*)
Raw pointwise multiplication of two vectors.

DiscreteLp._inner

DiscreteLp.**_inner**(*x*, *y*)
Return self.inner(x, y).

DiscreteLp._lincomb

DiscreteLp.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)
Raw linear combination.

DiscreteLp._multiply

DiscreteLp.**_multiply**(*x1*, *x2*, *out*)
Raw pointwise multiplication of two vectors.

DiscreteLp._norm

DiscreteLp.**_norm**(*x*)
Return self.norm(x).

DiscreteLp.astype

DiscreteLp.**astype**(*dtype*)
Return a copy of this space with new dtype.

Parametersdtype :

Data type of the returned space. Can be given in any way numpy.dtype understands, e.g. as string ('complex64') or data type (complex).

Returnsnewspace : *FnBase*

The version of this space with given data type

DiscreteLp.contains_all

DiscreteLp.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

DiscreteLp.contains_set

DiscreteLp.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

DiscreteLp.dist

DiscreteLp.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

DiscreteLp.divide

DiscreteLp.**divide**(*x1*, *x2*, *out=None*)
Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

DiscreteLp.element

DiscreteLp.**element**(*inp=None*)
Create an element from `inp` or from scratch.

Parametersinp : `object`, optional

The input data to create an element from. Must be recognizable by the *LinearSpace.element* method of either *RawDiscretization.dspace* or *RawDiscretization.uspace*.

Returnselement : *DiscreteLpVector*

The discretized element, calculated as `dspace.element(inp)` or `restriction(uspace.element(inp))`, tried in this order.

DiscreteLp.inner

`DiscreteLp.`**`inner`**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

DiscreteLp.lincomb

`DiscreteLp.`**`lincomb`**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

DiscreteLp.multiply

DiscreteLp.**multiply**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

DiscreteLp.norm

DiscreteLp.**norm**(*x*)

Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

DiscreteLp.one

DiscreteLp.**one**()

Create a vector of ones.

DiscreteLp.points

DiscreteLp.**points**()

All sampling points in the partition.

DiscreteLp.zero

DiscreteLp.**zero**()

Create a vector of zeros.

__init__ (*fspace*, *partition*, *dspace*, *exponent=2.0*, *interp='nearest'*, ***kwargs*)
Initialize a new instance.

Parametersfspace : *FunctionSpace*

The continuous space to be discretized

partition : *RectPartition*

Partition of (a subset of) `fspace.domain` based on a *TensorGrid*

dspace : *FnBase*

Space of elements used for data storage. It must have the same *FnBase.field* as `fspace`

exponent : positive `float`, optional

The parameter p in L^p. If the exponent is not equal to the default 2.0, the space has no inner product.

interp : `str` or `sequence` of `str`, optional

The interpolation type to be used for discretization. A sequence is interpreted as interpolation scheme per axis.

'nearest' : use nearest-neighbor interpolation (default)

'linear' : use linear interpolation

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

DiscreteLpVector

class odl.discr.lp_discr.**DiscreteLpVector**(*space*, *data*)
Bases: *odl.discr.discretization.DiscretizationVector*

Representation of a *DiscreteLp* element.

Attributes

T	The transpose of a vector, the functional given by (.
cell_sides	Side lengths of a cell in an underlying *uniform* partition.
cell_volume	Cell volume of an underlying regular grid.
dtype	type of data storage.
extension	The extension operator associated with this vector.
imag	Imaginary part of this element.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions.
ntuple	Structure for data storage.
order	Axis ordering for array flattening.
real	Real part of this element.
shape	Multi-dimensional shape of this discrete function.
size	size of data storage.

Continued on next page

Table 8.46 – continued from previous page

space	Space to which this vector.
ufunc	*DiscreteLpUFuncs*, access to numpy style ufuncs.

DiscreteLpVector.T

DiscreteLpVector.**T**
The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

DiscreteLpVector.cell_sides

DiscreteLpVector.**cell_sides**
Side lengths of a cell in an underlying *uniform* partition.

DiscreteLpVector.cell_volume

DiscreteLpVector.**cell_volume**
Cell volume of an underlying regular grid.

DiscreteLpVector.dtype

DiscreteLpVector.**dtype**
type of data storage.

DiscreteLpVector.extension

DiscreteLpVector.**extension**
The extension operator associated with this vector.

Returnsextension_op : *FunctionSetMapping*

Operatior representing a continuous extension of this vector.

See also:

RawDiscretization.extension For full description

Examples

```
>>> import odl
>>> import numpy as np
```

Create continuous extension of 1d function with nearest neighbour

```
>>> X = odl.uniform_discr(0, 1, 3, nodes_on_bdry=True)
>>> x = X.element([0, 1, 0])
>>> x.extension(np.array([0.24, 0.26]))
array([ 0.,  1.])
```

Create continuous extension of 1d function wiht linear interpolation

```
>>> X = odl.uniform_discr(0, 1, 3, nodes_on_bdry=True, interp='linear')
>>> x = X.element([0, 1, 0])
>>> x.extension(np.array([0.24, 0.26]))
array([ 0.48,  0.52])
```

DiscreteLpVector.imag

DiscreteLpVector.**imag**
Imaginary part of this element.

DiscreteLpVector.itemsize

DiscreteLpVector.**itemsize**
The size in bytes on one element of this type.

DiscreteLpVector.nbytes

DiscreteLpVector.**nbytes**
The number of bytes this vector uses in memory.

DiscreteLpVector.ndim

DiscreteLpVector.**ndim**
Number of dimensions.

DiscreteLpVector.ntuple

DiscreteLpVector.**ntuple**
Structure for data storage.

DiscreteLpVector.order

DiscreteLpVector.**order**
Axis ordering for array flattening.

DiscreteLpVector.real

DiscreteLpVector.**real**
Real part of this element.

DiscreteLpVector.shape

DiscreteLpVector.**shape**
Multi-dimensional shape of this discrete function.

DiscreteLpVector.size

DiscreteLpVector.**size**
size of data storage.

DiscreteLpVector.space

DiscreteLpVector.**space**
Space to which this vector.

DiscreteLpVector.ufunc

DiscreteLpVector.**ufunc**
DiscreteLpUFuncs, access to numpy style ufuncs.

Notes

These are optimized to use the underlying ntuple space and incur no overhead unless these do.

Examples

```
>>> X = uniform_discr(0, 1, 2)
>>> x = X.element([1, -2])
>>> x.ufunc.absolute()
uniform_discr(0.0, 1.0, 2).element([1.0, 2.0])
```

These functions can also be used with broadcasting

```
>>> x.ufunc.add(3)
uniform_discr(0.0, 1.0, 2).element([4.0, 1.0])
```

and non-space elements

```
>>> x.ufunc.subtract([3, 3])
uniform_discr(0.0, 1.0, 2).element([-2.0, -5.0])
```

There is also support for various reductions (sum, prod, min, max)

```
>>> x.ufunc.sum()
-1.0
```

Also supports out parameter

```
>>> y = X.element([3, 4])
>>> out = X.element()
>>> result = x.ufunc.add(y, out=out)
>>> result
uniform_discr(0.0, 1.0, 2).element([4.0, 2.0])
>>> result is out
True
```

Methods

__eq__(other)	Return `vec == other`.
__getitem__(indices)	Return `self[indices]`.
__setitem__(indices, values)	Set values of this vector.
asarray([out])	Extract the data of this array as a numpy array.
assign(other)	Assign the values of `other` to self.
conj([out])	The complex conjugate of this element.
copy()	Create an identical (deep) copy of this vector.
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
restriction(ufunc)	Restrict a continuous function and assign to this vector
set_zero()	Set this vector to zero.
show([title, method, coords, indices, show, fig])	Display the function graphically.

DiscreteLpVector.__eq__

DiscreteLpVector.**__eq__**(*other*)

Return `vec == other`.

Returnsequals : `bool`

`True` if all entries of `other` are equal to this vector's entries, `False` otherwise.

DiscreteLpVector.__getitem__

DiscreteLpVector.**__getitem__**(*indices*)

Return `self[indices]`.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : *NtuplesBaseVector*

The value(s) at the index (indices)

DiscreteLpVector.__setitem__

DiscreteLpVector.**__setitem__**(*indices*, *values*)
Set values of this vector.

Parametersindices : int or slice

The position(s) that should be set

values : scalar, *array-like* or *NtuplesVector*

The value(s) that are to be assigned. If indices is an int, values must be a single value. If indices is a slice, values must be broadcastable to the size of the slice (same size, shape (1,) or single value). For indices=slice(None), i.e. in the call vec[:] = values, a multi-dimensional array of correct shape is allowed as values.

DiscreteLpVector.asarray

DiscreteLpVector.**asarray**(*out=None*)
Extract the data of this array as a numpy array.

Parametersout : numpy.ndarray, optional

Array in which the result should be written in-place. Has to be contiguous and of the correct dtype and shape.

DiscreteLpVector.assign

DiscreteLpVector.**assign**(*other*)
Assign the values of other to self.

DiscreteLpVector.conj

DiscreteLpVector.**conj**(*out=None*)
The complex conjugate of this element.

Parametersout : *DiscreteLpVector*, optional

Element to which the complex conjugate is written. Must be an element of this vector's space.

Returnsout : *DiscreteLpVector*

The complex conjugate vector. If out is provided, the returned object is a reference to it.

Examples

```
>>> discr = uniform_discr(0, 1, 4, dtype='complex')
>>> x = discr.element([5+1j, 3, 2-2j, 1j])
>>> y = x.conj(); print(y)
[(5-1j), (3-0j), (2+2j), -1j]
```

The out parameter allows you to avoid a copy:

```
>>> z = discr.element()
>>> z_out = x.conj(out=z); print(z)
[(5-1j), (3-0j), (2+2j), -1j]
>>> z_out is z
True
```

It can also be used for in-place conjugation:

```
>>> x_out = x.conj(out=x); print(x)
[(5-1j), (3-0j), (2+2j), -1j]
>>> x_out is x
True
```

DiscreteLpVector.copy

DiscreteLpVector.**copy**()
Create an identical (deep) copy of this vector.

DiscreteLpVector.dist

DiscreteLpVector.**dist**(*other*)
Distance to `other`.

LinearSpace.dist

DiscreteLpVector.divide

DiscreteLpVector.**divide**(*x*, *y*)
Divide by `other` inplace.

LinearSpace.divide

DiscreteLpVector.inner

DiscreteLpVector.**inner**(*other*)
Inner product with `other`.

LinearSpace.inner

DiscreteLpVector.lincomb

DiscreteLpVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

DiscreteLpVector.multiply

`DiscreteLpVector.`**`multiply`**(*x*, *y*)

Multiply by `other` inplace.

LinearSpace.multiply

DiscreteLpVector.norm

`DiscreteLpVector.`**`norm`**()

Norm of vector

LinearSpace.norm

DiscreteLpVector.restriction

`DiscreteLpVector.`**`restriction`**(*ufunc*)

Restrict a continuous function and assign to this vector

Parametersufunc : `self.space.uspace` element

The continuous function that should be restricted.

See also:

`RawDiscretization.restriction`For full description

Examples

```
>>> import odl
>>> import numpy as np
```

Create discretization

```
>>> X = odl.uniform_discr(0, 1, 5)
>>> x = X.element()
```

Assign x according to continuous vector

```
>>> x.restriction(lambda x: x)
>>> print(x) # Print values at gridpoints (which are centered)
[0.1, 0.3, 0.5, 0.7, 0.9]
```

DiscreteLpVector.set_zero

`DiscreteLpVector.`**`set_zero`**()

Set this vector to zero.

LinearSpace.zero

DiscreteLpVector.show

DiscreteLpVector.**show**(*title=None*, *method=''*, *coords=None*, *indices=None*, *show=False*, *fig=None*, ***kwargs*)

Display the function graphically.

Parameterstitle : `str`, optional

Set the title of the figure

method : `str`, optional

1d methods:

'plot' : graph plot

'scatter' : scattered 2d points (2nd axis <-> value)

2d methods:

'imshow' : image plot with coloring according to value, including a colorbar.

'scatter' : cloud of scattered 3d points (3rd axis <-> value)

coords : array-like, optional

Display a slice of the array instead of the full array. The values are shown accordinging to the given values, `None` represent all values along that dimension. For example [None, None, 0.5] shows all values in the first two dimensions, with third coordinate equal to 0.5. This option is mutually exclusive to indices.

indices : index expression, optional

Display a slice of the array instead of the full array. The index expression is most easily created with the `numpy.s_` constructor, i.e. supply `np.s_[:, 1, :]` to display the first slice along the second axis. For data with 3 or more dimensions, the 2d slice in the first two axes at the "middle" along the remaining axes is shown (semantically `[:, :, shape[2:] // 2]`). This option is mutually exclusive to coords.

show : `bool`, optional

If the plot should be showed now or deferred until later.

fig : `matplotlib.figure.Figure`

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that `fig` is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', 'clim', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : `matplotlib.figure.Figure`

The resulting figure. It is also shown to the user.

See also:

odl.util.graphics.show_discrete_dataUnderlying implementation

__init__(*space*, *data*)

Initialize a new instance.

Functions

discr_sequence_space(shape[, exponent, impl])	Return an object mimicing the sequence space `l^p(R^d)`.
uniform_discr(min_corner, max_corner, nsamples)	Discretize an Lp function space by uniform sampling.
uniform_discr_fromintv(interval, nsamples[, ...])	Discretize an Lp function space by uniform sampling.
uniform_discr_frompartition(partition[, ...])	Discretize an Lp function space given a uniform partition.
uniform_discr_fromspace(fspace, nsamples[, ...])	Discretize an Lp function space by uniform partition.

discr_sequence_space

odl.discr.lp_discr.**discr_sequence_space**(*shape*, *exponent=2.0*, *impl='numpy'*, ***kwargs*)

Return an object mimicing the sequence space `l^p(R^d)`.

The returned object is a *DiscreteLp* without restriction and extension operators. It uses a grid with stride 1 and no weighting.

Parametersshape : `sequence` of `int`

Multi-dimensional size of the elements in this space

exponent : positive `float`, optional

The parameter `p` in `'L^p`. If the exponent is not equal to the default 2.0, the space has no inner product.

impl : {'numpy', 'cuda'}

Implementation of the data storage arrays

dtype : dtype

Data type for the discretized space

Default for 'numpy': 'float64'

Default for 'cuda': 'float32'

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

Returnsseqspc : *DiscreteLp*

The sequence-space-like discrete Lp

Examples

```
>>> seq_spc = discr_sequence_space((3, 3))
>>> seq_spc.one().norm() == 3.0
True
>>> seq_spc = discr_sequence_space((3, 3), exponent=1)
>>> seq_spc.one().norm() == 9.0
True
```

uniform_discr

odl.discr.lp_discr.**uniform_discr**(*min_corner*, *max_corner*, *nsamples*, *exponent=2.0*, *interp='nearest'*, *impl='numpy'*, ***kwargs*)

Discretize an Lp function space by uniform sampling.

Parametersmin_corner : `float` or `tuple` of `float`

Minimum corner of the result.

nsamples : `float` or `tuple` of `float`

Minimum corner of the result.

nsamples : `int` or `tuple` of `int`

Number of samples per axis. For dimension >= 2, a tuple is required.

exponent : positive `float`, optional

The parameter p in L^p. If the exponent is not equal to the default 2.0, the space has no inner product.

interp : `str` or `sequence` of `str`, optional

Interpolation type to be used for discretization. A sequence is interpreted as interpolation scheme per axis.

'nearest' : use nearest-neighbor interpolation

'linear' : use linear interpolation

impl : {'numpy', 'cuda'}, optional

Implementation of the data storage arrays

nodes_on_bdry : `bool` or `sequence`, optional

If a sequence is provided, it determines per axis whether to place the last grid point on the boundary (True) or shift it by half a cell size into the interior (False). In each axis, an entry may consist in a single `bool` or a 2-tuple of `bool`. In the latter case, the first tuple entry decides for the left, the second for the right boundary. The length of the sequence must be `array.ndim`.

A single boolean is interpreted as a global choice for all boundaries. Default: `False`

dtype : dtype, optional

Data type for the discretized space

Default for 'numpy': 'float64' / 'complex128'

Default for 'cuda': 'float32'

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

weighting : {'const', 'none'}, optional

Weighting of the discretized space functions.

'const' : weight is a constant, the cell volume (default)

'none' : no weighting

Returnsdiscr : *DiscreteLp*

The uniformly discretized function space

See also:

uniform_discr_frompartition uniform Lp discretization using a given uniform partition of a function domain

uniform_discr_fromspace uniform discretization from an existing function space

uniform_discr_fromintv uniform discretization from an existing interval product

Examples

Create real space:

```
>>> uniform_discr([0, 0], [1, 1], [10, 10])
uniform_discr([0.0, 0.0], [1.0, 1.0], [10, 10])
```

Can create complex space by giving a dtype

```
>>> uniform_discr([0, 0], [1, 1], [10, 10], dtype='complex')
uniform_discr([0.0, 0.0], [1.0, 1.0], [10, 10], dtype='complex')
```

uniform_discr_fromintv

odl.discr.lp_discr.**uniform_discr_fromintv**(*interval*, *nsamples*, *exponent=2.0*, *interp='nearest'*, *impl='numpy'*, ***kwargs*)

Discretize an Lp function space by uniform sampling.

Parametersdomain : *IntervalProd*

The domain of the uniformly discretized space.

nsamples : `float` or `tuple` of `float`

Minimum corner of the result.

nsamples : `int` or `tuple` of `int`

Number of samples per axis. For dimension >= 2, a tuple is required.

exponent : positive `float`, optional

The parameter p in L^p. If the exponent is not equal to the default 2.0, the space has no inner product.

interp : `str` or `sequence` of `str`, optional

Interpolation type to be used for discretization. A sequence is interpreted as interpolation scheme per axis.

'nearest' : use nearest-neighbor interpolation

'linear' : use linear interpolation

impl : {'numpy', 'cuda'}, optional

Implementation of the data storage arrays

nodes_on_bdry : `bool` or `sequence`, optional

If a sequence is provided, it determines per axis whether to place the last grid point on the boundary (True) or shift it by half a cell size into the interior (False). In each axis, an entry may consist in a single `bool` or a 2-tuple of `bool`. In the latter case, the first tuple entry decides for the left, the second for the right boundary. The length of the sequence must be `array.ndim`.

A single boolean is interpreted as a global choice for all boundaries. Default: `False`

dtype : dtype, optional

Data type for the discretized space

Default for 'numpy': 'float64' / 'complex128'

Default for 'cuda': 'float32'

order : {'C', 'F'}, optional

Ordering of the axes in the data storage. 'C' means the first axis varies slowest, the last axis fastest; vice versa for 'F'. Default: 'C'

weighting : {'const', 'none'}, optional

Weighting of the discretized space functions.

'const' : weight is a constant, the cell volume (default)

'none' : no weighting

Returnsdiscr : *DiscreteLp*

The uniformly discretized function space

See also:

uniform_discrimplicit uniform Lp discretization

uniform_discr_frompartitionuniform Lp discretization using a given uniform partition of a function domain

uniform_discr_fromspaceuniform discretization from an existing function space

Examples

```
>>> from odl import Interval
>>> intv = Interval(0, 1)
>>> uniform_discr_fromintv(intv, 10)
uniform_discr(0.0, 1.0, 10)
```

uniform_discr_frompartition

odl.discr.lp_discr.**uniform_discr_frompartition**(*partition*, *exponent=2.0*, *interp='nearest'*, *impl='numpy'*, ***kwargs*)

Discretize an Lp function space given a uniform partition.

Parameterspartition : *RectPartition*

Regular (uniform) partition to be used for discretization

exponent : positive `float`, optional

The parameter `p` in `L^p`. If the exponent is not equal to the default 2.0, the space has no inner product.

interp : `str` or `sequence` of `str`, optional

Interpolation type to be used for discretization. A sequence is interpreted as interpolation scheme per axis.

'nearest' : use nearest-neighbor interpolation

'linear' : use linear interpolation

impl : {'numpy', 'cuda'}, optional

Implementation of the data storage arrays

Returnsdiscr : *DiscreteLp*

The uniformly discretized function space

Other Parametersorder : {'C', 'F'}, optional

Axis ordering in the data storage. Default: 'C'

dtype : dtype

Data type for the discretized space

Default for 'numpy': 'float64' / 'complex128'

Default for 'cuda': 'float32'

weighting : {'const', 'none'}, optional

Weighting of the discretized space functions.

'const' : weight is a constant, the cell volume (default)

'none' : no weighting

See also:

uniform_discrimplicit uniform Lp discretization

uniform_discr_fromspaceuniform Lp discretization from an existing function space

odl.discr.partition.uniform_partitionpartition of the function domain

Examples

```
>>> from odl import uniform_partition
>>> part = uniform_partition(0, 1, 10)
>>> uniform_discr_frompartition(part)
uniform_discr(0.0, 1.0, 10)
```

uniform_discr_fromspace

odl.discr.lp_discr.**uniform_discr_fromspace**(*fspace*, *nsamples*, *exponent=2.0*, *interp='nearest'*, *impl='numpy'*, ***kwargs*)

Discretize an Lp function space by uniform partition.

Parametersfspace : *FunctionSpace*

Continuous function space. Its domain must be an *IntervalProd* instance.

nsamples : `int` or `tuple` of `int`

Number of samples per axis. For dimension >= 2, a tuple is required.

exponent : positive `float`, optional

The parameter `p` in `L^p`. If the exponent is not equal to the default 2.0, the space has no inner product.

interp : `str` or `sequence` of `str`, optional

Interpolation type to be used for discretization. A sequence is interpreted as interpolation scheme per axis.

'nearest' : use nearest-neighbor interpolation

'linear' : use linear interpolation

impl : {'numpy', 'cuda'}, optional

Implementation of the data storage arrays

Returnsdiscr : *DiscreteLp*

The uniformly discretized function space

Other Parametersnodes_on_bdry : `bool` or boolean *array-like*, optional

If `True`, place the outermost grid points at the boundary. For `False`, they are shifted by half a cell size to the 'inner'. If an array-like is given, it must have shape `(ndim, 2)`, where `ndim` is the number of dimensions. It defines per axis whether the leftmost (first column) and rightmost (second column) nodes node lie on the boundary. Default: `False`

order : {'C', 'F'}, optional

Axis ordering in the data storage. Default: 'C'

dtype : dtype, optional

Data type for the discretized space. If not specified, the *FunctionSpace.out_dtype* of `fspace` is used.

weighting : {'const', 'none'}, optional

Weighting of the discretized space functions.

'const' : weight is a constant, the cell volume (default)

'none' : no weighting

See also:

uniform_discrimplicit uniform Lp discretization

uniform_discr_frompartitionuniform Lp discretization using a given uniform partition of a function domain

uniform_discr_fromintvuniform discretization from an existing interval product

odl.discr.partition.uniform_partitionpartition of the function domain

Examples

```
>>> from odl import Interval, FunctionSpace
>>> intv = Interval(0, 1)
>>> space = FunctionSpace(intv)
>>> uniform_discr_fromspace(space, 10)
uniform_discr(0.0, 1.0, 10)
```

8.2.6 partition

Partitons of interval products based on tensor grids.

A partition of a set is a finite collection of nonempty, pairwise disjoint subsets whose union is the original set. The partitions considered here are based on hypercubes, i.e. the tensor products of partitions of intervals.

Classes

RectPartition(intv_prod, grid)	Rectangular partition by hypercubes based on *TensorGrid*.

RectPartition

class odl.discr.partition.**RectPartition**(*intv_prod*, *grid*)

Bases: object

Rectangular partition by hypercubes based on *TensorGrid*.

In 1d, a partition of an interval is implicitly defined by a collection of points x[0], ..., x[N-1] (a grid) which are chosen to lie in the center of the subintervals. The i-th subinterval is thus given by:

```
I[i] = [(x[i-1]+x[i])/2, (x[i]+x[i+1])/2]
```

Attributes

begin	Minimum coordinates of the partitioned set.
boundary_cell_fractions	Return a tuple of contained fractions of boundary cells.
cell_boundary_vecs	Return the cell boundaries as coordinate vectors.
cell_sides	Side lengths of all 'inner' cells of a regular partition.
cell_sizes_vecs	Return the cell sizes as coordinate vectors.
cell_volume	Volume of the 'inner' cells, regardless of begin and end.
end	Maximum coordinates of the partitioned set.
grid	The *TensorGrid* defining this partition.
is_regular	Return True if self.grid is a *RegularGrid*.
meshgrid	Return the sparse meshgrid of sampling points.
ndim	Number of dimensions.
set	The partitioned set, an *IntervalProd*.
shape	Number of cells per axis, equal to self.grid.shape.
size	Total number of cells, equal to self.grid.size.

RectPartition.begin

RectPartition.**begin**
Minimum coordinates of the partitioned set.

RectPartition.boundary_cell_fractions

RectPartition.**boundary_cell_fractions**
Return a tuple of contained fractions of boundary cells.

Since the outermost grid points can have any distance to the boundary of the partitioned set, the "natural" outermost cell around these points can either be cropped or extended. This property is a tuple of (float, float) tuples, one entry per dimension, where the fractions of the left- and rightmost cells inside the set are stored. If a grid point lies exactly on the boundary, the value is 1/2 since the cell is cut in half. Otherwise, any value larger than 1/2 is possible.

Returnson_bdry : `tuple` of 2-tuple of `float`

Each 2-tuple contains the fraction of the leftmost (first entry) and rightmost (second entry) cell in the partitioned set in the corresponding dimension.

See also:

cell_boundary_vecs

Examples

We create a partition of the rectangle [0, 1.5] x [-2, 2] with the grid points [0, 1] x [-1, 0, 2]. The "natural" cells at the boundary would be:

[-0.5, 0.5] and [0.5, 1.5] in the first axis

[-1.5, -0.5] and [1, 3] in the second axis

Thus, in the first axis, the fractions contained in [0, 1.5] are 0.5 and 1, and in the second axis, [-2, 2] contains the fractions 1.5 and 0.5.

```
>>> rect = IntervalProd([0, -2], [1.5, 2])
>>> grid = TensorGrid([0, 1], [-1, 0, 2])
>>> part = RectPartition(rect, grid)
>>> part.boundary_cell_fractions
((0.5, 1.0), (1.5, 0.5))
```

RectPartition.cell_boundary_vecs

RectPartition.**cell_boundary_vecs**
Return the cell boundaries as coordinate vectors.

Examples

```
>>> rect = IntervalProd([0, -1], [1, 2])
>>> grid = TensorGrid([0, 1], [-1, 0, 2])
>>> part = RectPartition(rect, grid)
>>> part.cell_boundary_vecs
(array([ 0. ,  0.5,  1. ]), array([-1. , -0.5,  1. ,  2. ]))
```

RectPartition.cell_sides

RectPartition.**cell_sides**
Side lengths of all 'inner' cells of a regular partition.

Only defined if `self.grid` is a *RegularGrid*.

Examples

We create a partition of the rectangle [0, 1] x [-1, 2] into 3 x 3 cells, where the grid points lie on the boundary. This means that the grid points are [0, 0.5, 1] x [-1, 0.5, 2], i.e. the inner cell has side lengths 0.5 x 1.5:

```
>>> rect = IntervalProd([0, -1], [1, 2])
>>> grid = RegularGrid([0, -1], [1, 2], (3, 3))
>>> part = RectPartition(rect, grid)
>>> part.cell_sides
array([ 0.5,  1.5])
```

RectPartition.cell_sizes_vecs

RectPartition.**cell_sizes_vecs**
Return the cell sizes as coordinate vectors.

Returnscsizes : `tuple` of `numpy.ndarray`

The cell sizes per axis. The length of the vectors is the same as the corresponding `grid.coord_vectors`. For axes with 1 grid point, cell size is set to 0.0.

Examples

We create a partition of the rectangle [0, 1] x [-1, 2] into 2 x 3 cells with the grid points [0, 1] x [-1, 0, 2]. This implies that the cell boundaries are given as [0, 0.5, 1] x [-1, -0.5, 1, 2], hence the cell size vectors are [0.5, 0.5] x [0.5, 1.5, 1]:

```
>>> rect = IntervalProd([0, -1], [1, 2])
>>> grid = TensorGrid([0, 1], [-1, 0, 2])
>>> part = RectPartition(rect, grid)
>>> part.cell_boundary_vecs
(array([ 0. ,  0.5,  1. ]), array([-1. , -0.5,  1. ,  2. ]))
>>> part.cell_sizes_vecs
(array([ 0.5,  0.5]), array([ 0.5,  1.5,  1. ]))
```

RectPartition.cell_volume

RectPartition.**cell_volume**
Volume of the 'inner' cells, regardless of begin and end.

Only defined if `self.grid` is a *RegularGrid*.

Examples

We create a partition of the rectangle [0, 1] x [-1, 2] into 3 x 3 cells, where the grid points lie on the boundary. This means that the grid points are [0, 0.5, 1] x [-1, 0.5, 2], i.e. the inner cell has side lengths 0.5 x 1.5:

```
>>> rect = IntervalProd([0, -1], [1, 2])
>>> grid = RegularGrid([0, -1], [1, 2], (3, 3))
>>> part = RectPartition(rect, grid)
>>> part.cell_sides
array([ 0.5,  1.5])
>>> part.cell_volume
0.75
```

RectPartition.end

`RectPartition.`**`end`**
Maximum coordinates of the partitioned set.

RectPartition.grid

`RectPartition.`**`grid`**
The *TensorGrid* defining this partition.

RectPartition.is_regular

`RectPartition.`**`is_regular`**
Return `True` if `self.grid` is a *RegularGrid*.

RectPartition.meshgrid

`RectPartition.`**`meshgrid`**
Return the sparse meshgrid of sampling points.

RectPartition.ndim

`RectPartition.`**`ndim`**
Number of dimensions.

RectPartition.set

`RectPartition.`**`set`**
The partitioned set, an *IntervalProd*.

RectPartition.shape

`RectPartition.`**`shape`**
Number of cells per axis, equal to `self.grid.shape`.

RectPartition.size

RectPartition.**size**
Total number of cells, equal to `self.grid.size`.

Methods

__eq__(other)	Return `self == other`.
approx_equals(other, atol)	Return `True` in case of approximate equality.
extent()	Return a vector containing the total extent (max - min).
insert(index, other)	Return a copy with `other` inserted before `index`.
max()	Return the maximum point of the partitioned set.
min()	Return the minimum point of the partitioned set.
points()	Return the sampling grid points.

RectPartition.__eq__

RectPartition.**__eq__**(*other*)
Return `self == other`.

RectPartition.approx_equals

RectPartition.**approx_equals**(*other*, *atol*)
Return `True` in case of approximate equality.

Returnsapprox_eq : `bool`

`True` if `other` is a *RectPartition* instance with `self.set == other.set` up to `atol` and `self.grid == other.other` up to `atol`.

RectPartition.extent

RectPartition.**extent**()
Return a vector containing the total extent (max - min).

RectPartition.insert

RectPartition.**insert**(*index*, *other*)
Return a copy with `other` inserted before `index`.

Parametersindex : `int`

Index of the dimension before which `other` is to be inserted. Negative indices count backwards from `self.ndim`.

other : *RectPartition*

Partition to be inserted

Returnsnewpart : *RectPartition*

Partition with the inserted other partition

RectPartition.max

RectPartition.**max**()
Return the maximum point of the partitioned set.

See also:

odl.set.domain.IntervalProd.max

RectPartition.min

RectPartition.**min**()
Return the minimum point of the partitioned set.

See also:

odl.set.domain.IntervalProd.min

RectPartition.points

RectPartition.**points**()
Return the sampling grid points.

__init__(*intv_prod*, *grid*)
Initialize a new instance.

Parametersintv_prod : *IntervalProd*

Set to be partitioned

grid : *TensorGrid*

Spatial points supporting the partition. They must be contained in `intv_prod`.

Functions

uniform_partition(begin, end, num_nodes[, ...])	Return a partition of [begin, end] with equally sized cells.
uniform_partition_fromgrid(grid[, begin, end])	Return a partition of an interval product based on a given grid.
uniform_partition_fromintv(intv_prod, num_nodes)	Return a partition of an interval product into equally sized cells.

uniform_partition

odl.discr.partition.**uniform_partition**(*begin*, *end*, *num_nodes*, *nodes_on_bdry=False*)
Return a partition of [begin, end] with equally sized cells.

Parametersbegin, end : *array-like*

Vectors defining the begin end end points of an *IntervalProd* (a rectangular box)

num_nodes : `int` or `sequence` of `int`

Number of nodes per axis. For 1d intervals, a single integer can be specified.

nodes_on_bdry : `bool` or `sequence`, optional

If a sequence is provided, it determines per axis whether to place the last grid point on the boundary (True) or shift it by half a cell size into the interior (False). In each axis,

an entry may consist in a single `bool` or a 2-tuple of `bool`. In the latter case, the first tuple entry decides for the left, the second for the right boundary. The length of the sequence must be `array.ndim`.

A single boolean is interpreted as a global choice for all boundaries.

See also:

uniform_partition_fromintv partition an existing set

uniform_partition_fromgrid use an existing grid as basis

Examples

By default, no grid points are placed on the boundary:

```
>>> part = uniform_partition(0, 1, 4)
>>> part.cell_boundary_vecs
(array([ 0.  ,  0.25,  0.5 ,  0.75,  1.  ]),)
>>> part.grid.coord_vectors
(array([ 0.125,  0.375,  0.625,  0.875]),)
```

This can be changed with the nodes_on_bdry parameter:

```
>>> part = uniform_partition(0, 1, 3, nodes_on_bdry=True)
>>> part.cell_boundary_vecs
(array([ 0.  ,  0.25,  0.75,  1.  ]),)
>>> part.grid.coord_vectors
(array([ 0. ,  0.5,  1. ]),)
```

We can specify this per axis, too. In this case we choose both in the first axis and only the rightmost in the second:

```
>>> part = uniform_partition([0, 0], [1, 1], (3, 3),
...                          nodes_on_bdry=(True, (False, True)))
...
>>> part.cell_boundary_vecs[0]  # first axis, as above
array([ 0.  ,  0.25,  0.75,  1.  ])
>>> part.grid.coord_vectors[0]
array([ 0. ,  0.5,  1. ])
>>> part.cell_boundary_vecs[1]  # second, asymmetric axis
array([ 0. ,  0.4,  0.8,  1. ])
>>> part.grid.coord_vectors[1]
array([ 0.2,  0.6,  1. ])
```

uniform_partition_fromgrid

odl.discr.partition.**uniform_partition_fromgrid**(*grid*, *begin=None*, *end=None*)

Return a partition of an interval product based on a given grid.

This method is complementary to *uniform_partition_fromintv* in that it infers the set to be partitioned from a given grid and optional parameters for the begin and the end of the set.

Parametersgrid : *TensorGrid*

Grid on which the partition is based

begin, end : *array-like* or `dictionary`

Spatial points defining the begin and end of an interval product to be partitioned. The points can be specified in two ways:

array-like: These values are used directly as begin and/or end.

dictionary: Index-value pairs specifying an axis and a spatial coordinate to be used in that axis. In axes which are not a key in the dictionary, the coordinate for the vector is calculated as:

```
begin = x[0] - (x[1] - x[0]) / 2
end = x[-1] + (x[-1] - x[-2]) / 2
```

See `Examples` below.

In general, `begin` may not be larger than `grid.min_pt`, and `end` not smaller than `grid.max_pt` in any component. `None` is equivalent to an empty dictionary, i.e. the values are calculated in each dimension.

See also:

uniform_partition_fromintv

Examples

Have begin and end of the bounding box automatically calculated:

```
>>> grid = RegularGrid(0, 1, 3)
>>> grid.coord_vectors
(array([ 0. ,  0.5,  1. ]),)
>>> part = uniform_partition_fromgrid(grid)
>>> part.cell_boundary_vecs
(array([-0.25,  0.25,  0.75,  1.25]),)
```

Begin and end can be given explicitly as array-like:

```
>>> part = uniform_partition_fromgrid(grid, begin=0, end=1)
>>> part.cell_boundary_vecs
(array([ 0.  ,  0.25,  0.75,  1.  ]),)
```

Using dictionaries, selective axes can be explicitly set. The keys refer to axes, the values to the coordinates to use:

```
>>> grid = RegularGrid([0, 0], [1, 1], (3, 3))
>>> part = uniform_partition_fromgrid(grid, begin={0: -1}, end={-1: 3})
>>> part.cell_boundary_vecs[0]
array([-1.  ,  0.25,  0.75,  1.25])
>>> part.cell_boundary_vecs[1]
array([-0.25,  0.25,  0.75,  3.  ])
```

uniform_partition_fromintv

odl.discr.partition.**uniform_partition_fromintv**(*intv_prod*, *num_nodes*, *nodes_on_bdry=False*)

Return a partition of an interval product into equally sized cells.

Parametersintv_prod : *IntervalProd*

Interval product to be partitioned

num_nodes : `int` or `sequence` of `int`

Number of nodes per axis. For 1d intervals, a single integer can be specified.

nodes_on_bdry : `bool` or `sequence`, optional

If a sequence is provided, it determines per axis whether to place the last grid point on the boundary (True) or shift it by half a cell size into the interior (False). In each axis, an entry may consist in a single `bool` or a 2-tuple of `bool`. In the latter case, the first tuple entry decides for the left, the second for the right boundary. The length of the sequence must be `array.ndim`.

A single boolean is interpreted as a global choice for all boundaries.

See also:

uniform_partition_fromgrid

Examples

By default, no grid points are placed on the boundary:

```
>>> interval = IntervalProd(0, 1)
>>> part = uniform_partition_fromintv(interval, 4)
>>> part.cell_boundary_vecs
(array([ 0.  ,  0.25,  0.5 ,  0.75,  1.  ]),)
>>> part.grid.coord_vectors
(array([ 0.125,  0.375,  0.625,  0.875]),)
```

This can be changed with the nodes_on_bdry parameter:

```
>>> part = uniform_partition_fromintv(interval, 3, nodes_on_bdry=True)
>>> part.cell_boundary_vecs
(array([ 0.  ,  0.25,  0.75,  1.  ]),)
>>> part.grid.coord_vectors
(array([ 0. ,  0.5,  1. ]),)
```

We can specify this per axis, too. In this case we choose both in the first axis and only the rightmost in the second:

```
>>> rect = IntervalProd([0, 0], [1, 1])
>>> part = uniform_partition_fromintv(
...     rect, (3, 3), nodes_on_bdry=(True, (False, True)))
...
>>> part.cell_boundary_vecs[0]  # first axis, as above
array([ 0.  ,  0.25,  0.75,  1.  ])
>>> part.grid.coord_vectors[0]
array([ 0. ,  0.5,  1. ])
>>> part.cell_boundary_vecs[1]  # second, asymmetric axis
array([ 0. ,  0.4,  0.8,  1. ])
>>> part.grid.coord_vectors[1]
array([ 0.2,  0.6,  1. ])
```

8.3 operator

Mathematical operators in ODL.

Modules

8.3.1 default_ops

Default operators defined on any (reasonable) space.

Classes

ConstantOperator(vector[, dom])	Operator that always returns the same value
IdentityOperator(space)	Operator mapping each element to itself.
InnerProductOperator(vector)	Operator taking the inner product with a fixed vector.
LinCombOperator(space, a, b)	Operator mapping two space elements to a linear combination.
MultiplyOperator(y[, domain])	Operator multiplying two elements.
ResidualOperator(op, vec)	Operator that calculates the residual `op(x) - vec`.
ScalingOperator(space, scalar)	Operator of multiplication with a scalar.
ZeroOperator(space)	Operator mapping each element to the zero element.

ConstantOperator

class `odl.operator.default_ops.`**`ConstantOperator`**(*vector*, *dom=None*)

Bases: *odl.operator.operator.Operator*

Operator that always returns the same value

```
ConstantOperator(vector)(x) <==> vector
```

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ConstantOperator.adjoint

`ConstantOperator.`**`adjoint`**

The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

ConstantOperator.domain

`ConstantOperator.`**`domain`**

Set of objects on which this operator can be evaluated.

ConstantOperator.inverse

ConstantOperator.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

ConstantOperator.is_functional

ConstantOperator.**is_functional**
`True` if the this operator's range is a *Field*.

ConstantOperator.is_linear

ConstantOperator.**is_linear**
`True` if this operator is linear.

ConstantOperator.range

ConstantOperator.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Return the constant vector or assign it to `out`.
derivative(point)	Return the operator derivative at `point`.

ConstantOperator.__call__

ConstantOperator.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_call Implementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ConstantOperator._call

`ConstantOperator.`**`_call`**(*x*, *out=None*)

Return the constant vector or assign it to `out`.

Parametersx : `domain` *element*

An element of the domain

out : `range` element

Vector that gets assigned to the constant vector

Returnsout : `range` element

Result of the assignment. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> x = r3.element([1, 2, 3])
>>> op = ConstantOperator(x)
>>> op(x, out=r3.element())
Rn(3).element([1.0, 2.0, 3.0])
```

ConstantOperator.derivative

ConstantOperator.**derivative**(*point*)
Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*vector*, *dom=None*)
Initialize an instance.

Parametersvector : *LinearSpaceVector*

The vector constant to be returned

dom : *LinearSpace*, default

The domain of the operator.

IdentityOperator

class odl.operator.default_ops.**IdentityOperator**(*space*)
Bases: *odl.operator.default_ops.ScalingOperator*

Operator mapping each element to itself.

Attributes

adjoint	Adjoint, given as scaling with the conjugate of the scalar.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the inverse operator.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

IdentityOperator.adjoint

IdentityOperator.**adjoint**
Adjoint, given as scaling with the conjugate of the scalar.

IdentityOperator.domain

IdentityOperator.**domain**
Set of objects on which this operator can be evaluated.

IdentityOperator.inverse

IdentityOperator.**inverse**
Return the inverse operator.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> vec = r3.element([1, 2, 3])
>>> op = ScalingOperator(r3, 2.0)
>>> inv = op.inverse
>>> inv(op(vec)) == vec
True
>>> op(inv(vec)) == vec
True
```

IdentityOperator.is_functional

IdentityOperator.**is_functional**
`True` if the this operator's range is a *Field*.

IdentityOperator.is_linear

IdentityOperator.**is_linear**
`True` if this operator is linear.

IdentityOperator.range

IdentityOperator.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Scale input and write to output.
derivative(point)	Return the operator derivative at `point`.

IdentityOperator.__call__

IdentityOperator.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

IdentityOperator._call

`IdentityOperator.`**`_call`**(*x*, *out=None*)

Scale input and write to output.

Parametersx : `domain` *element*

input vector to be scaled

out : `range` *element*, optional

Output vector to which the result is written

Returnsout : `range` *element*

Result of the scaling. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> vec = r3.element([1, 2, 3])
>>> out = r3.element()
>>> op = ScalingOperator(r3, 2.0)
>>> op(vec, out)  # In place, Returns out
```

```
        Rn(3).element([2.0, 4.0, 6.0])
        >>> out
        Rn(3).element([2.0, 4.0, 6.0])
        >>> op(vec)  # Out of place
        Rn(3).element([2.0, 4.0, 6.0])
```

IdentityOperator.derivative

IdentityOperator.**derivative**(*point*)

Return the operator derivative at point.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*space*)

Initialize an IdentityOperator instance.

Parametersspace : LinearSpace

The space of elements which the operator is acting on

InnerProductOperator

class odl.operator.default_ops.**InnerProductOperator**(*vector*)

Bases: *odl.operator.operator.Operator*

Operator taking the inner product with a fixed vector.

`InnerProductOperator(vec)(x) <==> x.inner(vec)`

This is only applicable in inner product spaces.

Attributes

T	The vector of this operator.
adjoint	The adjoint operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

InnerProductOperator.T

InnerProductOperator.**T**

The vector of this operator.

Returnsvector : *LinearSpaceVector*

Vector used in this operator

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> x = r3.element([1, 2, 3])
>>> x.T
InnerProductOperator(Rn(3).element([1.0, 2.0, 3.0]))
>>> x.T.T
Rn(3).element([1.0, 2.0, 3.0])
```

InnerProductOperator.adjoint

`InnerProductOperator.`**`adjoint`**
The adjoint operator.

Returnsadjoint : *MultiplyOperator*

The operator of multiplication with `vector`.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> x = r3.element([1, 2, 3])
>>> op = InnerProductOperator(x)
>>> op.adjoint(2.0)
Rn(3).element([2.0, 4.0, 6.0])
```

InnerProductOperator.domain

`InnerProductOperator.`**`domain`**
Set of objects on which this operator can be evaluated.

InnerProductOperator.inverse

`InnerProductOperator.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

InnerProductOperator.is_functional

`InnerProductOperator.`**`is_functional`**
`True` if the this operator's range is a *Field*.

InnerProductOperator.is_linear

`InnerProductOperator.`**`is_linear`**
`True` if this operator is linear.

InnerProductOperator.range

`InnerProductOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x)	Multiply the input and write to output.
derivative(point)	Return the operator derivative at `point`.

InnerProductOperator.__call__

`InnerProductOperator.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

InnerProductOperator._call

`InnerProductOperator.`**`_call`**`(`*x*`)`

Multiply the input and write to output.

Parametersx : `vector.space` *element*

An element in the space of the vector

Returnsout : `field` *element*

Result of the inner product calculation

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> x = r3.element([1, 2, 3])
>>> op = InnerProductOperator(x)
>>> op(r3.element([1, 2, 3]))
14.0
```

InnerProductOperator.derivative

`InnerProductOperator.`**`derivative`**`(`*point*`)`

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__``(`*vector*`)`

Initialize a InnerProductOperator instance.

Parametersvector : *LinearSpaceVector*

The vector to take the inner product with

LinCombOperator

class `odl.operator.default_ops.`**`LinCombOperator`**`(`*space*, *a*, *b*`)`

Bases: *odl.operator.operator.Operator*

Operator mapping two space elements to a linear combination.

This opertor calculates:

```
out = a*x[0] + b*x[1]
```

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

LinCombOperator.adjoint

`LinCombOperator.`**`adjoint`**
The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

LinCombOperator.domain

`LinCombOperator.`**`domain`**
Set of objects on which this operator can be evaluated.

LinCombOperator.inverse

`LinCombOperator.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

LinCombOperator.is_functional

`LinCombOperator.`**`is_functional`**
`True` if the this operator's range is a *Field*.

LinCombOperator.is_linear

`LinCombOperator.`**`is_linear`**
`True` if this operator is linear.

LinCombOperator.range

`LinCombOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Linearly combine the input and write to output.
derivative(point)	Return the operator derivative at `point`.

LinCombOperator.__call__

`LinCombOperator.`**`__call__`**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

LinCombOperator._call

LinCombOperator.**_call**(*x*, *out=None*)
Linearly combine the input and write to output.

Parametersx : domain *element*

An element of the operator domain (2-tuple of space elements) whose linear combination is calculated

out : `range *element*

Vector to which the result is written

Returnsout : range *element*

Result of the linear combination. If out was provided, the returned object is a reference to it.

Examples

```
>>> from odl import Rn, ProductSpace
>>> r3 = Rn(3)
>>> r3xr3 = ProductSpace(r3, r3)
>>> xy = r3xr3.element([[1, 2, 3], [1, 2, 3]])
>>> z = r3.element()
>>> op = LinCombOperator(r3, 1.0, 1.0)
>>> op(xy, out=z)  # Returns z
Rn(3).element([2.0, 4.0, 6.0])
>>> z
Rn(3).element([2.0, 4.0, 6.0])
```

LinCombOperator.derivative

LinCombOperator.**derivative**(*point*)
Return the operator derivative at point.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*space*, *a*, *b*)
Initialize a LinCombOperator instance.

Parametersspace : *LinearSpace*

The space of elements which the operator is acting on

a, b : scalar

Scalars to multiply x[0] and x[1] with, respectively

MultiplyOperator

class odl.operator.default_ops.**MultiplyOperator**(*y*, *domain=None*)
Bases: *odl.operator.operator.Operator*

Operator multiplying two elements.

`MultiplyOperator(y)(x) <==> x * y`

Here, `x` is a *LinearSpaceVector* or *Field* element and `y` is a *LinearSpaceVector*. Hence, this operator can be defined either on a *LinearSpace* or on a *Field*. In the first case it is the pointwise multiplication, in the second the scalar multiplication.

Attributes

adjoint	The adjoint operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

MultiplyOperator.adjoint

`MultiplyOperator.`**`adjoint`**

The adjoint operator.

Returns **adjoint** : {*InnerProductOperator*, *MultiplyOperator*}

If the domain of this operator is the scalar field of a *LinearSpace* the adjoint is the inner product with `y`, else it is the multiplication with `y`

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> x = r3.element([1, 2, 3])
```

Multiply by vector

```
>>> op = MultiplyOperator(x)
>>> out = r3.element()
>>> op.adjoint(x)
Rn(3).element([1.0, 4.0, 9.0])
```

Multiply by scalar

```
>>> op2 = MultiplyOperator(x, domain=r3.field)
>>> op2.adjoint(x)
14.0
```

MultiplyOperator.domain

`MultiplyOperator.`**`domain`**

Set of objects on which this operator can be evaluated.

MultiplyOperator.inverse

MultiplyOperator.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

MultiplyOperator.is_functional

MultiplyOperator.**is_functional**
`True` if the this operator's range is a *Field*.

MultiplyOperator.is_linear

MultiplyOperator.**is_linear**
`True` if this operator is linear.

MultiplyOperator.range

MultiplyOperator.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Multiply the input and write to output.
derivative(point)	Return the operator derivative at `point`.

MultiplyOperator.__call__

MultiplyOperator.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_call Implementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

MultiplyOperator._call

`MultiplyOperator.`**`_call`**(*x*, *out=None*)

Multiply the input and write to output.

Parametersx : `domain` *element*

An element in the operator domain (2-tuple of space elements) whose elementwise product is calculated

out : `range` *element*, optional

Vector to which the result is written

Returnsout : `range` *element*

Result of the multiplication. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> x = r3.element([1, 2, 3])
```

Multiply by vector

```
>>> op = MultiplyOperator(x)
>>> out = r3.element()
>>> op(x, out)
Rn(3).element([1.0, 4.0, 9.0])
```

Multiply by scalar

```
>>> op2 = MultiplyOperator(x, domain=r3.field)
>>> out = r3.element()
>>> op2(3, out)
Rn(3).element([3.0, 6.0, 9.0])
```

MultiplyOperator.derivative

MultiplyOperator.**derivative**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*y*, *domain=None*)

Initialize a MultiplyOperator instance.

Parametersy : *LinearSpaceVector*

The value to multiply by

domain : *LinearSpace* or *Field*, optional

The set to take values in. Default: `x.space`

ResidualOperator

class odl.operator.default_ops.**ResidualOperator**(*op*, *vec*)

Bases: *odl.operator.operator.Operator*

Operator that calculates the residual `op(x) - vec`.

`ResidualOperator(op, vector)(x) <==> op(x) - vec`

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ResidualOperator.adjoint

ResidualOperator.**adjoint**

The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

ResidualOperator.domain

`ResidualOperator.`**`domain`**
Set of objects on which this operator can be evaluated.

ResidualOperator.inverse

`ResidualOperator.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

ResidualOperator.is_functional

`ResidualOperator.`**`is_functional`**
`True` if the this operator's range is a *Field*.

ResidualOperator.is_linear

`ResidualOperator.`**`is_linear`**
`True` if this operator is linear.

ResidualOperator.range

`ResidualOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Evaluate the residual at `x`.
derivative(point)	The derivative the residual operator.

ResidualOperator.__call__

`ResidualOperator.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the

`self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ResidualOperator._call

`ResidualOperator.`**`_call`**(*x*, *out=None*)

Evaluate the residual at `x`.

Parametersx : `domain` *element*

Any element of the domain

out : `range` *element*

Vector that gets assigned to the constant vector

Returnsout : `range` *element*

Result of the evaluation. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> vec = r3.element([1, 2, 3])
>>> op = IdentityOperator(r3)
>>> res = ResidualOperator(op, vec)
>>> x = r3.element([4, 5, 6])
>>> res(x, out=r3.element())
Rn(3).element([3.0, 3.0, 3.0])
```

ResidualOperator.derivative

ResidualOperator.**derivative**(*point*)

The derivative the residual operator.

It is equal to the derivative of the "inner" operator:

```
ResidualOperator(op, vec).derivative(x) <==> op.derivative(x)
```

Parametersx : domain *element*

Any element in the domain where the derivative should be taken

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> op = IdentityOperator(r3)
>>> res = ResidualOperator(op, r3.element([1, 2, 3]))
>>> x = r3.element([4, 5, 6])
>>> res.derivative(x)(x)
Rn(3).element([4.0, 5.0, 6.0])
```

__init__(*op*, *vec*)

Initialize a new instance.

Parametersop : *Operator*

Operator to be used in the residual expression. Its *Operator.range* must be a *LinearSpace*.

vec : *Operator.range element-like*

Vector to be subtracted from the operator result

ScalingOperator

class odl.operator.default_ops.**ScalingOperator**(*space*, *scalar*)

Bases: *odl.operator.operator.Operator*

Operator of multiplication with a scalar.

Attributes

adjoint	Adjoint, given as scaling with the conjugate of the scalar.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the inverse operator.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ScalingOperator.adjoint

`ScalingOperator.`**`adjoint`**
Adjoint, given as scaling with the conjugate of the scalar.

ScalingOperator.domain

`ScalingOperator.`**`domain`**
Set of objects on which this operator can be evaluated.

ScalingOperator.inverse

`ScalingOperator.`**`inverse`**
Return the inverse operator.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> vec = r3.element([1, 2, 3])
>>> op = ScalingOperator(r3, 2.0)
>>> inv = op.inverse
>>> inv(op(vec)) == vec
True
>>> op(inv(vec)) == vec
True
```

ScalingOperator.is_functional

`ScalingOperator.`**`is_functional`**
`True` if the this operator's range is a *Field*.

ScalingOperator.is_linear

`ScalingOperator.`**`is_linear`**
`True` if this operator is linear.

ScalingOperator.range

`ScalingOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Scale input and write to output.
derivative(point)	Return the operator derivative at `point`.

ScalingOperator.__call__

`ScalingOperator.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ScalingOperator._call

`ScalingOperator.`**`_call`**(*x*, *out=None*)

Scale input and write to output.

Parametersx : `domain` *element*

input vector to be scaled

out : `range` *element*, optional

Output vector to which the result is written

Returnsout : `range` *element*

Result of the scaling. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> vec = r3.element([1, 2, 3])
>>> out = r3.element()
>>> op = ScalingOperator(r3, 2.0)
>>> op(vec, out)  # In place, Returns out
Rn(3).element([2.0, 4.0, 6.0])
>>> out
Rn(3).element([2.0, 4.0, 6.0])
>>> op(vec)  # Out of place
Rn(3).element([2.0, 4.0, 6.0])
```

ScalingOperator.derivative

`ScalingOperator.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*space*, *scalar*)

Initialize a ScalingOperator instance.

Parametersspace : *LinearSpace*

The space of elements which the operator is acting on

scalar : *LinearSpace.field element*

An element of the field of the space which vectors are scaled with

ZeroOperator

class odl.operator.default_ops.**ZeroOperator**(*space*)
Bases: *odl.operator.default_ops.ScalingOperator*

Operator mapping each element to the zero element.

Attributes

adjoint	Adjoint, given as scaling with the conjugate of the scalar.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the inverse operator.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ZeroOperator.adjoint

ZeroOperator.**adjoint**
Adjoint, given as scaling with the conjugate of the scalar.

ZeroOperator.domain

ZeroOperator.**domain**
Set of objects on which this operator can be evaluated.

ZeroOperator.inverse

ZeroOperator.**inverse**
Return the inverse operator.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> vec = r3.element([1, 2, 3])
>>> op = ScalingOperator(r3, 2.0)
>>> inv = op.inverse
>>> inv(op(vec)) == vec
True
>>> op(inv(vec)) == vec
True
```

ZeroOperator.is_functional

ZeroOperator.**is_functional**
`True` if the this operator's range is a *Field*.

ZeroOperator.is_linear

`ZeroOperator.`**`is_linear`**
`True` if this operator is linear.

ZeroOperator.range

`ZeroOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Scale input and write to output.
derivative(point)	Return the operator derivative at `point`.

ZeroOperator.__call__

`ZeroOperator.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ZeroOperator._call

`ZeroOperator.`**`_call`**(*x*, *out=None*)

Scale input and write to output.

Parametersx : `domain` *element*

input vector to be scaled

out : `range` *element*, optional

Output vector to which the result is written

Returnsout : `range` *element*

Result of the scaling. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> from odl import Rn
>>> r3 = Rn(3)
>>> vec = r3.element([1, 2, 3])
>>> out = r3.element()
>>> op = ScalingOperator(r3, 2.0)
>>> op(vec, out)  # In place, Returns out
Rn(3).element([2.0, 4.0, 6.0])
>>> out
Rn(3).element([2.0, 4.0, 6.0])
>>> op(vec)  # Out of place
Rn(3).element([2.0, 4.0, 6.0])
```

ZeroOperator.derivative

`ZeroOperator.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*space*)

Initialize a ZeroOperator instance.

Parametersspace : *LinearSpace*

The space of elements which the operator is acting on

8.3.2 operator

Abstract mathematical operators.

Classes

FunctionalLeftVectorMult(op, vector)	Expression type for the functional left vector multiplication.
OpDomainError	Exception for domain errors.
OpNotImplementedError	Exception for not implemented errors in *LinearSpace*'s.
OpRangeError	Exception for domain errors.
OpTypeError	Exception for operator type errors.
Operator(domain, range[, linear])	Abstract mathematical operator.
OperatorComp(left, right[, tmp])	Expression type for the composition of operators.
OperatorLeftScalarMult(op, scalar)	Expression type for the operator left scalar multiplication.
OperatorLeftVectorMult(op, vector)	Expression type for the operator left vector multiplication.
OperatorPointwiseProduct(op1, op2)	Expression type for the pointwise operator mulitplication.
OperatorRightScalarMult(op, scalar[, tmp])	Expression type for the operator right scalar multiplication.
OperatorRightVectorMult(op, vector)	Expression type for the operator right vector multiplication.
OperatorSum(op1, op2[, tmp_ran, tmp_dom])	Expression type for the sum of operators.

FunctionalLeftVectorMult

class `odl.operator.operator.`**`FunctionalLeftVectorMult`**(*op*, *vector*)

Bases: *odl.operator.operator.Operator*

Expression type for the functional left vector multiplication.

A functional is a *Operator* whose *Operator.range* is a *Field*. It is multiplied from left with a vector, resulting in an operator mapping from the *Operator.domain* to the vector's *LinearSpaceVector.space*.

```
FunctionalLeftVectorMult(op, vector)(x) <==> vector * op(x)
```

Attributes

adjoint	The operator adjoint.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

FunctionalLeftVectorMult.adjoint

`FunctionalLeftVectorMult.`**`adjoint`**

The operator adjoint.

The adjoint of the operator scalar multiplication is the scalar multiplication of the operator adjoint:

```
FunctionalLeftVectorMult(op, vector).adjoint == OperatorComp(op.adjoint,
vector.T)
```

```
(x * A)^T = A^T * x^T
```

RaisesOpNotImplementedError

If the underlying operator is non-linear.

FunctionalLeftVectorMult.domain

`FunctionalLeftVectorMult.`**`domain`**
Set of objects on which this operator can be evaluated.

FunctionalLeftVectorMult.inverse

`FunctionalLeftVectorMult.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

FunctionalLeftVectorMult.is_functional

`FunctionalLeftVectorMult.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

FunctionalLeftVectorMult.is_linear

`FunctionalLeftVectorMult.`**`is_linear`**
`True` if this operator is linear.

FunctionalLeftVectorMult.range

`FunctionalLeftVectorMult.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

`__call__`(x[, out])	Return `self(x[, out, **kwargs])`.
`__eq__`	Return self==value.
`_call`(x[, out])	Implement `self(x[, out])`.
`derivative`(x)	Return the derivative at `x`.

FunctionalLeftVectorMult.__call__

`FunctionalLeftVectorMult.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *`Operator.domain element-like`*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

FunctionalLeftVectorMult._call

`FunctionalLeftVectorMult.`**`_call`**(*x*, *out=None*)

Implement `self(x[, out])`.

FunctionalLeftVectorMult.derivative

`FunctionalLeftVectorMult.`**`derivative`**(*x*)

Return the derivative at `x`.

Left scalar multiplication and derivative are commutative:

```
FunctionalLeftVectorMult(op, vector).derivative(x) <==>
FunctionalLeftVectorMult(op.derivative(x), vector)
```

See also:

*FunctionalLeftVectorMult*the result

__init__(*op*, *vector*)
Initialize a new instance.

Parametersop : *Operator*

The range of `op` must be a *Field*.

vector : *LinearSpaceVector*

The vector to multiply by. Its space's *LinearSpace.field* must be the same as `op.range`

OpDomainError

exception odl.operator.operator.**OpDomainError**
Exception for domain errors.

Domain errors are raised by *Operator* subclasses when trying to call them with input not in the domain (*Operator.domain*).

OpNotImplementedError

exception odl.operator.operator.**OpNotImplementedError**
Exception for not implemented errors in *LinearSpace*'s.

These are raised when a method in *LinearSpace* that has not been defined in a specific space is called.

OpRangeError

exception odl.operator.operator.**OpRangeError**
Exception for domain errors.

Domain errors are raised by *Operator* subclasses when the returned value does not lie in the range (*Operator.range*).

OpTypeError

exception odl.operator.operator.**OpTypeError**
Exception for operator type errors.

Domain errors are raised by *Operator* subclasses when trying to call them with input not in the domain (*Operator.domain*) or with the wrong range (*Operator.range*).

Operator

class odl.operator.operator.**Operator**(*domain*, *range*, *linear=False*)
Bases: `object`

Abstract mathematical operator.

An operator is a mapping

$$\mathcal{A} : \mathcal{X} \to \mathcal{Y}$$

between sets $\mathcal{X}$ (domain) and $\mathcal{Y}$ (range). The evaluation of $\mathcal{A}$ at an element $x \in \mathcal{X}$ is denoted by $\mathcal{A}(x)$ and produces an element in $\mathcal{Y}$:

$$y = \mathcal{A}(x) \in \mathcal{Y}.$$

Programmatically, these properties are reflected in the *Operator* class described in the following.

Abstract attributes and methods

Operator is an **abstract** class, i.e. it can only be subclassed, not used directly.

Any subclass of *Operator* must have the following attributes:

domain[*Set*] The set of elements this operator can be applied to

range[*Set*] The set this operator maps to

It is **highly** recommended to call `super().__init__(dom, ran)` (Note: add `from builtins import super` in Python 2) in the `__init__()` method of any subclass, where `dom` and `ran` are the arguments specifying domain and range of the new operator. In that case, the attributes *Operator.domain* and *Operator.range* are automatically provided by the parent class *Operator*.

In addition, any subclass **must** implement the private method *Operator._call()*. It signature determines how it is interpreted:

In-place-only evaluation: `_call(self, x, out[, **kwargs])`

In-place evaluation means that the operator is applied, and the result is written to an existing element `out` provided, i.e.

```
_call(self, x, out) <==> out <-- operator(x)
```

Parameters:

x[*Operator.domain element*] An object in the operator domain to which the operator is applied

out[*Operator.range element*] An object in the operator range to which the result of the operator evaluation is written.

Returns:

`None` (return value is ignored)

Out-of-place-only evaluation: `_call(self, x[, **kwargs])`

Out-of-place evaluation means that the operator is applied, and the result is written to a **new** element which is returned. In this case, a subclass has to implement the method

```
_call(self, x) <==> operator(x)
```

Parameters:

x[*Operator.domain element*] An object in the operator domain to which the operator is applied

Returns:

out[*Operator.range element-like*] An object in the operator range holding the result of the operator evaluation

Dual-use evaluation: `_call(self, x, out=None[, **kwargs])`

Evaluate in place if `out` is given, otherwise out of place.

Parameters:

x[*Operator.domain element*] An object in the operator domain to which the operator is applied

out[*Operator.range element*, optional] An object in the operator range to which the result of the operator evaluation is written

Returns:

`None` (return value is ignored)

Notes

- If *Operator._call* is implemented in-place-only or out-of-place-only and the *Operator.range* is a *LinearSpace*, a default implementation of the respective other is provided.
- *Operator._call* is allowed to have keyword-only arguments (Python 3 only).
- The term "element-like" means that an object must be convertible to an element by the `domain.element()` method.

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

Operator.adjoint

`Operator.`**`adjoint`**
The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

Operator.domain

`Operator.`**`domain`**
Set of objects on which this operator can be evaluated.

Operator.inverse

`Operator.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

Operator.is_functional

Operator.**is_functional**
`True` if the this operator's range is a *Field*.

Operator.is_linear

Operator.**is_linear**
`True` if this operator is linear.

Operator.range

Operator.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Implementation of the operator evaluation.
derivative(point)	Return the operator derivative at `point`.

Operator.__call__

Operator.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

Operator._call

`Operator.__call__`(*x*, *out=None*, ***kwargs*)

Implementation of the operator evaluation.

This method is the private backend for the evaluation of an operator. It needs to match certain signature conventions, and its implementation type is inferred from its signature.

The following signatures are allowed:

Python 2 and 3:

- `_call(self, x)` –> out-of-place evaluation
- `_call(self, vec, out)` –> in-place evaluation
- `_call(self, x, out=None)` –> both

Python 3 only:

- `_call(self, x, *, out=None)` (`out` as keyword-only argument) –> both

For disambiguation, the instance name (the first argument) **must** be 'self'.

The name of the `out` argument **must** be 'out', the second argument may have any name.

Additional variable `**kwargs` and keyword-only arguments (Python 3 only) are also allowed.

Parametersx : *Operator.domain element-like*

Element to which the operator is applied

out : *Operator.range element*, optional

Element to which the result is written

Returnsout : *Operator.range element-like*

Result of the evaluation. If `out` was provided, the returned object is a reference to it.

Notes

Some general advice on how to implement operator evaluation:

- If you just write a quick implementation or are not too worried about efficiency, it may be easiest to write the evaluation *out of place*.
- We recommend advanced and performance-aware users to implement the *in-place* pattern if the wrapped code supports it. In-place evaluation is usually significantly faster since it avoids the allocation of new memory and a copy compared to out-of-place evaluation.
- If there is a significant performance gain from implementing an out-of-place method separately, use the pattern for both (`out` optional) and decide according to the given `out` parameter which one to use.
- If your evaluation code does not support in-place evaluation, use the out-of-place pattern.

Note that the public call pattern `op()` using `op.__call__` provides a default implementation of the underlying in-place or out-of-place call even if you choose the respective other pattern.

See the documentation for more info on in-place vs. out-of-place evaluation.

Operator.derivative

`Operator.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*domain*, *range*, *linear=False*)

Initialize a new instance.

Parametersdomain : *Set*

The domain of this operator, i.e., the set of elements to which this operator can be applied

range : *Set*

The range of this operator, i.e., the set this operator maps to

linear : `bool`

If `True`, the operator is considered as linear. In this case, `domain` and `range` have to be instances of *LinearSpace*, or *Field*.

OperatorComp

class `odl.operator.operator.`**`OperatorComp`**(*left*, *right*, *tmp=None*)

Bases: *odl.operator.operator.Operator*

Expression type for the composition of operators.

```
OperatorComp(left, right) <==> (x --> left(right(x)))
```

The composition is only well-defined if `left.domain == right.range`.

Attributes

adjoint	The operator adjoint.
domain	Set of objects on which this operator can be evaluated.
inverse	The operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

OperatorComp.adjoint

`OperatorComp.`**`adjoint`**
The operator adjoint.

The adjoint of the operator composition is the composition of the operator adjoints in reverse order:

```
OperatorComp(left, right).adjoint == OperatorComp(right.adjoint,
left.adjoint)
```

RaisesOpNotImplementedError

If any of the underlying operators are non-linear.

OperatorComp.domain

`OperatorComp.`**`domain`**
Set of objects on which this operator can be evaluated.

OperatorComp.inverse

`OperatorComp.`**`inverse`**
The operator inverse.

The inverse of the operator composition is the composition of the inverses in reverse order:

```
OperatorComp(left, right).inverse ==        OperatorComp(right.inverse,
left.inverse)
```

OperatorComp.is_functional

`OperatorComp.`**`is_functional`**
`True` if the this operator's range is a *Field*.

OperatorComp.is_linear

`OperatorComp.`**`is_linear`**
`True` if this operator is linear.

OperatorComp.range

`OperatorComp.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Implement `self(x[, out])`.
derivative(x)	Return the operator derivative.

OperatorComp.__call__

`OperatorComp.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorComp._call

`OperatorComp.`**`_call`**(*x*, *out=None*)
Implement `self(x[, out])`.

OperatorComp.derivative

`OperatorComp.`**`derivative`**(*x*)
Return the operator derivative.

The derivative of the operator composition follows the chain rule:

`OperatorComp(left, right).derivative(x) == OperatorComp(left.derivative(right(x)), right.derivative(x))`

Parametersx : *Operator.domain element-like*

Evaluation point of the derivative. Needs to be usable as input for the `right` operator.

`__init__`(*left*, *right*, *tmp=None*)
Initialize a new *OperatorComp* instance.

Parametersleft : *Operator*

The left ("outer") operator

right : *Operator*

The right ("inner") operator. Its range must coincide with the domain of `left`.

tmp : *element* of the range of `right`, optional

Used to avoid the creation of a temporary when applying the operator.

OperatorLeftScalarMult

class `odl.operator.operator.`**`OperatorLeftScalarMult`**(*op*, *scalar*)
Bases: *odl.operator.operator.Operator*

Expression type for the operator left scalar multiplication.

`OperatorLeftScalarMult(op, scalar) <==> (x --> scalar * op(x))`

The scalar multiplication is well-defined only if `op.range` is a *LinearSpace*.

Attributes

adjoint	The operator adjoint.
domain	Set of objects on which this operator can be evaluated.

Continued on next page

Table 8.77 – continued from previous page

inverse	The inverse operator.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

OperatorLeftScalarMult.adjoint

`OperatorLeftScalarMult.`**`adjoint`**

The operator adjoint.

The adjoint of the operator scalar multiplication is the scalar multiplication of the operator adjoint:

```
OperatorLeftScalarMult(op, scalar).adjoint == OperatorLeftScalarMult(op.adjoint,
scalar)
```

RaisesOpNotImplementedError

If the underlying operator is non-linear.

OperatorLeftScalarMult.domain

`OperatorLeftScalarMult.`**`domain`**

Set of objects on which this operator can be evaluated.

OperatorLeftScalarMult.inverse

`OperatorLeftScalarMult.`**`inverse`**

The inverse operator.

The inverse of `scalar * op` is given by `op.inverse * 1/scalar` if `scalar != 0`. If `scalar == 0`, the inverse is not defined.

```
OperatorLeftScalarMult(op, scalar).inverse <==> OperatorRightScalarMult(op.inverse,
1.0/scalar)
```

OperatorLeftScalarMult.is_functional

`OperatorLeftScalarMult.`**`is_functional`**

`True` if the this operator's range is a *Field*.

OperatorLeftScalarMult.is_linear

`OperatorLeftScalarMult.`**`is_linear`**

`True` if this operator is linear.

OperatorLeftScalarMult.range

`OperatorLeftScalarMult.`**`range`**

Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Implement `self(x[, out])`.
derivative(x)	Return the derivative at `x`.

OperatorLeftScalarMult.__call__

OperatorLeftScalarMult.**__call__**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorLeftScalarMult._call

OperatorLeftScalarMult.**_call**(*x*, *out=None*)
Implement `self(x[, out])`.

OperatorLeftScalarMult.derivative

OperatorLeftScalarMult.**derivative**(*x*)
Return the derivative at `x`.

Left scalar multiplication and derivative are commutative:

```
OperatorLeftScalarMult(op, scalar).derivative(x) <==>
OperatorLeftScalarMult(op.derivative(x), scalar)
```

Parametersx : *Operator.domain element-like*

Evaluation point of the derivative

See also:

OperatorLeftScalarMultthe result

__init__(*op*, *scalar*)
Initialize a new *OperatorLeftScalarMult* instance.

Parametersop : *Operator*

The range of `op` must be a *LinearSpace* or *Field*.

scalar : `op.range.field` *element*

A real or complex number, depending on the field of the range.

OperatorLeftVectorMult

class odl.operator.operator.**OperatorLeftVectorMult**(*op*, *vector*)
Bases: *odl.operator.operator.Operator*

Expression type for the operator left vector multiplication.

```
OperatorLeftVectorMult(op, vector)(x) <==> vector * op(x)
```

The scalar multiplication is well-defined only if `op.range` is a `vector.space.field`.

Attributes

adjoint	The operator adjoint.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

OperatorLeftVectorMult.adjoint

OperatorLeftVectorMult.**adjoint**
The operator adjoint.

The adjoint of the operator vector multiplication is the vector multiplication of the operator adjoint:

```
OperatorLeftVectorMult(op, vector).adjoint == OperatorRightVectorMult(op.adjoint,
vector)
```

```
(x * A)^T = A^T * x
```

RaisesOpNotImplementedError

If the underlying operator is non-linear.

OperatorLeftVectorMult.domain

OperatorLeftVectorMult.**domain**
Set of objects on which this operator can be evaluated.

OperatorLeftVectorMult.inverse

OperatorLeftVectorMult.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

OperatorLeftVectorMult.is_functional

OperatorLeftVectorMult.**is_functional**
`True` if the this operator's range is a *Field*.

OperatorLeftVectorMult.is_linear

OperatorLeftVectorMult.**is_linear**
`True` if this operator is linear.

OperatorLeftVectorMult.range

OperatorLeftVectorMult.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Implement `self(x[, out])`.

Continued on next page

Table 8.80 – continued from previous page

derivative(x)	Return the derivative at x.

OperatorLeftVectorMult.__call__

OperatorLeftVectorMult.**__call__**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorLeftVectorMult._call

OperatorLeftVectorMult.**_call**(*x*, *out=None*)

Implement `self(x[, out])`.

OperatorLeftVectorMult.derivative

`OperatorLeftVectorMult.`**`derivative`**`(x)`

Return the derivative at `x`.

Left scalar multiplication and derivative are commutative:

```
OperatorLeftVectorMult(op, vector).derivative(x) <==>
OperatorLeftVectorMult(op.derivative(x), vector)
```

See also:

*OperatorLeftVectorMult*the result

`__init__``(op, vector)`

Initialize a new *OperatorLeftVectorMult* instance.

Parametersop : *Operator*

The range of `op` must be a *LinearSpace*.

vector : *LinearSpaceVector* in `op.range`

The vector to multiply by

OperatorPointwiseProduct

class `odl.operator.operator.`**`OperatorPointwiseProduct`**`(op1, op2)`

Bases: *odl.operator.operator.Operator*

Expression type for the pointwise operator mulitplication.

```
OperatorPointwiseProduct(op1, op2) <==> (x --> op1(x) * op2(x))
```

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

OperatorPointwiseProduct.adjoint

`OperatorPointwiseProduct.`**`adjoint`**

The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

OperatorPointwiseProduct.domain

OperatorPointwiseProduct.**domain**
Set of objects on which this operator can be evaluated.

OperatorPointwiseProduct.inverse

OperatorPointwiseProduct.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

OperatorPointwiseProduct.is_functional

OperatorPointwiseProduct.**is_functional**
`True` if the this operator's range is a *Field*.

OperatorPointwiseProduct.is_linear

OperatorPointwiseProduct.**is_linear**
`True` if this operator is linear.

OperatorPointwiseProduct.range

OperatorPointwiseProduct.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Implement `self(x[, out])`.
derivative(point)	Return the operator derivative at `point`.

OperatorPointwiseProduct.__call__

OperatorPointwiseProduct.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorPointwiseProduct._call

`OperatorPointwiseProduct.`**`_call`**(*x*, *out=None*)
Implement `self(x[, out])`.

OperatorPointwiseProduct.derivative

`OperatorPointwiseProduct.`**`derivative`**(*point*)
Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*op1*, *op2*)
Initialize a new instance.

Parametersop1 : *Operator*

The first factor

op2 : *Operator*

The second factor. Must have the same domain and range as `op1`.

OperatorRightScalarMult

class `odl.operator.operator.`**`OperatorRightScalarMult`**(*op*, *scalar*, *tmp=None*)
Bases: *odl.operator.operator.Operator*

Expression type for the operator right scalar multiplication.

`OperatorRightScalarMult(op, scalar) <==> (x --> op(scalar * x))`

The scalar multiplication is well-defined only if `op.domain` is a *LinearSpace*.

Attributes

adjoint	The operator adjoint.
domain	Set of objects on which this operator can be evaluated.
inverse	The inverse operator.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

OperatorRightScalarMult.adjoint

`OperatorRightScalarMult.`**`adjoint`**
The operator adjoint.

The adjoint of the operator scalar multiplication is the scalar multiplication of the operator adjoint:

`OperatorLeftScalarMult(op, scalar).adjoint == OperatorLeftScalarMult(op.adjoint, scalar)`

RaisesOpNotImplementedError

If the underlying operator is non-linear.

OperatorRightScalarMult.domain

`OperatorRightScalarMult.`**`domain`**
Set of objects on which this operator can be evaluated.

OperatorRightScalarMult.inverse

`OperatorRightScalarMult.`**`inverse`**
The inverse operator.

The inverse of `op * scalar` is given by `1/scalar * op.inverse` if `scalar != 0`. If `scalar == 0`, the inverse is not defined.

`OperatorRightScalarMult(op, scalar).inverse <==> OperatorLeftScalarMult(op.inverse, 1.0/scalar)`

OperatorRightScalarMult.is_functional

`OperatorRightScalarMult.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

OperatorRightScalarMult.is_linear

`OperatorRightScalarMult.`**`is_linear`**
`True` if this operator is linear.

OperatorRightScalarMult.range

`OperatorRightScalarMult.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

`__call__`(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
`_call`(x[, out])	Implement `self(x[, out])`.
`derivative`(x)	Return the derivative at `x`.

OperatorRightScalarMult.__call__

`OperatorRightScalarMult.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *`Operator.domain element-like`*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *`Operator.range element`*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *`_call`*

Returnsout : *`Operator.range element`*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

`_call`Implementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorRightScalarMult._call

`OperatorRightScalarMult.`**`_call`**(*x*, *out=None*)
Implement `self(x[, out])`.

OperatorRightScalarMult.derivative

`OperatorRightScalarMult.`**`derivative`**(*x*)
Return the derivative at `x`.

The derivative of the right scalar operator multiplication follows the chain rule:

```
OperatorRightScalarMult(op, scalar).derivative(x) <==>
OperatorLeftScalarMult(op.derivative(scalar * x), scalar)
```

Parametersx : *Operator.domain element-like*

Evaluation point of the derivative

`__init__`(*op*, *scalar*, *tmp=None*)
Initialize a new *OperatorLeftScalarMult* instance.

Parametersop : *Operator*

The domain of `op` must be a *LinearSpace* or *Field*.

scalar : `op.range.field` *element*

A real or complex number, depending on the field of the operator domain.

tmp : domain *element*, optional

Used to avoid the creation of a temporary when applying the operator.

OperatorRightVectorMult

class `odl.operator.operator.`**`OperatorRightVectorMult`**(*op*, *vector*)
Bases: *odl.operator.operator.Operator*

Expression type for the operator right vector multiplication.

`OperatorRightVectorMult(op, vector)(x) <==> op(vector * x)`

The scalar multiplication is well-defined only if `vector in op.domain == True`.

Attributes

adjoint	The operator adjoint.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

OperatorRightVectorMult.adjoint

`OperatorRightVectorMult.`**`adjoint`**

The operator adjoint.

The adjoint of the operator vector multiplication is the vector multiplication of the operator adjoint:

`OperatorRightVectorMult(op, vector).adjoint == OperatorLeftVectorMult(op.adjoint, vector)`

`(A x)^T = x * A^T`

RaisesOpNotImplementedError

If the underlying operator is non-linear.

OperatorRightVectorMult.domain

`OperatorRightVectorMult.`**`domain`**

Set of objects on which this operator can be evaluated.

OperatorRightVectorMult.inverse

`OperatorRightVectorMult.`**`inverse`**

Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

OperatorRightVectorMult.is_functional

`OperatorRightVectorMult.`**`is_functional`**

`True` if the this operator's range is a *Field*.

OperatorRightVectorMult.is_linear

`OperatorRightVectorMult.`**`is_linear`**
`True` if this operator is linear.

OperatorRightVectorMult.range

`OperatorRightVectorMult.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Implement `self(x[, out])`.
derivative(x)	Return the derivative at `x`.

OperatorRightVectorMult.__call__

`OperatorRightVectorMult.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorRightVectorMult._call

OperatorRightVectorMult.**_call**(*x*, *out=None*)
Implement `self(x[, out])`.

OperatorRightVectorMult.derivative

OperatorRightVectorMult.**derivative**(*x*)
Return the derivative at `x`.

Left vector multiplication and derivative are commutative:

```
OperatorRightVectorMult(op, vector).derivative(x) <==>
OperatorRightVectorMult(op.derivative(x), vector)
```

See also:

*OperatorRightVectorMult*the result

__init__(*op*, *vector*)
Initialize a new *OperatorRightVectorMult* instance.

Parametersop : *Operator*

The domain of `op` must be a `vector.space`.

vector : *LinearSpaceVector* in `op.domain`

The vector to multiply by

OperatorSum

class odl.operator.operator.**OperatorSum**(*op1*, *op2*, *tmp_ran=None*, *tmp_dom=None*)
Bases: *odl.operator.operator.Operator*

Expression type for the sum of operators.

```
OperatorSum(op1, op2) <==> (x --> op1(x) + op2(x))
```

The sum is only well-defined for *Operator* instances where *Operator.range* is a *LinearSpace*.

Attributes

adjoint	The operator adjoint.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

OperatorSum.adjoint

`OperatorSum.`**`adjoint`**
The operator adjoint.

The adjoint of the operator sum is the sum of the operator adjoints:

```
OperatorSum(op1, op2).adjoint == OperatorSum(op1.adjoint, op2.adjoint)
```

RaisesOpNotImplementedError

If either of the underlying operators are non-linear.

OperatorSum.domain

`OperatorSum.`**`domain`**
Set of objects on which this operator can be evaluated.

OperatorSum.inverse

`OperatorSum.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

OperatorSum.is_functional

`OperatorSum.`**`is_functional`**
`True` if the this operator's range is a *Field*.

OperatorSum.is_linear

`OperatorSum.`**`is_linear`**
`True` if this operator is linear.

OperatorSum.range

`OperatorSum.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Implement `self(x[, out])`.
derivative(x)	Return the operator derivative at `x`.

OperatorSum.__call__

OperatorSum.**__call__**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorSum._call

OperatorSum.**_call**(*x*, *out=None*)
Implement `self(x[, out])`.

Examples

```
>>> from odl import Rn, IdentityOperator
>>> r3 = Rn(3)
>>> op = IdentityOperator(r3)
>>> x = r3.element([1, 2, 3])
>>> out = r3.element()
>>> OperatorSum(op, op)(x, out)  # In place, returns out
Rn(3).element([2.0, 4.0, 6.0])
>>> out
Rn(3).element([2.0, 4.0, 6.0])
>>> OperatorSum(op, op)(x)
Rn(3).element([2.0, 4.0, 6.0])
```

OperatorSum.derivative

OperatorSum.**derivative**(*x*)
Return the operator derivative at `x`.

The derivative of a sum of two operators is equal to the sum of the derivatives.

Parametersx : *Operator.domain element-like*

Evaluation point of the derivative

__init__(*op1*, *op2*, *tmp_ran=None*, *tmp_dom=None*)
Initialize a new instance.

Parametersop1 : *Operator*

The first summand. Its *Operator.range* must be a *LinearSpace* or *Field*.

op2 : *Operator*

The second summand. Must have the same *Operator.domain* and *Operator.range* as `op1`.

tmp_ran : *Operator.range element*, optional

Used to avoid the creation of a temporary when applying the operator.

tmp_dom : *Operator.domain element*, optional

Used to avoid the creation of a temporary when applying the operator adjoint.

Functions

simple_operator([call, inv, deriv, dom, ...])	Create a simple operator.

simple_operator

odl.operator.operator.**simple_operator**(*call=None*, *inv=None*, *deriv=None*, *dom=None*, *ran=None*, *linear=False*)

Create a simple operator.

Mostly intended for simple prototyping rather than final use.

Parameterscall : `callable`

Function with valid call signature, see *Operator*

inv : *Operator*, optional

The operator inverse

deriv : *Operator*, optional

The operator derivative, linear

dom : *Set*, optional

The domain of the operator Default: *UniversalSpace* if linear, else *UniversalSet*

ran : *Set*, optional

The range of the operator Default: *UniversalSpace* if linear, else *UniversalSet*

linear : `bool`, optional

`True` if the operator is linear Default: `False`

Returnsop : *Operator*

An operator with the provided attributes and methods.

Notes

It suffices to supply one of the functions `call` and `apply`. If `dom` is a *LinearSpace*, a default implementation of the respective other method is automatically provided; if not, a *OpNotImplementedError* is raised when the other method is called.

Examples

```
>>> A = simple_operator(lambda x: 3*x)
>>> A(5)
15
```

8.3.3 oputils

Convenience functions for operators.

Functions

matrix_representation(op)	Returns a matrix representation of a linear operator.
power_method_opnorm(op, niter[, xstart])	Estimate the operator norm with the power method.

matrix_representation

odl.operator.oputils.**matrix_representation**(*op*)
Returns a matrix representation of a linear operator.

Parametersop : *Operator*

The linear operator of which one wants a matrix representation.

Returnsmatrix : numpy.ndarray

The matrix representation of the operator.

Notes

The algorithm works by letting the operator act on all unit vectors, and stacking the output as a matrix.

power_method_opnorm

odl.operator.oputils.**power_method_opnorm**(*op*, *niter*, *xstart=None*)
Estimate the operator norm with the power method.

Parametersop : *Operator*

Operator whose norm is to be estimated. If its *Operator.range* range does not coincide with its *Operator.domain*, an *Operator.adjoint* must be defined (which implies that the operator must be linear).

niter : positive int

Number of iterations to perform

xstart : *Operator.domain element*, optional

Starting point of the iteration. By default, the one element of the *Operator.domain* is used.

Returnsest_norm : float

The estimated operator norm

8.3.4 pspace_ops

Default operators defined on any *ProductSpace*.

Classes

BroadcastOperator(*operators)	Broadcast argument to set of operators.
ComponentProjection(space, index)	Projection onto the subspace identified by an index.
ComponentProjectionAdjoint(space, index)	Adjoint operator to *ComponentProjection*.
ProductSpaceOperator(operators[, dom, ran])	A “matrix of operators” on product spaces.
ReductionOperator(*operators)	Reduce argument over set of operators.

BroadcastOperator

class odl.operator.pspace_ops.**BroadcastOperator**(**operators*)
Bases: *odl.operator.operator.Operator*

Broadcast argument to set of operators.

An argument is broadcast by evaluating several operators in the same point

```
BroadcastOperator(op1, op2)(x) = [op1(x), op2(x)]
```

It is implemented using a *ProductSpaceOperator*.

Attributes

adjoint	Adjoint of the broadcast operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
operators	A tuple of sub-operators
prod_op	The prod-op implementation
range	Set in which the result of an evaluation of this operator lies.

BroadcastOperator.adjoint

BroadcastOperator.**adjoint**
Adjoint of the broadcast operator.

Returnsadjoint : linear *BroadcastOperator*

The adjoint

Examples

```
>>> import odl
>>> I = odl.IdentityOperator(odl.Rn(3))
>>> op = BroadcastOperator(I, 2 * I)
>>> op.adjoint([[1, 2, 3], [2, 3, 4]])
Rn(3).element([5.0, 8.0, 11.0])
```

BroadcastOperator.domain

BroadcastOperator.**domain**
Set of objects on which this operator can be evaluated.

BroadcastOperator.inverse

BroadcastOperator.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

BroadcastOperator.is_functional

`BroadcastOperator.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

BroadcastOperator.is_linear

`BroadcastOperator.`**`is_linear`**
`True` if this operator is linear.

BroadcastOperator.operators

`BroadcastOperator.`**`operators`**
A tuple of sub-operators

BroadcastOperator.prod_op

`BroadcastOperator.`**`prod_op`**
The prod-op implementation

BroadcastOperator.range

`BroadcastOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

`__call__`(x[, out])	Return `self(x[, out, **kwargs])`.
`__eq__`	Return self==value.
`_call`(x[, out])	Apply operators to `x`.
`derivative`(x)	Derivative of the broadcast operator.

BroadcastOperator.__call__

`BroadcastOperator.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *`Operator.domain element-like`*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *`Operator.range element`*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

BroadcastOperator._call

`BroadcastOperator.`**`_call`**(*x*, *out=None*)

Apply operators to `x`.

Parametersx : domain element

Input vector to be evaluated by operators

out : range element, optional

output vector to write result to

Returnsout : range element

Values of operators evaluated in point

Examples

```
>>> import odl
>>> I = odl.IdentityOperator(odl.Rn(3))
>>> op = BroadcastOperator(I, 2 * I)
>>> x = [1, 2, 3]
>>> op(x)
ProductSpace(Rn(3), 2).element([
    [1.0, 2.0, 3.0],
    [2.0, 4.0, 6.0]
])
```

BroadcastOperator.derivative

BroadcastOperator.**derivative**(*x*)

Derivative of the broadcast operator.

Parametersx : domain element

The point to take the derivative in

Returnsadjoint : linear *BroadcastOperator*

The derivative

Examples

Example with affine operator

```
>>> import odl
>>> I = odl.IdentityOperator(odl.Rn(3))
>>> residual_op = odl.ResidualOperator(I, I.domain.element([1, 1, 1]))
>>> op = BroadcastOperator(residual_op, 2 * residual_op)
```

Calling operator gives offset by [1, 1, 1]

```
>>> x = [1, 2, 3]
>>> op(x)
ProductSpace(Rn(3), 2).element([
    [0.0, 1.0, 2.0],
    [0.0, 2.0, 4.0]
])
```

Derivative of affine operator does not have this offset

```
>>> op.derivative(x)(x)
ProductSpace(Rn(3), 2).element([
    [1.0, 2.0, 3.0],
    [2.0, 4.0, 6.0]
])
```

__init__(**operators*)

ComponentProjection

class odl.operator.pspace_ops.**ComponentProjection**(*space*, *index*)

Bases: *odl.operator.operator.Operator*

Projection onto the subspace identified by an index.

For a product space $\mathcal{X} = \mathcal{X}_1 \times \cdots \times \mathcal{X}_n$, the component projection

$$\mathcal{P}_i : \mathcal{X} \to \mathcal{X}_i$$

is given by $\mathcal{P}_i(x) = x_i$ for an element $x = (x_1, \ldots, x_n) \in \mathcal{X}$.

More generally, for an index set $I \subset \{1, \ldots, n\}$, the projection operator $\mathcal{P}_I$ is defined by $\mathcal{P}_I(x) = (x_i)_{i \in I}$.

Note that this is a special case of a product space operator where the "operator matrix" has only one row and contains only identity operators.

Attributes

adjoint	Return the adjoint operator.
domain	Set of objects on which this operator can be evaluated.
index	Index of the subspace.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ComponentProjection.adjoint

ComponentProjection.**adjoint**
Return the adjoint operator.

The adjoint is given by extending along *ComponentProjection.index*, and setting zero along the others.

See also:

ComponentProjectionAdjoint

ComponentProjection.domain

ComponentProjection.**domain**
Set of objects on which this operator can be evaluated.

ComponentProjection.index

ComponentProjection.**index**
Index of the subspace.

ComponentProjection.inverse

ComponentProjection.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

ComponentProjection.is_functional

ComponentProjection.**is_functional**
`True` if the this operator's range is a *Field*.

ComponentProjection.is_linear

ComponentProjection.**is_linear**
`True` if this operator is linear.

ComponentProjection.range

ComponentProjection.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Project x onto subspace.
derivative(point)	Return the operator derivative at `point`.

ComponentProjection.__call__

ComponentProjection.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ComponentProjection._call

`ComponentProjection.`**`_call`**(*x*, *out=None*)

Project x onto subspace.

Parametersx : domain *element*

input vector to be projected

out : range *element*, optional

output vector to write result to

Returnsout : range *element*

Projection of x onto subspace. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> import odl
>>> r1 = odl.Rn(1)
>>> r2 = odl.Rn(2)
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r1, r2, r3)
>>> x = X.element([[1], [2, 3], [4, 5, 6]])
```

Projection on n-th component

```
>>> proj = odl.ComponentProjection(X, 0)
>>> proj(x)
Rn(1).element([1.0])
```

Projection on sub-space

```
>>> proj = odl.ComponentProjection(X, [0, 2])
>>> proj(x)
ProductSpace(Rn(1), Rn(3)).element([
```

```
            [1.0],
            [4.0, 5.0, 6.0]
        ])
```

ComponentProjection.derivative

ComponentProjection.**derivative**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*space*, *index*)

Parametersspace : *ProductSpace*

The space to project from

index : `int`, `slice`, or `iterable` [int]

The indices defining the subspace. If `index` is not and `int`, the *Operator.range* of this operator is also a *ProductSpace*.

Examples

```
>>> import odl
>>> r1 = odl.Rn(1)
>>> r2 = odl.Rn(2)
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r1, r2, r3)
```

Projection on n-th component

```
>>> proj = odl.ComponentProjection(X, 0)
>>> proj.range
Rn(1)
```

Projection on sub-space

```
>>> proj = odl.ComponentProjection(X, [0, 2])
>>> proj.range
ProductSpace(Rn(1), Rn(3))
```

ComponentProjectionAdjoint

class odl.operator.pspace_ops.**ComponentProjectionAdjoint**(*space*, *index*)

Bases: *odl.operator.operator.Operator*

Adjoint operator to *ComponentProjection*.

As a special case of the adjoint of a *ProductSpaceOperator*, this operator is given as a column vector of identity operators and zero operators, with the identities placed in the positions defined by *ComponentProjectionAdjoint.index*.

In weighted product spaces, the adjoint needs to take the weightings into account. This is currently not supported.

Attributes

adjoint	The adjoint operator.
domain	Set of objects on which this operator can be evaluated.
index	Index of the subspace.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ComponentProjectionAdjoint.adjoint

ComponentProjectionAdjoint.**adjoint**
The adjoint operator.

The adjoint is given by the *ComponentProjection* related to this operator's *index*.

See also:

ComponentProjection

ComponentProjectionAdjoint.domain

ComponentProjectionAdjoint.**domain**
Set of objects on which this operator can be evaluated.

ComponentProjectionAdjoint.index

ComponentProjectionAdjoint.**index**
Index of the subspace.

ComponentProjectionAdjoint.inverse

ComponentProjectionAdjoint.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

ComponentProjectionAdjoint.is_functional

ComponentProjectionAdjoint.**is_functional**
`True` if the this operator's range is a *Field*.

ComponentProjectionAdjoint.is_linear

ComponentProjectionAdjoint.**is_linear**
`True` if this operator is linear.

ComponentProjectionAdjoint.range

`ComponentProjectionAdjoint.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Extend `x` from the subspace.
derivative(point)	Return the operator derivative at `point`.

ComponentProjectionAdjoint.__call__

`ComponentProjectionAdjoint.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ComponentProjectionAdjoint._call

ComponentProjectionAdjoint.**_call**(*x*, *out=None*)

Extend x from the subspace.

Parametersx : domain *element*

Input vector to be extended

out : range *element*, optional

output vector to write result to

Returnsout : range *element*

Extension of x to superspace. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> import odl
>>> r1 = odl.Rn(1)
>>> r2 = odl.Rn(2)
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r1, r2, r3)
>>> x = X.element([[1], [2, 3], [4, 5, 6]])
```

Projection on n-th component

```
>>> proj = odl.ComponentProjectionAdjoint(X, 0)
>>> proj(x[0])
ProductSpace(Rn(1), Rn(2), Rn(3)).element([
    [1.0],
    [0.0, 0.0],
    [0.0, 0.0, 0.0]
])
```

Projection on sub-space

```
>>> proj = odl.ComponentProjectionAdjoint(X, [0, 2])
>>> proj(x[0, 2])
ProductSpace(Rn(1), Rn(2), Rn(3)).element([
    [1.0],
    [0.0, 0.0],
    [4.0, 5.0, 6.0]
])
```

ComponentProjectionAdjoint.derivative

ComponentProjectionAdjoint.**derivative**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__ (*space*, *index*)

Initialize a new instance

Parametersspace : *ProductSpace*

The space to project to

index : `int`, `slice`, or `iterable` [int]

The indexes to project from

Examples

```
>>> import odl
>>> r1 = odl.Rn(1)
>>> r2 = odl.Rn(2)
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r1, r2, r3)
```

Projection on n-th component

```
>>> proj = odl.ComponentProjectionAdjoint(X, 0)
>>> proj.domain
Rn(1)
```

Projection on sub-space

```
>>> proj = odl.ComponentProjectionAdjoint(X, [0, 2])
>>> proj.domain
ProductSpace(Rn(1), Rn(3))
```

ProductSpaceOperator

class `odl.operator.pspace_ops.`**ProductSpaceOperator** (*operators*, *dom=None*, *ran=None*)

Bases: *odl.operator.operator.Operator*

A "matrix of operators" on product spaces.

This is intended for the case where an operator can be decomposed as a linear combination of "sub-operators", e.g.

$$\begin{pmatrix} A & B & 0 \\ 0 & C & 0 \\ 0 & 0 & D \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} A(x) + B(y) \\ C(y) \\ D(z) \end{pmatrix}$$

Mathematically, a *ProductSpaceOperator* is an operator

$$\mathcal{A} : \mathcal{X} \to \mathcal{Y}$$

between product spaces $\mathcal{X} = \mathcal{X}_1 \times \cdots \times \mathcal{X}_m$ and $\mathcal{Y} = \mathcal{Y}_1 \times \cdots \times \mathcal{Y}_n$ which can be written in the form

$$\mathcal{A} = (\mathcal{A}_{ij})_{i,j}, \quad i = 1, \ldots, n,\ j = 1, \ldots, m$$

with *component operators* $\mathcal{A}_{ij} : \mathcal{X}_j \to \mathcal{Y}_i$.

Its action on a vector $x = (x_1, \ldots, x_m)$ is defined as the matrix multiplication

$$[\mathcal{A}(x)]_i = \sum_{j=1}^{m} \mathcal{A}_{ij}(x_j).$$

Notes

In many cases it is of interest to have an operator from a *ProductSpace* to any *LinearSpace*. It that case this operator can be used with a slight modification, simply run

`prod_op = ProductSpaceOperator(prod_space, ProductSpace(linear_space))`

The same can be done for operators *LinearSpace* -> *ProductSpace*

`prod_op = ProductSpaceOperator(ProductSpace(linear_space), prod_space)`

Attributes

adjoint	Adjoint of the product space operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ProductSpaceOperator.adjoint

`ProductSpaceOperator.`**`adjoint`**

Adjoint of the product space operator.

The adjoint is given by taking the transpose of the matrix and the adjoint of each component operator.

In weighted product spaces, the adjoint needs to take the weightings into account. This is currently not supported.

Returnsadjoint : *ProductSpaceOperator*

The adjoint

Examples

```
>>> import odl
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r3, r3)
>>> I = odl.IdentityOperator(r3)
>>> x = X.element([[1, 2, 3], [4, 5, 6]])
```

Matrix is transposed:

```
>>> prod_op = ProductSpaceOperator([[0, I], [0, 0]],
...                                dom=X, ran=X)
>>> prod_op(x)
ProductSpace(Rn(3), 2).element([
    [4.0, 5.0, 6.0],
    [0.0, 0.0, 0.0]
])
>>> prod_op.adjoint(x)
ProductSpace(Rn(3), 2).element([
    [0.0, 0.0, 0.0],
```

```
            [1.0, 2.0, 3.0]
        ])
```

ProductSpaceOperator.domain

`ProductSpaceOperator.`**`domain`**
Set of objects on which this operator can be evaluated.

ProductSpaceOperator.inverse

`ProductSpaceOperator.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

ProductSpaceOperator.is_functional

`ProductSpaceOperator.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

ProductSpaceOperator.is_linear

`ProductSpaceOperator.`**`is_linear`**
`True` if this operator is linear.

ProductSpaceOperator.range

`ProductSpaceOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

`__call__`(x[, out])	Return `self(x[, out, **kwargs])`.
`__eq__`	Return self==value.
`_call`(x[, out])	Call the ProductSpace operators.
`derivative`(x)	Derivative of the product space operator.

ProductSpaceOperator.__call__

`ProductSpaceOperator.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *`Operator.domain element-like`*

An object which can be converted into an element of this operator's domain with the

`self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ProductSpaceOperator._call

`ProductSpaceOperator.`**`_call`**(*x*, *out=None*)

Call the ProductSpace operators.

Parametersx : domain *element*

input vector to be evaluated

out : range *element*, optional

output vector to write result to

Returnsout : range *element*

Result of the evaluation. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> import odl
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r3, r3)
>>> I = odl.IdentityOperator(r3)
>>> x = X.element([[1, 2, 3], [4, 5, 6]])
```

Sum of elements:

```
>>> prod_op = ProductSpaceOperator([I, I])
>>> prod_op(x)
ProductSpace(Rn(3), 1).element([
    [5.0, 7.0, 9.0]
])
```

Diagonal operator – 0 or `None` means ignore, or the implicit zero operator:

```
>>> prod_op = ProductSpaceOperator([[I, 0], [0, I]])
>>> prod_op(x)
ProductSpace(Rn(3), 2).element([
    [1.0, 2.0, 3.0],
    [4.0, 5.0, 6.0]
])
```

Complicated combinations:

```
>>> prod_op = ProductSpaceOperator([[I, I], [I, 0]])
>>> prod_op(x)
ProductSpace(Rn(3), 2).element([
    [5.0, 7.0, 9.0],
    [1.0, 2.0, 3.0]
])
```

ProductSpaceOperator.derivative

`ProductSpaceOperator.`**`derivative`**`(x)`

Derivative of the product space operator.

Parametersx : domain element

The point to take the derivative in

Returnsadjoint : linear‘ProductSpaceOperator‘

The derivative

Examples

```
>>> import odl
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r3, r3)
>>> I = odl.IdentityOperator(r3)
>>> x = X.element([[1, 2, 3], [4, 5, 6]])
```

Example with linear operator (derivative is itself)

```
>>> prod_op = ProductSpaceOperator([[0, I], [0, 0]],
...                                dom=X, ran=X)
>>> prod_op(x)
ProductSpace(Rn(3), 2).element([
    [4.0, 5.0, 6.0],
    [0.0, 0.0, 0.0]
])
>>> prod_op.derivative(x)(x)
ProductSpace(Rn(3), 2).element([
    [4.0, 5.0, 6.0],
    [0.0, 0.0, 0.0]
])
```

Example with affine operator

```
>>> residual_op = odl.ResidualOperator(I, r3.element([1, 1, 1]))
>>> op = ProductSpaceOperator([[0, residual_op], [0, 0]],
...                           dom=X, ran=X)
```

Calling operator gives offset by [1, 1, 1]

```
>>> op(x)
ProductSpace(Rn(3), 2).element([
    [3.0, 4.0, 5.0],
    [0.0, 0.0, 0.0]
])
```

Derivative of affine operator does not have this offset

```
>>> op.derivative(x)(x)
ProductSpace(Rn(3), 2).element([
    [4.0, 5.0, 6.0],
    [0.0, 0.0, 0.0]
])
```

__init__(*operators*, *dom=None*, *ran=None*)

Initialize a new instance.

Parametersoperators : *array-like*

An array of *Operator*'s

dom : *ProductSpace*, optional

Domain of the operator. If not provided, it is tried to be inferred from the operators. This requires each **column** to contain at least one operator.

ran : *ProductSpace*, optional

Range of the operator. If not provided, it is tried to be inferred from the operators. This requires each **row** to contain at least one operator.

Examples

```
>>> import odl
>>> r3 = odl.Rn(3)
>>> X = odl.ProductSpace(r3, r3)
>>> I = odl.IdentityOperator(r3)
```

Sum of elements

```
>>> prod_op = ProductSpaceOperator([I, I])
```

Diagonal operator, 0 or None means ignore, or the implicit zero op.

```
>>> prod_op = ProductSpaceOperator([[I, 0], [None, I]])
```

Complicated combinations also possible

```
>>> prod_op = ProductSpaceOperator([[I, I], [I, 0]])
```

ReductionOperator

class odl.operator.pspace_ops.**ReductionOperator**(**operators*)

Bases: *odl.operator.operator.Operator*

Reduce argument over set of operators.

An argument is reduced by evaluating several operators and summing the result

```
ReductionOperator(op1, op2)(x) = op1(x[0]) + op2(x[1])
```

It is implemented using a *ProductSpaceOperator*.

Attributes

adjoint	Adjoint of the reduction operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
operators	A tuple of sub-operators
prod_op	The prod-op implementation
range	Set in which the result of an evaluation of this operator lies.

ReductionOperator.adjoint

ReductionOperator.**adjoint**

Adjoint of the reduction operator.

Returnsadjoint : linear *BroadcastOperator*

The adjoint

Examples

```
>>> import odl
>>> I = odl.IdentityOperator(odl.Rn(3))
>>> op = ReductionOperator(I, 2 * I)
>>> op.adjoint([1, 2, 3])
ProductSpace(Rn(3), 2).element([
    [1.0, 2.0, 3.0],
    [2.0, 4.0, 6.0]
])
```

ReductionOperator.domain

`ReductionOperator.`**`domain`**
Set of objects on which this operator can be evaluated.

ReductionOperator.inverse

`ReductionOperator.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

ReductionOperator.is_functional

`ReductionOperator.`**`is_functional`**
`True` if the this operator's range is a *Field*.

ReductionOperator.is_linear

`ReductionOperator.`**`is_linear`**
`True` if this operator is linear.

ReductionOperator.operators

`ReductionOperator.`**`operators`**
A tuple of sub-operators

ReductionOperator.prod_op

`ReductionOperator.`**`prod_op`**
The prod-op implementation

ReductionOperator.range

`ReductionOperator.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Apply operators to `x` and sum.
derivative(x)	Derivative of the reduction operator.

ReductionOperator.__call__

ReductionOperator.**__call__**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ReductionOperator._call

ReductionOperator.**_call**(*x*, *out=None*)

Apply operators to `x` and sum.

Parametersx : domain element

Input vector to be evaluated by operators

out : range element, optional

output vector to write result to

Returnsout : range element

Sum of operators evaluated in point

Examples

```
>>> import odl
>>> I = odl.IdentityOperator(odl.Rn(3))
>>> op = ReductionOperator(I, 2 * I)
>>> op([[1.0, 2.0, 3.0], [4.0, 6.0, 8.0]])
Rn(3).element([9.0, 14.0, 19.0])
```

ReductionOperator.derivative

ReductionOperator.**derivative**(*x*)

Derivative of the reduction operator.

Parametersx : domain element

The point to take the derivative in

Returnsadjoint : linear *BroadcastOperator*

The derivative

Examples

```
>>> import odl
>>> r3 = odl.Rn(3)
>>> I = odl.IdentityOperator(r3)
>>> x = r3.element([1.0, 2.0, 3.0])
>>> y = r3.element([4.0, 6.0, 8.0])
```

Example with linear operator (derivative is itself)

```
>>> op = ReductionOperator(I, 2 * I)
>>> op([x, y])
Rn(3).element([9.0, 14.0, 19.0])
>>> op.derivative([x, y])([x, y])
Rn(3).element([9.0, 14.0, 19.0])
```

Example with affine operator

```
>>> residual_op = odl.ResidualOperator(I, r3.element([1, 1, 1]))
>>> op = ReductionOperator(residual_op, 2 * residual_op)
```

Calling operator gives offset by [3, 3, 3]

```
>>> op([x, y])
Rn(3).element([6.0, 11.0, 16.0])
```

Derivative of affine operator does not have this offset

```
>>> op.derivative([x, y])([x, y])
Rn(3).element([9.0, 14.0, 19.0])
```

__init__(**operators*)

Functions

diagonal_operator(operators[, dom, ran])	Broadcast argument to set of operators.

diagonal_operator

odl.operator.pspace_ops.**diagonal_operator**(*operators*, *dom=None*, *ran=None*)

Broadcast argument to set of operators.

Parametersoperators : array-like

An array of *Operator*'s

dom : *ProductSpace*, optional

Domain of the operator. If not provided, it is tried to be inferred from the operators. This requires each **column** to contain at least one operator.

ran : *ProductSpace*, optional

Range of the operator. If not provided, it is tried to be inferred from the operators. This requires each **row** to contain at least one operator.

8.4 set

Core Spaces and set support.

Modules

8.4.1 domain

Domains for continuous functions.

Classes

IntervalProd(begin, end)	An n-dimensional rectangular box.

IntervalProd

class odl.set.domain.**IntervalProd**(*begin*, *end*)

Bases: *odl.set.sets.Set*

An n-dimensional rectangular box.

An interval product is a Cartesian product of n intervals, i.e. an n-dimensional rectangular box aligned with the coordinate axes as a subset of R^n.

IntervalProd objects are immutable, all methods involving them return a new *IntervalProd*.

Attributes

area	The length of this interval.
begin	The left interval boundary/boundaries.
end	The right interval boundary/boundaries.
length	The length of this interval.
midpoint	The midpoint of the interval product.
ndim	The number of intervals in the product.
true_ndim	The number of non-degenerate (zero-length) intervals.
volume	The 'dim'-dimensional volume of this interval product.

IntervalProd.area

IntervalProd.**area**
The length of this interval.

IntervalProd.begin

IntervalProd.**begin**
The left interval boundary/boundaries.

IntervalProd.end

IntervalProd.**end**
The right interval boundary/boundaries.

IntervalProd.length

IntervalProd.**length**
The length of this interval.

IntervalProd.midpoint

IntervalProd.**midpoint**
The midpoint of the interval product.

IntervalProd.ndim

IntervalProd.**ndim**
The number of intervals in the product.

IntervalProd.true_ndim

IntervalProd.**true_ndim**
The number of non-degenerate (zero-length) intervals.

IntervalProd.volume

IntervalProd.**volume**
The 'dim'-dimensional volume of this interval product.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
__getitem__(indices)	Return `self[indices]`
append(other)	Insert at the end.
approx_contains(point, tol)	Test if a point is contained.
approx_equals(other, tol)	Test if `other` is equal to this set up to `tol`.
collapse(indices, values)	Partly collapse the interval product to single values.
contains_all(other)	Test if all points defined by `other` are contained.
contains_set(other[, tol])	Test if another set is contained.
corners([order])	The corner points in a single array.
dist(point[, ord])	Calculate the distance to a point.
element([inp])	Create element in this set.
extent()	The interval length per axis.
insert(index, other)	Return a copy with `other` inserted before `index`.
max()	The maximum value in this interval product
measure([ndim])	The (Lebesgue) measure of this interval product.
min()	The minimum value in this interval product
squeeze()	Remove the degenerate dimensions.

IntervalProd.__contains__

IntervalProd.**__contains__**(*other*)
Return `other in self`.

Parametersother

Arbitrary object to be tested.

Returnscontains : `bool`

True if other is inside self.

Examples

```
>>> interv = IntervalProd(0, 1)
>>> 0.5 in interv
True
>>> 2 in interv
False
```

```
>>> 'string' in interv
False
```

IntervalProd.__eq__

IntervalProd.**__eq__**(*other*)
Return `self == other`.

IntervalProd.__getitem__

IntervalProd.**__getitem__**(*indices*)
Return `self[indices]`

Parametersindices : numpy style index

Any of: int, slice, list of ints

Returnssubinterval : *IntervalProd*

Interval given by the indices

Examples

```
>>> rbox = IntervalProd([-1, 2, 0], [-0.5, 3, 0.5])
```

By integer

```
>>> rbox[0]
Interval(-1.0, -0.5)
```

By slice

```
>>> rbox[:]
Cuboid([-1.0, 2.0, 0.0], [-0.5, 3.0, 0.5])
>>> rbox[::2]
Rectangle([-1.0, 0.0], [-0.5, 0.5])
```

By list of ints

```
>>> rbox[[0, 1]]
Rectangle([-1.0, 2.0], [-0.5, 3.0])
```

IntervalProd.append

IntervalProd.**append**(*other*)
Insert at the end.

Parametersother : *IntervalProd*, `float` or array-like

The set to be inserted. A `float` or array a is treated as an `IntervalProd(a, a)`.

See also:

insert

Examples

```
>>> rbox = IntervalProd([-1, 2], [-0.5, 3])
>>> rbox.append(Interval(-1.0, 0.0))
Cuboid([-1.0, 2.0, -1.0], [-0.5, 3.0, 0.0])
```

IntervalProd.approx_contains

`IntervalProd.`**`approx_contains`**(*point*, *tol*)

Test if a point is contained.

Parameters

point : *array-like* or `float`

The point to be tested. Its length must be equal to the set's dimension. In the 1d case, 'point' can be given as a `float`.

tol : `float`

The maximum allowed distance in 'inf'-norm between the point and the set. Default: 0.0

Examples

```
>>> from math import sqrt
>>> b, e = [-1, 0, 2], [-0.5, 0, 3]
>>> rbox = IntervalProd(b, e)
>>> # Numerical error
>>> rbox.approx_contains([-1 + sqrt(0.5)**2, 0., 2.9], tol=0)
False
>>> rbox.approx_contains([-1 + sqrt(0.5)**2, 0., 2.9], tol=1e-9)
True
```

IntervalProd.approx_equals

`IntervalProd.`**`approx_equals`**(*other*, *tol*)

Test if `other` is equal to this set up to `tol`.

Parameters

other : `object`

The object to be tested

tol : `float`

The maximum allowed difference in 'inf'-norm between the interval endpoints.

Examples

```
>>> from math import sqrt
>>> rbox1 = IntervalProd(0, 0.5)
>>> rbox2 = IntervalProd(0, sqrt(0.5)**2)
>>> rbox1.approx_equals(rbox2, tol=0)  # Num error
False
>>> rbox1.approx_equals(rbox2, tol=1e-15)
True
```

IntervalProd.collapse

IntervalProd.**collapse**(*indices*, *values*)

Partly collapse the interval product to single values.

Note that no changes are made in-place.

Parametersindices : `int` or `tuple` of `int`

The indices of the dimensions along which to collapse

values : *array-like* or `float`

The values to which to collapse. Must have the same length as `indices`. Values must lie within the interval boundaries.

Returnscollapsed : *IntervalProd*

The collapsed set

Examples

```
>>> b, e = [-1, 0, 2], [-0.5, 1, 3]
>>> rbox = IntervalProd(b, e)
>>> rbox.collapse(1, 0)
Cuboid([-1.0, 0.0, 2.0], [-0.5, 0.0, 3.0])
>>> rbox.collapse([1, 2], [0, 2.5])
Cuboid([-1.0, 0.0, 2.5], [-0.5, 0.0, 2.5])
```

IntervalProd.contains_all

IntervalProd.**contains_all**(*other*)

Test if all points defined by `other` are contained.

Parametersother :

Can be a single point, a `(d, N)` array where `d` is the number of dimensions or a length-`d` meshgrid tuple

Returnscontains : `bool`

`True` if all points are contained, `False` otherwise

Examples

```
>>> import odl
>>> b, e = [-1, 0, 2], [-0.5, 0, 3]
>>> rbox = IntervalProd(b, e)
```

rrays are expected in (ndim, npoints) shape

```
>>> arr = np.array([[-1, 0, 2],    # defining one point at a time
...                 [-0.5, 0, 2]])
>>> rbox.contains_all(arr.T)
True
```

Implicit meshgrids defined by coordinate vectors

```
>>> from odl.discr.grid import sparse_meshgrid
>>> vec1 = (-1, -0.9, -0.7)
>>> vec2 = (0, 0, 0)
>>> vec3 = (2.5, 2.75, 3)
>>> mg = sparse_meshgrid(vec1, vec2, vec3)
>>> rbox.contains_all(mg)
True
```

Also works with any iterable

```
>>> rbox.contains_all([[-1, -0.5], # define points by axis
...                    [0, 0],
...                    [2, 2]])
True
```

And with grids

```
>>> agrid = odl.uniform_sampling(rbox.begin, rbox.end, [3, 1, 3])
>>> rbox.contains_all(agrid)
True
```

IntervalProd.contains_set

`IntervalProd.`**`contains_set`**(*other*, *tol=0.0*)

Test if another set is contained.

Parametersother : *Set*

The set to be tested. It must implement a `min()` and a `max()` method, otherwise a `TypeError` is raised.

tol : `float`, optional

The maximum allowed distance in 'inf'-norm between the other set and this interval product. Default: 0.0

Examples

```
>>> b1, e1 = [-1, 0, 2], [-0.5, 0, 3]
>>> rbox1 = IntervalProd(b1, e1)
>>> b2, e2 = [-0.6, 0, 2.1], [-0.5, 0, 2.5]
>>> rbox2 = IntervalProd(b2, e2)
>>> rbox1.contains_set(rbox2)
True
>>> rbox2.contains_set(rbox1)
False
```

IntervalProd.corners

`IntervalProd.`**`corners`**(*order='C'*)

The corner points in a single array.

Parametersorder : {'C', 'F'}

The ordering of the axes in which the corners appear in the output. 'C' means that the first axis varies slowest and the last one fastest, vice versa in 'F' ordering.

Returnscorners : `numpy.ndarray`

The size of the array is `2^m * ndim`, where `m` is the number of non-degenerate axes, i.e. the corners are stored as rows.

Examples

```
>>> rbox = IntervalProd([-1, 2, 0], [-0.5, 3, 0.5])
>>> rbox.corners()
array([[-1. ,  2. ,  0. ],
       [-1. ,  2. ,  0.5],
       [-1. ,  3. ,  0. ],
       [-1. ,  3. ,  0.5],
       [-0.5,  2. ,  0. ],
       [-0.5,  2. ,  0.5],
       [-0.5,  3. ,  0. ],
       [-0.5,  3. ,  0.5]])
>>> rbox.corners(order='F')
array([[-1. ,  2. ,  0. ],
       [-0.5,  2. ,  0. ],
       [-1. ,  3. ,  0. ],
       [-0.5,  3. ,  0. ],
       [-1. ,  2. ,  0.5],
       [-0.5,  2. ,  0.5],
       [-1. ,  3. ,  0.5],
       [-0.5,  3. ,  0.5]])
```

IntervalProd.dist

`IntervalProd.`**`dist`**(*point*, *ord=2.0*)

Calculate the distance to a point.

Parameterspoint : *array-like* or `float`

The point. Its length must be equal to the set's dimension. Can be a `float` in the 1d case.

ord : non-zero int or float('inf'), optional

The order of the norm (see `numpy.linalg.norm`). Default: 2.0

Returnsdist : `float`

Distance to the interior of the IntervalProd. Points strictly inside have distance `0.0`, points with `NaN` have distance `infinity`.

Examples

```
>>> b, e = [-1, 0, 2], [-0.5, 0, 3]
>>> rbox = IntervalProd(b, e)
>>> rbox.dist([-5, 3, 2])
5.0
>>> rbox.dist([-5, 3, 2], ord=float('inf'))
4.0
```

IntervalProd.element

IntervalProd.**element**(*inp=None*)

Create element in this set.

Parameters

inp : `float` or array-like, optional

Point to be cast to an element in self

Returns

element

Returns `inp` if given, else `self.midpoint`

Raises

TypeError

If `inp` is not a valid element.

Examples

```
>>> interv = IntervalProd(0, 1)
>>> interv.element(0.5)
0.5
```

IntervalProd.extent

IntervalProd.**extent**()

The interval length per axis.

IntervalProd.insert

IntervalProd.**insert**(*index*, *other*)

Return a copy with `other` inserted before `index`.

The given interval product (`ndim=m`) is inserted into the current one (`ndim=n`) before the given index, resulting in a new interval product with `n+m` dimensions.

Parameters

index : `int`

Index of the dimension before which `other` is to be inserted. Must fulfill `-ndim <= index <= ndim`. Negative indices count backwards from `self.ndim`.

other : *IntervalProd*

Interval product to be inserted

Returns

newintvp : *IntervalProd*

Interval product with `other` inserted

Examples

```
>>> rbox = IntervalProd([-1, 2], [-0.5, 3])
>>> rbox2 = IntervalProd([0, 0], [1, 0])
>>> rbox.insert(1, rbox2)
IntervalProd([-1.0, 0.0, 0.0, 2.0], [-0.5, 1.0, 0.0, 3.0])
>>> rbox.insert(-1, rbox2)
IntervalProd([-1.0, 0.0, 0.0, 2.0], [-0.5, 1.0, 0.0, 3.0])
```

IntervalProd.max

IntervalProd.**max**()
The maximum value in this interval product

IntervalProd.measure

IntervalProd.**measure**(*ndim=None*)
The (Lebesgue) measure of this interval product.

Parametersndim : int, optional

The dimension of the measure to apply. Default: *true_ndim*

Examples

```
>>> b, e = [-1, 2.5, 0], [-0.5, 10, 0]
>>> rbox = IntervalProd(b, e)
>>> rbox.measure()
3.75
>>> rbox.measure(ndim=3)
0.0
>>> rbox.measure(ndim=3) == rbox.volume
True
>>> rbox.measure(ndim=1)
inf
>>> rbox.measure() == rbox.squeeze().volume
True
```

IntervalProd.min

IntervalProd.**min**()
The minimum value in this interval product

IntervalProd.squeeze

IntervalProd.**squeeze**()
Remove the degenerate dimensions.

Note that no changes are made in-place.

Returnssqueezed : *IntervalProd*

The squeezed set

Examples

```
>>> b, e = [-1, 0, 2], [-0.5, 1, 3]
>>> rbox = IntervalProd(b, e)
>>> rbox.collapse(1, 0).squeeze()
Rectangle([-1.0, 2.0], [-0.5, 3.0])
>>> rbox.collapse([1, 2], [0, 2.5]).squeeze()
```

```
        Interval(-1.0, -0.5)
        >>> rbox.collapse([0, 1, 2], [-1, 0, 2.5]).squeeze()
        IntervalProd([], [])
```

__init__(*begin*, *end*)
Initialize a new instance.

Parametersbegin : *array-like* or `float`

The lower ends of the intervals in the product

end : *array-like* or `float`

The upper ends of the intervals in the product

Examples

```
        >>> b, e = [-1, 2.5, 70, 80], [-0.5, 10, 75, 90]
        >>> rbox = IntervalProd(b, e)
        >>> rbox
        IntervalProd([-1.0, 2.5, 70.0, 80.0], [-0.5, 10.0, 75.0, 90.0])
```

Functions

Cuboid(begin, end)	Three-dimensional interval product.
Interval(begin, end)	One-dimensional interval product.
Rectangle(begin, end)	Two-dimensional interval product.

Cuboid

odl.set.domain.**Cuboid**(*begin*, *end*)
Three-dimensional interval product.

Parametersbegin : *array-like*, shape `(3,)`

The lower ends of the intervals in the product

end : *array-like*, shape `(3,)`

The upper ends of the intervals in the product

Interval

odl.set.domain.**Interval**(*begin*, *end*)
One-dimensional interval product.

Parametersbegin : *array-like*, shape `(1,)`, or `float`

The lower ends of the intervals in the product

end : *array-like*, shape `(1,)`, or `float`

The upper ends of the intervals in the product

Rectangle

odl.set.domain.**Rectangle**(*begin*, *end*)
Two-dimensional interval product.

Parametersbegin : *array-like*, shape (2,)

The lower ends of the intervals in the product

end : *array-like*, shape (2,)

The upper ends of the intervals in the product

8.4.2 pspace

Cartesian products of *LinearSpace* instances.

Classes

ProductSpace(*spaces, **kwargs)	Cartesian product of *LinearSpace*'s.
ProductSpaceVector(space, parts)	Elements of a *ProductSpace*.

ProductSpace

class odl.set.pspace.**ProductSpace**(**spaces*, ***kwargs*)
Bases: *odl.set.space.LinearSpace*

Cartesian product of *LinearSpace*'s.

Attributes

element_type	*ProductSpaceVector*
field	The field of this vector space.
size	The number of factors.
spaces	A tuple containing all spaces.
weights	Weighting vector or scalar of this product space.

ProductSpace.element_type

ProductSpace.**element_type**
ProductSpaceVector

ProductSpace.field

ProductSpace.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

ProductSpace.size

ProductSpace.**size**
The number of factors.

ProductSpace.spaces

ProductSpace.**spaces**
A tuple containing all spaces.

ProductSpace.weights

ProductSpace.**weights**
Weighting vector or scalar of this product space.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
__getitem__(indices)	Return `self[indices]`.
_dist(x1, x2)	Distance between two vectors.
_divide(x1, x2, out)	Quotient `out = x1 / x2`.
_inner(x1, x2)	Inner product of two vectors.
_lincomb(a, x, b, y, out)	Linear combination `out = a*x + b*y`.
_multiply(x1, x2, out)	Product `out = x1 * x2`.
_norm(x)	Norm of a vector.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp, cast])	Create an element in the product space.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	Create the one vector of the product space.
zero()	Create the zero vector of the product space.

ProductSpace.__contains__

ProductSpace.**__contains__**(*other*)
Return `other in self`.

Returnscontains : `bool`

`True` if `other` is a *LinearSpaceVector* instance and `other.space` is equal to this space, `False` otherwise.

Notes

This is the strict default where spaces must be equal. Subclasses may choose to implement a less strict check.

ProductSpace.__eq__

`ProductSpace.__eq__(other)`
Return `self == other`.

Returnsequals : `bool`

`True` if `other` is a *`ProductSpace`* instance, has the same length and the same factors. `False` otherwise.

Examples

```
>>> from odl import Rn
>>> r2, r3 = Rn(2), Rn(3)
>>> rn, rm = Rn(2), Rn(3)
>>> r2x3, rnxm = ProductSpace(r2, r3), ProductSpace(rn, rm)
>>> r2x3 == rnxm
True
>>> r3x2 = ProductSpace(r3, r2)
>>> r2x3 == r3x2
False
>>> r5 = ProductSpace(*[Rn(1)]*5)
>>> r2x3 == r5
False
>>> r5 = Rn(5)
>>> r2x3 == r5
False
```

ProductSpace.__getitem__

`ProductSpace.__getitem__(indices)`
Return `self[indices]`.

ProductSpace._dist

`ProductSpace._dist(x1, x2)`
Distance between two vectors.

ProductSpace._divide

`ProductSpace._divide(x1, x2, out)`
Quotient `out = x1 / x2`.

ProductSpace._inner

`ProductSpace.`**`_inner`**(*x1*, *x2*)
Inner product of two vectors.

ProductSpace._lincomb

`ProductSpace.`**`_lincomb`**(*a*, *x*, *b*, *y*, *out*)
Linear combination `out = a*x + b*y`.

ProductSpace._multiply

`ProductSpace.`**`_multiply`**(*x1*, *x2*, *out*)
Product `out = x1 * x2`.

ProductSpace._norm

`ProductSpace.`**`_norm`**(*x*)
Norm of a vector.

ProductSpace.contains_all

`ProductSpace.`**`contains_all`**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

ProductSpace.contains_set

`ProductSpace.`**`contains_set`**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

ProductSpace.dist

`ProductSpace.`**`dist`**(*x1*, *x2*)
Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

ProductSpace.divide

ProductSpace.**divide**(*x1*, *x2*, *out=None*)

Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

ProductSpace.element

ProductSpace.**element**(*inp=None*, *cast=True*)

Create an element in the product space.

Parametersinp : optional

If `inp` is `None`, a new element is created from scratch by allocation in the spaces. If `inp` is already an element of this space, it is re-wrapped. Otherwise, a new element is created from the components by calling the `element()` methods in the component spaces.

cast : `bool`

True if casting should be allowed

Returnselement : *ProductSpaceVector*

The new element

Examples

```
>>> from odl import Rn
>>> r2, r3 = Rn(2), Rn(3)
>>> vec_2, vec_3 = r2.element(), r3.element()
>>> r2x3 = ProductSpace(r2, r3)
>>> vec_2x3 = r2x3.element()
>>> vec_2.space == vec_2x3[0].space
True
>>> vec_3.space == vec_2x3[1].space
True
```

Create an element of the product space

```
>>> from odl import Rn
>>> r2, r3 = Rn(2), Rn(3)
>>> prod = ProductSpace(r2, r3)
>>> x2 = r2.element([1, 2])
>>> x3 = r3.element([1, 2, 3])
```

```
>>> x = prod.element([x2, x3])
>>> print(x)
{[1.0, 2.0], [1.0, 2.0, 3.0]}
```

ProductSpace.inner

ProductSpace.**inner**(*x1*, *x2*)

Calculate the inner product of x1 and x2.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If out was provided, the returned object is a reference to it.

ProductSpace.lincomb

ProductSpace.**lincomb**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply x1 with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply x2 with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If out was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

ProductSpace.multiply

`ProductSpace.`**`multiply`**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

ProductSpace.norm

`ProductSpace.`**`norm`**(*x*)

Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

ProductSpace.one

`ProductSpace.`**`one`**()

Create the one vector of the product space.

The i:th component of the product space one vector is the one vector of the i:th space in the product.

ParametersNone

Returnsone : ProductSpaceVector

The one vector in the product space

Examples

```
>>> from odl import Rn
>>> r2, r3 = Rn(2), Rn(3)
>>> one_2, one_3 = r2.one(), r3.one()
>>> r2x3 = ProductSpace(r2, r3)
>>> one_2x3 = r2x3.one()
>>> one_2 == one_2x3[0]
True
>>> one_3 == one_2x3[1]
True
```

ProductSpace.zero

ProductSpace.**zero**()

Create the zero vector of the product space.

The i:th component of the product space zero vector is the zero vector of the i:th space in the product.

ParametersNone

Returnszero : ProductSpaceVector

The zero vector in the product space

Examples

```
>>> from odl import Rn
>>> r2, r3 = Rn(2), Rn(3)
>>> zero_2, zero_3 = r2.zero(), r3.zero()
>>> r2x3 = ProductSpace(r2, r3)
>>> zero_2x3 = r2x3.zero()
>>> zero_2 == zero_2x3[0]
True
>>> zero_3 == zero_2x3[1]
True
```

__init__(**spaces*, ***kwargs*)

Initialize a new instance.

The Cartesian product $\mathcal{X}_1 \times \cdots \times \mathcal{X}_n$ for linear spaces $\mathcal{X}_i$ is itself a linear space, where the linear combination is defined component-wise.

Parametersspaces : *LinearSpace* or int

Can be specified either as a space and an integer, in which case the power space `space**n` is created, or an arbitrary number of spaces.

ord : float, optional

Order of the product distance/norm, i.e.

```
dist(x, y) = np.linalg.norm(x-y, ord=ord)
```

```
norm(x) = np.linalg.norm(x, ord=ord)
```

Default: 2.0

The following float values for ord can be specified. Note that any value of `ord < 1` only gives a pseudo-norm.

'prod_norm'	Distance Definition
'inf'	`max(w * z)`
'-inf'	`min(w * z)`
other	`sum(w * z**ord)**(1/ord)`

Here,

`z = (x[0].dist(y[0]),..., x[n-1].dist(y[n-1]))`

and `w = weights`.

Note that `0 <= ord < 1` are not allowed since these pseudo-norms are very unstable numerically.

weights : *array-like*, optional

Array of weights, same size as number of space components. All weights must be positive. It is multiplied with the tuple of distances before applying the Rn norm or `prod_norm`. Default: `(1.0,...,1.0)`

This option can only be used together with `ord`.

prod_norm : `callable`, optional

Function that should be applied to the array of distances/norms. Specifying a product norm causes the space to NOT be a Hilbert space.

Default: `np.linalg.norm(x, ord=ord)`.

field : *Field*, optional

The field that should be used. Default: spaces[0].field

Returnsprodspace : *ProductSpace*

Examples

```
>>> from odl import Rn
>>> r2x3 = ProductSpace(Rn(2), Rn(3))
```

ProductSpaceVector

class `odl.set.pspace.`**`ProductSpaceVector`**(*space*, *parts*)

Bases: *odl.set.space.LinearSpaceVector*

Elements of a *ProductSpace*.

Attributes

T	The transpose of a vector, the functional given by (.
parts	The parts of this vector.
size	The number of factors of this vector's space.
space	Space to which this vector belongs.
ufunc	*ProductSpaceUFuncs*, access to numpy style ufuncs.

ProductSpaceVector.T

ProductSpaceVector.**T**
The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

ProductSpaceVector.parts

ProductSpaceVector.**parts**
The parts of this vector.

ProductSpaceVector.size

ProductSpaceVector.**size**
The number of factors of this vector's space.

ProductSpaceVector.space

ProductSpaceVector.**space**
Space to which this vector belongs.

LinearSpace

ProductSpaceVector.ufunc

ProductSpaceVector.**ufunc**
ProductSpaceUFuncs, access to numpy style ufuncs.

These are always available if the underlying spaces are *NtuplesBase*.

See also:

odl.util.ufuncs.NtuplesBaseUFuncsBase class for ufuncs in *NtuplesBase* spaces, sub spaces may override this for greater efficiency.

*odl.util.ufuncs.ProductSpaceUFuncs*For a list of available ufuncs.

Examples

```
>>> from odl import Rn
>>> r22 = ProductSpace(Rn(2), 2)
>>> x = r22.element([[1, -2], [-3, 4]])
>>> x.ufunc.absolute()
ProductSpace(Rn(2), 2).element([
    [1.0, 2.0],
    [3.0, 4.0]
])
```

These functions can also be used with non-vector arguments and support broadcasting, both by element

```
>>> x.ufunc.add([1, 1])
ProductSpace(Rn(2), 2).element([
    [2.0, -1.0],
    [-2.0, 5.0]
])
```

and also recursively

```
>>> x.ufunc.subtract(1)
ProductSpace(Rn(2), 2).element([
    [0.0, -3.0],
    [-4.0, 3.0]
])
```

There is also support for various reductions (sum, prod, min, max)

```
>>> x.ufunc.sum()
0.0
```

Also supports out parameter

```
>>> y = r22.element()
>>> result = x.ufunc.absolute(out=y)
>>> result
ProductSpace(Rn(2), 2).element([
    [1.0, 2.0],
    [3.0, 4.0]
])
>>> result is y
True
```

Methods

__eq__(other)	Return `self == other`.
__getitem__(indices)	Return `self[indices]`.
__setitem__(indices, values)	Implement `self[indices] = vals`.
assign(other)	Assign the values of `other` to self.
copy()	Create an identical (deep) copy of self.
dist(other)	Distance to `other`.

Continued on next page

Table 8.111 – continued from previous page

divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
set_zero()	Set this vector to zero.
show([title, indices])	Display the parts of this vector graphically

ProductSpaceVector.__eq__

ProductSpaceVector.**__eq__**(*other*)
Return `self == other`.

Overrides the default *LinearSpace* method since it is implemented with the distance function, which is prone to numerical errors. This function checks equality per component.

ProductSpaceVector.__getitem__

ProductSpaceVector.**__getitem__**(*indices*)
Return `self[indices]`.

ProductSpaceVector.__setitem__

ProductSpaceVector.**__setitem__**(*indices*, *values*)
Implement `self[indices] = vals`.

ProductSpaceVector.assign

ProductSpaceVector.**assign**(*other*)
Assign the values of `other` to self.

ProductSpaceVector.copy

ProductSpaceVector.**copy**()
Create an identical (deep) copy of self.

ProductSpaceVector.dist

ProductSpaceVector.**dist**(*other*)
Distance to `other`.

LinearSpace.dist

ProductSpaceVector.divide

ProductSpaceVector.**divide**(*x*, *y*)
Divide by `other` inplace.

LinearSpace.divide

ProductSpaceVector.inner

`ProductSpaceVector.`**`inner`**(*other*)
Inner product with `other`.

LinearSpace.inner

ProductSpaceVector.lincomb

`ProductSpaceVector.`**`lincomb`**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

ProductSpaceVector.multiply

`ProductSpaceVector.`**`multiply`**(*x*, *y*)
Multiply by `other` inplace.

LinearSpace.multiply

ProductSpaceVector.norm

`ProductSpaceVector.`**`norm`**()
Norm of vector

LinearSpace.norm

ProductSpaceVector.set_zero

`ProductSpaceVector.`**`set_zero`**()
Set this vector to zero.

LinearSpace.zero

ProductSpaceVector.show

`ProductSpaceVector.`**`show`**(*title=None*, *indices=None*, ***kwargs*)
Display the parts of this vector graphically

Parameters

title : `str`

Title of the figures

indices : index expression, optional

Indices can refer to parts of a *ProductSpaceVector* and slices in the parts in the following way:

Single index (`indices=0`) => display that part

Single `slice` (`indices=slice(None)`), or index `list` (`indices=[0, 1, 3]`) => display those parts

Any `tuple`, for example: Created by `numpy.s_` `indices=np.s_[0, :, :]` or Using a raw `tuple` `indices=([0, 3], slice(None))` => take the first elements to select the parts and pass the rest on to the underlying show methods.

kwargs

Additional arguments passed on to the underlying vectors

Returnsfig : list of `matplotlib.figure.Figure`

The resulting figures. It is also shown to the user.

See also:

odl.discr.lp_discr.DiscreteLpVector.showDisplay of a discretized function

odl.space.base_ntuples.NtuplesBaseVector.showDisplay of sequence type data

odl.util.graphics.show_discrete_dataUnderlying implementation

__init__ (*space*, *parts*)
"Initialize a new instance.

8.4.3 sets

Basic abstract and concrete sets.

Classes

CartesianProduct(*sets)	The Cartesian product of `n` sets.
ComplexNumbers	The set of complex numbers.
EmptySet	The empty set.
Field	Any set that satisfies the field axioms
Integers	The set of integers.
RealNumbers	The set of real numbers.
Set	An abstract set.
Strings(length)	The set of fixed-length (unicode) strings.
UniversalSet	The set of all objects.

CartesianProduct

class `odl.set.sets.`**CartesianProduct**(**sets*)
Bases: *odl.set.sets.Set*

The Cartesian product of `n` sets.

The elements of this set are `n`-tuples where the i-th entry is an element of the i-th set.

Attributes

sets	The factors (sets) as a `tuple`.

CartesianProduct.sets

`CartesianProduct.`**`sets`**
The factors (sets) as a `tuple`.

Methods

__contains__(other)	Test if `other` is contained in this set.
__eq__(other)	Return `self == other`.
__getitem__(indcs)	Return `self[indcs]`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([inp])	Create a *CartesianProduct* element.

CartesianProduct.__contains__

`CartesianProduct.`**`__contains__`**(*other*)
Test if `other` is contained in this set.

Returnscontains : `bool`

`True` if `other` has the same length as this Cartesian product and each entry is contained in the set with corresponding index, `False` otherwise.

CartesianProduct.__eq__

`CartesianProduct.`**`__eq__`**(*other*)
Return `self == other`.

Returnsequals : `bool`

`True` if `other` is a *CartesianProduct* instance, has the same length as this Cartesian product and all sets with the same index are equal, `False` otherwise.

CartesianProduct.__getitem__

`CartesianProduct.`**`__getitem__`**(*indcs*)
Return `self[indcs]`.

Examples

```
>>> emp, univ = EmptySet(), UniversalSet()
>>> prod = CartesianProduct(emp, univ, univ, emp, emp)
>>> prod[2]
UniversalSet()
```

```
>>> prod[2:4]
CartesianProduct(UniversalSet(), EmptySet())
```

CartesianProduct.contains_all

CartesianProduct.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

CartesianProduct.contains_set

CartesianProduct.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

CartesianProduct.element

CartesianProduct.**element**(*inp=None*)
Create a *CartesianProduct* element.

Parametersinp : `iterable`, optional

Collection of input values for the *LinearSpace.element* methods of all sets in the Cartesian product.

Returnselement : `tuple`

A tuple of the given input

__init__(**sets*)
Initialize a new instance.

ComplexNumbers

class odl.set.sets.**ComplexNumbers**
Bases: *odl.set.sets.Field*

The set of complex numbers.

Attributes

field	The field of scalars for a field is itself.

ComplexNumbers.field

ComplexNumbers.**field**
The field of scalars for a field is itself.

Notes

This is a hack for this to work with duck-typing with *LinearSpace*'s.

Methods

__contains__(other)	Test if `other` is a complex number.
__eq__(other)	Return `self == other`.
contains_all(array)	Test if `array` is an array of real or complex numbers.
contains_set(other)	Test if `other` is a subset of the complex numbers
element([inp])	Return a complex number from `inp` or from scratch.

ComplexNumbers.__contains__

ComplexNumbers.**__contains__**(*other*)
Test if `other` is a complex number.

ComplexNumbers.__eq__

ComplexNumbers.**__eq__**(*other*)
Return `self == other`.

ComplexNumbers.contains_all

ComplexNumbers.**contains_all**(*array*)
Test if `array` is an array of real or complex numbers.

ComplexNumbers.contains_set

ComplexNumbers.**contains_set**(*other*)
Test if `other` is a subset of the complex numbers

Returnscontained : `bool`

`True` if other is *ComplexNumbers*, *RealNumbers* or *Integers*, `False` else.

Examples

```
>>> C = ComplexNumbers()
>>> C.contains_set(RealNumbers())
True
```

ComplexNumbers.element

ComplexNumbers.**element**(*inp=None*)
Return a complex number from `inp` or from scratch.

EmptySet

class odl.set.sets.**EmptySet**
Bases: *odl.set.sets.Set*

The empty set.

`None` is considered as "no element", i.e. `None in EmptySet()` is `True`

Methods

__contains__(other)	Test if `other` is `None`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Return `True` for the empty set, otherwise `False`.
element([inp])	Return `None`.

EmptySet.__contains__

EmptySet.**__contains__**(*other*)
Test if `other` is `None`.

EmptySet.__eq__

EmptySet.**__eq__**(*other*)
Return `self == other`.

EmptySet.contains_all

EmptySet.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

EmptySet.contains_set

EmptySet.**contains_set**(*other*)
Return `True` for the empty set, otherwise `False`.

EmptySet.element

EmptySet.**element**(*inp=None*)
Return `None`.

Field

class odl.set.sets.**Field**
Bases: *odl.set.sets.Set*

Any set that satisfies the field axioms

For example *RealNumbers*, *ComplexNumbers* or the finite field F_2.

Attributes

field	The field of scalars for a field is itself.

Field.field

Field.**field**
The field of scalars for a field is itself.

Notes

This is a hack for this to work with duck-typing with *LinearSpace*'s.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([inp])	Return an element from `inp` or from scratch.

Field.__contains__

Field.**__contains__**(*other*)
Return `other in self`.

Field.__eq__

Field.**__eq__**(*other*)
Return `self == other`.

Field.contains_all

Field.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

Field.contains_set

Field.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

Field.element

Field.**element**(*inp=None*)
Return an element from `inp` or from scratch.

Implementing this method is optional.

Integers

class odl.set.sets.**Integers**
Bases: *odl.set.sets.Set*

The set of integers.

Methods

__contains__(other)	Test if `other` is an integer.
__eq__(other)	Return `self == other`.
contains_all(array)	Test if `array` is an array of integers.
contains_set(other)	Test if `other` is a subset of the real numbers
element([inp])	Return an integer from `inp` or from scratch.

Integers.__contains__

Integers.**__contains__**(*other*)
Test if `other` is an integer.

Integers.__eq__

Integers.**__eq__**(*other*)
Return `self == other`.

Integers.contains_all

Integers.**contains_all**(*array*)
Test if `array` is an array of integers.

Integers.contains_set

Integers.**contains_set**(*other*)
Test if `other` is a subset of the real numbers

Returnscontained : `bool`

`True` if other is *Integers*, `False` otherwise.

Examples

```
>>> Z = Integers()
>>> Z.contains_set(RealNumbers())
False
```

Integers.element

Integers.**element**(*inp=None*)
Return an integer from inp or from scratch.

RealNumbers

class odl.set.sets.**RealNumbers**
Bases: *odl.set.sets.Field*

The set of real numbers.

Attributes

field	The field of scalars for a field is itself.

RealNumbers.field

RealNumbers.**field**
The field of scalars for a field is itself.

Notes

This is a hack for this to work with duck-typing with *LinearSpace*'s.

Methods

__contains__(other)	Test if other is a real number.
__eq__(other)	Return self == other.
contains_all(array)	Test if array is an array of real numbers.
contains_set(other)	Test if other is a subset of the real numbers
element([inp])	Return a real number from inp or from scratch.

RealNumbers.__contains__

RealNumbers.**__contains__**(*other*)
Test if other is a real number.

RealNumbers.__eq__

RealNumbers.**__eq__**(*other*)
Return `self == other`.

RealNumbers.contains_all

RealNumbers.**contains_all**(*array*)
Test if `array` is an array of real numbers.

RealNumbers.contains_set

RealNumbers.**contains_set**(*other*)
Test if `other` is a subset of the real numbers

Returnscontained : `bool`

`True` if other is *RealNumbers* or *Integers* `False` else.

Examples

```
>>> R = RealNumbers()
>>> R.contains_set(RealNumbers())
True
```

RealNumbers.element

RealNumbers.**element**(*inp=None*)
Return a real number from `inp` or from scratch.

Set

class odl.set.sets.**Set**
Bases: `object`

An abstract set.

Abstract Methods

Each subclass of *Set* must implement two methods: one to check if an object is contained in the set and one to test if two sets are equal.

Membership test: `__contains__(self, other)`

Test if `other` is a member of this set. This function provides the operator overload for `in`.

Parameters:

other[`object`] The object to be tested for membership

Returns:

contains[`bool`] `True` if `other` is a member of this set, `False` otherwise.

Equality test: `__eq__(self, other)`

Test if `other` is the same set as this set, i.e. both sets are of the same type and contain the same elements. This function provides the operator overload for ==.

Parameters:

other[`object`] The object to be tested for equality.

Returns:

equals[`bool`] `True` if both sets are of the same type and contain the same elements, `False` otherwise.

A default implementation of the operator overload for `!=` via `__ne__(self, other)` is provided as `not self.__eq__(other)`.

Element creation (optional): `element(self, inp=None)`

Create an element of this set, either from scratch or from an input parameter.

Parameters:

inp[`object`, optional] The object from which to create the new element

Returns:

element[member of this set] If `inp` is `None`, return an arbitrary element. Otherwise, return the element created from `inp`.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([inp])	Return an element from `inp` or from scratch.

Set.__contains__

Set.**__contains__**(*other*)
Return `other in self`.

Set.__eq__

Set.**__eq__**(*other*)
Return `self == other`.

Set.contains_all

Set.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

Set.contains_set

Set.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

Set.element

Set.**element**(*inp=None*)
Return an element from `inp` or from scratch.

Implementing this method is optional.

Strings

class odl.set.sets.**Strings**(*length*)
Bases: *odl.set.sets.Set*

The set of fixed-length (unicode) strings.

Attributes

length	The length attribute.

Strings.length

Strings.**length**
The length attribute.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(array)	Test if `array` is an array of strings with correct length.
contains_set(other)	Test if `other` is a subset of this set.
element([inp])	Return a string from `inp` or from scratch.

Strings.__contains__

Strings.**__contains__**(*other*)
Return `other in self`.

`True` if `other` is a string of at max *length* characters, `False` otherwise.

Strings.__eq__

Strings.**__eq__**(*other*)
Return `self == other`.

Strings.contains_all

Strings.**contains_all**(*array*)
Test if `array` is an array of strings with correct length.

Strings.contains_set

Strings.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

Strings.element

Strings.**element**(*inp=None*)
Return a string from `inp` or from scratch.

__init__(*length*)
Initialize a new instance.

Parameterslength : `int`

The fixed length of the strings in this set. Must be positive.

UniversalSet

class odl.set.sets.**UniversalSet**
Bases: *odl.set.sets.Set*

The set of all objects.

Forget about set theory for a moment :-).

Methods

__contains__(other)	Return `True`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Return `True` for any set.
element([inp])	Return `inp` in any case.

UniversalSet.__contains__

UniversalSet.**__contains__**(*other*)
Return `True`.

UniversalSet.__eq__

UniversalSet.**__eq__**(*other*)
Return `self == other`.

UniversalSet.contains_all

UniversalSet.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

UniversalSet.contains_set

UniversalSet.**contains_set**(*other*)
Return `True` for any set.

UniversalSet.element

UniversalSet.**element**(*inp=None*)
Return `inp` in any case.

8.4.4 space

Abstract linear vector spaces.

Classes

LinearSpace(field)	Abstract linear vector space.
LinearSpaceNotImplementedError	Exception for not implemented errors in *LinearSpace*'s.
LinearSpaceTypeError	Exception for type errors in *LinearSpace*'s.
LinearSpaceVector(space)	Abstract *LinearSpace* element.
UniversalSpace()	A dummy linear space class.

LinearSpace

class odl.set.space.**LinearSpace**(*field*)
Bases: *odl.set.sets.Set*

Abstract linear vector space.

Its elements are represented as instances of the inner *LinearSpaceVector* class.

Attributes

element_type	*LinearSpaceVector*
field	The field of this vector space.

LinearSpace.element_type

LinearSpace.**element_type**
LinearSpaceVector

LinearSpace.field

LinearSpace.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
_dist(x1, x2)	Calculate the distance between x1 and x2.
_inner(x1, x2)	Calculate the inner product of x1 and x2.
_lincomb(a, x1, b, x2, out)	Calculate `out = a*x1 + b*x2`.
_multiply(x1, x2, out)	Calculate the pointwise multiplication out = x1 * x2.
_norm(x)	Calculate the norm of x.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp])	Create a *LinearSpaceVector* from `inp` or from scratch.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	A one vector in this space.
zero()	A zero vector in this space.

LinearSpace.__contains__

LinearSpace.**__contains__**(*other*)
Return `other in self`.

Returnscontains : `bool`

`True` if `other` is a *LinearSpaceVector* instance and `other.space` is equal to this space, `False` otherwise.

Notes

This is the strict default where spaces must be equal. Subclasses may choose to implement a less strict check.

LinearSpace.__eq__

LinearSpace.**__eq__**(*other*)
Return `self == other`.

LinearSpace._dist

LinearSpace.**_dist**(*x1*, *x2*)
Calculate the distance between x1 and x2.

This method is intended to be private, public callers should resort to *dist* which is type-checked.

LinearSpace._inner

LinearSpace.**_inner**(*x1*, *x2*)
Calculate the inner product of x1 and x2.

This method is intended to be private, public callers should resort to *inner* which is type-checked.

LinearSpace._lincomb

LinearSpace.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)
Calculate `out = a*x1 + b*x2`.

This method is intended to be private, public callers should resort to *lincomb* which is type-checked.

LinearSpace._multiply

LinearSpace.**_multiply**(*x1*, *x2*, *out*)
Calculate the pointwise multiplication out = x1 * x2.

This method is intended to be private, public callers should resort to *multiply* which is type-checked.

LinearSpace._norm

LinearSpace.**_norm**(*x*)
Calculate the norm of x.

This method is intended to be private, public callers should resort to *norm* which is type-checked.

LinearSpace.contains_all

LinearSpace.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

LinearSpace.contains_set

LinearSpace.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

LinearSpace.dist

LinearSpace.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

LinearSpace.divide

LinearSpace.**divide**(*x1*, *x2*, *out=None*)
Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

LinearSpace.element

LinearSpace.**element**(*inp=None*, ***kwargs*)
Create a *LinearSpaceVector* from `inp` or from scratch.

If called without `inp` argument, an arbitrary element of the space is generated without guarantee of its state.

Parametersinp : optional

Input data from which to create the element

kwargs :

Optional further arguments

Returnselement : *LinearSpaceVector*

A vector in this space

LinearSpace.inner

LinearSpace.**inner**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

LinearSpace.lincomb

LinearSpace.**lincomb**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

LinearSpace.multiply

LinearSpace.**multiply**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

LinearSpace.norm

LinearSpace.**norm**(*x*)

Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

LinearSpace.one

LinearSpace.**one**()

A one vector in this space.

The one vector is defined as the multiplicative unit of a space.

Returnsv : *LinearSpaceVector*

The one vector of this space

LinearSpace.zero

LinearSpace.**zero**()

A zero vector in this space.

The zero vector is defined as the additive unit of a space.

Returnsv : *LinearSpaceVector*

The zero vector of this space

__init__(*field*)

Initialize a LinearSpace.

This method should be called by all inheriting methods so that the field property of the space is set properly.

Parametersfield : *Field*

The underlying scalar field of the space

LinearSpaceNotImplementedError

exception odl.set.space.**LinearSpaceNotImplementedError**
Exception for not implemented errors in *LinearSpace*'s.

These are raised when a method in *LinearSpace* that has not been defined in a specific space is called.

LinearSpaceTypeError

exception odl.set.space.**LinearSpaceTypeError**
Exception for type errors in *LinearSpace*'s.

These are raised when the wrong type of element is fed to *LinearSpace.lincomb* and related functions.

LinearSpaceVector

class odl.set.space.**LinearSpaceVector**(*space*)
Bases: object

Abstract *LinearSpace* element.

Not intended for creation of vectors, use the space's *LinearSpace.element* method instead.

Attributes

T	The transpose of a vector, the functional given by (.
space	Space to which this vector belongs.

LinearSpaceVector.T

LinearSpaceVector.**T**
The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

LinearSpaceVector.space

`LinearSpaceVector.`**`space`**
Space to which this vector belongs.

LinearSpace

Methods

__eq__(other)	Return `self == other`.
assign(other)	Assign the values of `other` to self.
copy()	Create an identical (deep) copy of self.
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
set_zero()	Set this vector to zero.

LinearSpaceVector.__eq__

`LinearSpaceVector.`**`__eq__`**(*other*)
Return `self == other`.

Two vectors are equal if their distance is 0

Parametersother : *LinearSpaceVector*

Vector in this space.

Returnsequals : `bool`

True if the vectors are equal, else false.

Notes

Equality is very sensitive to numerical errors, thus any operations on a vector should be expected to break equality testing.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(1, norm=np.linalg.norm)
>>> x = rn.element([0.1])
>>> x == x
True
>>> y = rn.element([0.1])
>>> x == y
True
>>> z = rn.element([0.3])
```

```
>>> x+x+x == z
False
```

LinearSpaceVector.assign

LinearSpaceVector.**assign**(*other*)
Assign the values of `other` to self.

LinearSpaceVector.copy

LinearSpaceVector.**copy**()
Create an identical (deep) copy of self.

LinearSpaceVector.dist

LinearSpaceVector.**dist**(*other*)
Distance to `other`.

LinearSpace.dist

LinearSpaceVector.divide

LinearSpaceVector.**divide**(*x*, *y*)
Divide by `other` inplace.

LinearSpace.divide

LinearSpaceVector.inner

LinearSpaceVector.**inner**(*other*)
Inner product with `other`.

LinearSpace.inner

LinearSpaceVector.lincomb

LinearSpaceVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

LinearSpaceVector.multiply

LinearSpaceVector.**multiply**(*x*, *y*)
Multiply by `other` inplace.

LinearSpace.multiply

LinearSpaceVector.norm

LinearSpaceVector.**norm**()
Norm of vector

LinearSpace.norm

LinearSpaceVector.set_zero

LinearSpaceVector.**set_zero**()
Set this vector to zero.

LinearSpace.zero

__init__(*space*)
Default initializer of vectors.

All deriving classes must call this method to set space.

UniversalSpace

class odl.set.space.**UniversalSpace**
Bases: *odl.set.space.LinearSpace*

A dummy linear space class.

Mostly raising *LinearSpaceNotImplementedError*.

Attributes

element_type	*LinearSpaceVector*
field	The field of this vector space.

UniversalSpace.element_type

UniversalSpace.**element_type**
LinearSpaceVector

UniversalSpace.field

UniversalSpace.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
_dist(x1, x2)	Dummy distance method.
_divide(x1, x2, out)	Dummy division method.
_inner(x1, x2)	Dummy inner product method.
_lincomb(a, x1, b, x2, out)	Dummy linear combination.
_multiply(x1, x2, out)	Dummy multiplication method.
_norm(x)	Dummy norm method.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp])	Dummy element creation method.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	A one vector in this space.
zero()	A zero vector in this space.

UniversalSpace.__contains__

UniversalSpace.**__contains__**(*other*)

Return `other in self`.

Dummy membership check, `True` for any *LinearSpaceVector*.

UniversalSpace.__eq__

UniversalSpace.**__eq__**(*other*)

Return `self == other`.

Dummy check, `True` for any *LinearSpace*.

UniversalSpace._dist

UniversalSpace.**_dist**(*x1*, *x2*)

Dummy distance method.

raises *LinearSpaceNotImplementedError*.

UniversalSpace._divide

UniversalSpace.**_divide**(*x1*, *x2*, *out*)

Dummy division method.

raises *LinearSpaceNotImplementedError*.

UniversalSpace._inner

UniversalSpace.**_inner**(*x1*, *x2*)
Dummy inner product method.

raises *LinearSpaceNotImplementedError*.

UniversalSpace._lincomb

UniversalSpace.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)
Dummy linear combination.

raises *LinearSpaceNotImplementedError*.

UniversalSpace._multiply

UniversalSpace.**_multiply**(*x1*, *x2*, *out*)
Dummy multiplication method.

raises *LinearSpaceNotImplementedError*.

UniversalSpace._norm

UniversalSpace.**_norm**(*x*)
Dummy norm method.

raises *LinearSpaceNotImplementedError*.

UniversalSpace.contains_all

UniversalSpace.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

UniversalSpace.contains_set

UniversalSpace.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

UniversalSpace.dist

UniversalSpace.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

UniversalSpace.divide

UniversalSpace.**divide**(*x1*, *x2*, *out=None*)

Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

UniversalSpace.element

UniversalSpace.**element**(*inp=None*)

Dummy element creation method.

raises *LinearSpaceNotImplementedError*.

UniversalSpace.inner

UniversalSpace.**inner**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

UniversalSpace.lincomb

UniversalSpace.**lincomb**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

UniversalSpace.multiply

`UniversalSpace.`**`multiply`**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

UniversalSpace.norm

`UniversalSpace.`**`norm`**(*x*)

Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

UniversalSpace.one

UniversalSpace.**one**()
A one vector in this space.

The one vector is defined as the multiplicative unit of a space.

Returnsv : *LinearSpaceVector*

The one vector of this space

UniversalSpace.zero

UniversalSpace.**zero**()
A zero vector in this space.

The zero vector is defined as the additive unit of a space.

Returnsv : *LinearSpaceVector*

The zero vector of this space

__init__()
Initialize a universal space

8.5 solvers

Modules

8.5.1 advanced

Modules

chambolle_pock

First-order primal-dual algorithm developed by Chambolle and Pock.

The Chambolle-Pock algorithm is a flexible method well suited for non-smooth convex optimization problems in imaging. It was first proposed in *[CP2011a]*.

Functions

chambolle_pock_solver(op, x, tau, sigma, ...)	Chambolle-Pock algorithm for non-smooth convex optimization problems.

chambolle_pock_solver

odl.solvers.advanced.chambolle_pock.**chambolle_pock_solver**(*op*, *x*, *tau*, *sigma*, *proximal_primal*, *proximal_dual*, *niter=1*, ***kwargs*)
Chambolle-Pock algorithm for non-smooth convex optimization problems.

First order primal-dual hybrid-gradient method for non-smooth convex optimization problems with known saddle-point structure. The primal formulation of the general problem is:

```
min_{x in X} F(K x) + G(x)
```

where `X` and `Y` are finite-dimensional Hilbert spaces, `K` is a linear operator `K : X -> Y`. and `G : X -> [0, +inf]` and `F : Y -> [0, +inf]` are proper, convex, lower-semicontinuous functionals.

The Chambolle-Pock algorithm basically consists of alternating a gradient ascent in the dual variable y and a gradient descent in the primal variable x. The proximal operator is used to generate a ascent direction for the convex conjugate of F and descent direction for G. Additionally an over-relaxation in the primal variable is performed.

Parametersop : *Operator*

A (product space) operator between Hilbert spaces with domain X and range Y

x : element in the domain of `op`

Starting point of the iteration

tau : positive `float`

Step size parameter for the update of the primal variable x. Controls the extent to which `proximal_primal` maps points towards the minimum of G.

sigma : positive `float`

Step size parameter for the update of the dual variable y. Controls the extent to which `proximal_dual` maps points towards the minimum of F_cc.

proximal_primal : `callable`

Evaluated at `tau`, the function returns the proximal operator, prox_tau[G](x), of the functional G. The domain of G and its proximal operator instance are the space, X, of the primal variable x i.e. the domain of `op`.

proximal_dual : `callable`

Evaluated at `sigma`, the function returns the proximal operator, prox_sigma[F_cc](x), of the convex conjugate, F_cc, of the function F. The domain of F_cc and its proximal operator instance are the space, Y, of the dual variable y i.e. the range of `op`.

niter : non-negative `int`, optional

Number of iterations

Other Parameterstheta : `float` in [0, 1], optional

Relaxation parameter. Default: 1

gamma : non-negative `float`, optional

Acceleration parameter. If not `None` overwrites `theta` and uses variable relaxation parameter and step sizes with `tau` and `sigma` as initial values. Requires G or F_cc to be uniformly convex. Default: `None`

partial : *Partial*, optional

If not `None` the *Partial* instance(s) are executed in each iteration, e.g. plotting each iterate. Default: `None`

x_relax : element in the domain of `op`, optional

Required to resume iteration. If `None` it is a copy of the primal variable x. Default: `None`

y : element in the range of `op`, optional

Required to resume iteration. If `None` it is set to a zero element in Y which is the range of `op`. Default: `None`

Notes

For a more detailed documentation see chambolle_pock.

For references on the Chambolle-Pock algorithm see *[CP2011a]* and *[CP2011b]*.

This implementation of the CP algorithm is along the lines of *[Sid+2012]*.

For more on convex analysis including convex conjugates and resolvent operators see *[Roc1970]*.

For more on proximal operators and algorithms see *[PB2014]*.

proximal_operators

Factory functions for creating proximal operators.

For more details see proximal_operators and references therein. For more details on proximal operators including how to evaluate the proximal operator of a variety of functions see *[PB2014]*.

Functions

combine_proximals(factory_list)	Combine proximal operators into a diagonal product space operator.
proximal_convexconjugate_l1(space[, lam, g])	Proximal operator factory of the convex conjugate of the l1-semi-norm.
proximal_convexconjugate_l2(space[, lam, g])	Proximal operator factory of the convex conjugate of the l2-norm.
proximal_nonnegativity(space)	Function to create the proximal operator of G(x) = ind(x > 0).
proximal_zero(space)	Function to create the proximal operator of G(x) = 0.

combine_proximals

odl.solvers.advanced.proximal_operators.**combine_proximals**(*factory_list*)

Combine proximal operators into a diagonal product space operator.

This assumes the functional to be separable across variables in order to make use of the separable sum property of proximal operators.

prox_tau[f(x) + g(y)](x, y) = (prox_tau[f](x), prox_tau[g](y))

Parametersfactory_list : list of *Operator*

A list containing proximal operators which are created by the corresponding factory functions

Returnsdiag_op : *Operator*

Returns a diagonal product space operator to be initialized with the same step size parameter

proximal_convexconjugate_l1

odl.solvers.advanced.proximal_operators.**proximal_convexconjugate_l1**(*space*, *lam=1*, *g=None*)

Proximal operator factory of the convex conjugate of the l1-semi-norm.

Function for the proximal operator of the convex conjugate of the functional F where F is an l1-semi-norm

F(x) = lam || ||x-g||_p ||_1

with x and g elements in `space`, scaling factor lam, and point-wise magnitude ||x||_p of x. If x is vector-valued, ||x||_p is the point-wise l2-norm across the vector components.

The convex conjugate, F_cc, of F is given by the indicator function of the set box(lam)

F_cc(y) = lam ind_{box(lam)}(||y / lam||_p + <y / lam, g>)

where box(lam) is a hypercube centered at the origin with width 2 lam.

The proximal operator of F_cc is

prox_sigma[F_cc](y) = lam (y - sigma g) / (max(lam 1_{||y||_p}, ||y - sigma g||_p)

where max(.,.) thresholds the lower bound of ||y||_p point-wise and 1_{||y||_p} is a unit vector in the space of ||y||_p.

Parametersspace : *DiscreteLp* or *ProductSpace* of *DiscreteLp* spaces

Domain of the functional F

g : *DiscreteLpVector*

An element in `space`

lam : positive `float`

Scaling factor or regularization parameter

Returnsprox : *Operator*

Returns the proximal operator to be initialized

proximal_convexconjugate_l2

odl.solvers.advanced.proximal_operators.**proximal_convexconjugate_l2**(*space*, *lam=1*, *g=None*)

Proximal operator factory of the convex conjugate of the l2-norm.

Function for the proximal operator of the convex conjugate of the functional F where F is the l2-norm

F(x) = lam 1/2 ||x - g||_2^2

with x and g elements in `space`, scaling factor lam, and given data g.

The convex conjugate, F_cc, of F is given by

F_cc(y) = 1/lam (1/2 ||y/lam||_2^2 + <y/lam,g>)

The proximal operator of F_cc is given by

prox_sigma[F_cc](y) = (y - sigma g) / (1 + sigma/lam)

Parametersspace : *DiscreteLp* or *ProductSpace* of *DiscreteLp*

Domain of F(x)

g : *DiscreteLpVector*

An element in `space`

lam : positive `float`

Scaling factor or regularization parameter

Returnsprox : *Operator*

Returns the proximal operator to be initialized

proximal_nonnegativity

`odl.solvers.advanced.proximal_operators.`**`proximal_nonnegativity`**(*space*)

Function to create the proximal operator of G(x) = ind(x > 0).

Function for the proximal operator of the functional G(x)=ind(x > 0) to be initialized.

If P is the set of non-negative elements, the indicator function of which is defined as

ind(x > 0) = {0 if x in P, infinity if x is not in P}

with x being an element in `space`.

The proximal operator of G is the point-wise non-negativity thresholding of x

prox_tau[G](x) = {x if x > 0, 0 if <= 0}

It is independent of tau and invariant under a positive rescaling of G which leaves the indicator function as it stands.

Parametersspace : *DiscreteLp* or *ProductSpace* of *DiscreteLp*

Domain of the functional G(x)

Returnsprox : *Operator*

Returns the proximal operator to be initialized

proximal_zero

`odl.solvers.advanced.proximal_operators.`**`proximal_zero`**(*space*)

Function to create the proximal operator of G(x) = 0.

Function to initialize the proximal operator of G(x) = 0 where x is an element in `space`. The proximal operator of this functional is the identity operator

prox_tau[G](x) = x

It is independent of tau.

Parametersspace : *DiscreteLp* or *ProductSpace* of *DiscreteLp* spaces

Domain of the functional G

Returnsprox : *Operator*

Returns the proximal operator to be initialized

8.5.2 findroot

Modules

newton

(Quasi-)Newton schemes to find zeros of functions (gradients).

Functions

bfgs_method(grad, x, line_search[, niter, ...])	Quasi-Newton BFGS method to minimize a differentiable function.
broydens_first_method(grad, x, line_search)	Broyden's first method, a quasi-Newton scheme.
broydens_second_method(grad, x, line_search)	Broyden's first method, a quasi-Newton scheme.

bfgs_method

odl.solvers.findroot.newton.**bfgs_method**(*grad*, *x*, *line_search*, *niter=1*, *partial=None*)

Quasi-Newton BFGS method to minimize a differentiable function.

This is a general and optimized implementation of a quasi-Newton method with BFGS update for solving a general unconstrained optimization problem

$$\min f(x)$$

for a differentiable function $f : \mathcal{X} \to \mathbb{R}$ on a Hilbert space $\mathcal{X}$. It does so by finding a zero of the gradient

$$\nabla f : \mathcal{X} \to \mathcal{X}.$$

The QN method is an approximate Newton method, where the Hessian is approximated and gradually updated in each step. This implementation uses the rank-one BFGS update schema where the inverse of the Hessian is recalculated in each iteration.

The algorithm is described in *[GNS2009]*, Section 12.3 and in the BFGS Wikipedia article

Parametersgrad : *Operator*

Gradient mapping of the objective function, i.e. the mapping $x \mapsto \nabla f(x) \in \mathcal{X}$

x : *element* of the domain of grad

Starting point of the iteration

line_search : *LineSearch*

Strategy to choose the step length

niter : int, optional

Number of iterations

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

ReturnsNone

broydens_first_method

odl.solvers.findroot.newton.**broydens_first_method**(*grad*, *x*, *line_search*, *niter=1*, *partial=None*)

Broyden's first method, a quasi-Newton scheme.

This is a general and optimized implementation of Broyden's first (or 'good') method, a quasi-Newton method for solving a general unconstrained optimization problem

$$\min f(x)$$

for a differentiable function $f : \mathcal{X} \to \mathbb{R}$ on a Hilbert space $\mathcal{X}$. It does so by finding a zero of the gradient

$$\nabla f : \mathcal{X} \to \mathcal{X}$$

using a Newton-type update scheme with approximate Hessian.

The algorithm is described in *[Bro1965]* and *[Kva1991]*, and in a Wikipedia article.

Parametersgrad : *Operator*

Gradient mapping of the objective function, i.e. the mapping $x \mapsto \nabla f(x) \in \mathcal{X}$

x : *element* of the domain of grad

Starting point of the iteration

line_search : *LineSearch*

Strategy to choose the step length

niter : int, optional

Number of iterations

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

ReturnsNone

broydens_second_method

odl.solvers.findroot.newton.**broydens_second_method**(*grad*, *x*, *line_search*, *niter=1*, *partial=None*)

Broyden's first method, a quasi-Newton scheme.

This is a general and optimized implementation of Broyden's second (or 'bad') method, a quasi-Newton method for solving a general unconstrained optimization problem

$$\min f(x)$$

for a differentiable function $f : \mathcal{X} \to \mathbb{R}$ on a Hilbert space $\mathcal{X}$. It does so by finding a zero of the gradient

$$\nabla f : \mathcal{X} \to \mathcal{X}$$

using a Newton-type update scheme with approximate Hessian.

The algorithm is described in *[Bro1965]* and *[Kva1991]*, and in a Wikipedia article

Parametersgrad : *Operator*

Gradient mapping of the objective function, i.e. the mapping $x \mapsto \nabla f(x) \in \mathcal{X}$

x : *element* of the domain of grad

Starting point of the iteration

line_search : *LineSearch*

Strategy to choose the step length

niter : int, optional

Number of iterations

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

8.5.3 iterative

Modules

iterative

Simple iterative type optimization schemes.

Functions

conjugate_gradient(op, x, rhs[, niter, partial])	Optimized implementation of CG for self-adjoint operators.
conjugate_gradient_normal(op, x, rhs[, ...])	Optimized implementation of CG for the normal equation.
exp_zero_seq(base)	The default exponential zero sequence.
gauss_newton(op, x, rhs[, niter, zero_seq, ...])	Optimized implementation of a Gauss-Newton method.
landweber(op, x, rhs[, niter, omega, ...])	Optimized implementation of Landweber's method.

conjugate_gradient

odl.solvers.iterative.iterative.**conjugate_gradient**(*op*, *x*, *rhs*, *niter=1*, *partial=None*)

Optimized implementation of CG for self-adjoint operators.

This method solves the inverse problem (of the first kind)

$Ax = y$

for a linear and self-adjoint *Operator* A.

It uses a minimum amount of memory copies by applying re-usable temporaries and in-place evaluation.

The method is described (for linear systems) in a Wikipedia article.

Parametersop : linear *Operator*

Operator in the inverse problem. It must be linear and self-adjoint. This implies in particular that its domain and range are equal.

x : *element* of the domain of op

Vector to which the result is written. Its initial value is used as starting point of the iteration, and its values are updated in each iteration step.

rhs : *element* of the range of op

Right-hand side of the equation defining the inverse problem

niter : int, optional

Maximum number of iterations

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

Returns None

See also:

conjugate_gradient_normal Solver for nonsymmetric matrices

conjugate_gradient_normal

odl.solvers.iterative.iterative.**conjugate_gradient_normal**(*op*, *x*, *rhs*, *niter=1*, *partial=None*)

Optimized implementation of CG for the normal equation.

This method solves the normal equation

$A^*Ax = A^*y$

to the inverse problem (of the first kind)

$Ax = y$

with a linear *Operator* A.

It uses a minimum amount of memory copies by applying re-usable temporaries and in-place evaluation.

The method is described (for linear systems) in a Wikipedia article.

Parametersop : *Operator*

Operator in the inverse problem. If not linear, it must have an implementation of *Operator.derivative*, which in turn must implement *Operator.adjoint*, i.e. the call `op.derivative(x).adjoint` must be valid.

x : *element* of the domain of op

Vector to which the result is written. Its initial value is used as starting point of the iteration, and its values are updated in each iteration step.

rhs : *element* of the range of op

Right-hand side of the equation defining the inverse problem

niter : int, optional

Maximum number of iterations

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

Returns None

See also:

conjugate_gradient Optimized solver for symmetric matrices

exp_zero_seq

odl.solvers.iterative.iterative.**exp_zero_seq**(*base*)

The default exponential zero sequence.

It is defined by

t_0 = 1.0 t_m = t_(m-1) / base

or, in closed form

t_m = base^(-m-1)

Parametersbase : `float`

Base of the sequence. Its absolute value must be larger than 1.

Yieldsval : `float`

The next value in the exponential sequence

gauss_newton

odl.solvers.iterative.iterative.**gauss_newton**(*op*, *x*, *rhs*, *niter=1*, *zero_seq=<generator object exp_zero_seq>*, *partial=None*)

Optimized implementation of a Gauss-Newton method.

This method solves the inverse problem (of the first kind)

$A(x) = y$

for a (Frechet-) differentiable *Operator* `A` using a Gauss-Newton iteration.

It uses a minimum amount of memory copies by applying re-usable temporaries and in-place evaluation.

A variant of the method applied to a specific problem is described in a Wikipedia article.

Parametersop : *Operator*

Operator in the inverse problem. If not linear, it must have an implementation of *Operator.derivative*, which in turn must implement *Operator.adjoint*, i.e. the call `op.derivative(x).adjoint` must be valid.

x : *element* of the domain of `op`

Vector to which the result is written. Its initial value is used as starting point of the iteration, and its values are updated in each iteration step.

rhs : *element* of the range of `op`

Right-hand side of the equation defining the inverse problem

niter : `int`, optional

Maximum number of iterations

zero_seq : `iterable`, optional

Zero sequence whose values are used for the regularization of the linearized problem in each Newton step

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

ReturnsNone

landweber

odl.solvers.iterative.iterative.**landweber**(*op*, *x*, *rhs*, *niter=1*, *omega=1*, *projection=None*, *partial=None*)

Optimized implementation of Landweber's method.

This method calculates an approximate least-squares solution of the inverse problem of the first kind

$$\mathcal{A}(x) = y,$$

for a given $y \in \mathcal{Y}$, i.e. an approximate solution x^* to

$$\min_{x \in \mathcal{X}} \|\mathcal{A}(x) - y\|_{\mathcal{Y}}^2$$

for a (Frechet-) differentiable operator $\mathcal{A} : \mathcal{X} \to \mathcal{Y}$ between Hilbert spaces $\mathcal{X}$ and $\mathcal{Y}$. The method starts from an initial guess x_0 and uses the iteration

$$x_{k+1} = x_k - \omega \, \partial\mathcal{A}(x)^*(\mathcal{A}(x_k) - y),$$

where $\partial\mathcal{A}(x)$ is the Frechet derivativ of $\mathcal{A}$ at x and ω is a relaxation parameter. For linear problems, a choice $0 < \omega < 2/\|\mathcal{A}\|$ guarantees convergence, where $\|\mathcal{A}\|$ stands for the operator norm of $\mathcal{A}$.

Users may also optionally provide a projection to project each iterate onto some subset. For example enforcing positivity.

This implementation uses a minimum amount of memory copies by applying re-usable temporaries and in-place evaluation.

The method is also described in a Wikipedia article.

Parameters

op : *Operator*

Operator in the inverse problem. It must have a *Operator.derivative* property, which returns a new operator which in turn has an *Operator.adjoint* property, i.e. `op.derivative(x).adjoint` must be well-defined for `x` in the operator domain.

x : *element* of the domain of `op`

Vector to which the result is written. Its initial value is used as starting point of the iteration, and its values are updated in each iteration step.

rhs : *element* of the range of `op`

Right-hand side of the equation defining the inverse problem

niter : `int`, optional

Maximum number of iterations

omega : positive `float`, optional

Relaxation parameter in the iteration

projection : `callable`, optional

Function that can be used to modify the iterates in each iteration, for example enforcing positivity. The function should take one argument and modify it in place.

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

ReturnsNone

8.5.4 linear

8.5.5 scalar

Gradient-based optimization schemes.

Modules

gradient

Gradient-based optimization schemes.

Functions

steepest_descent(grad, x[, niter, ...])	Steepest descent method to minimize an objective function.

steepest_descent

odl.solvers.scalar.gradient.**steepest_descent**(*grad*, *x*, *niter=1*, *line_search=1*, *projection=None*, *partial=None*)

Steepest descent method to minimize an objective function.

General implementation of steepest decent (also known as gradient decent) for solving

$$\min f(x)$$

The algorithm is intended for unconstrained problems. It needs line search in order guarantee convergence. With appropriate line search, it can also be used for constrained problems where one wants to minimize over some given set C. This can be done by defining $f(x) = \infty$ for $x \notin C$, or by providing a `projection` function that projects the iterates on C.

The algorithm is described in *[BV2004]*, section 9.3–9.4 (book available online), *[GNS2009]*, Section 12.2, and wikipedia Gradient_descent.

Parametersgrad : *Operator*

Gradient of the objective function, $x \mapsto \nabla f(x)$

x : *element* of the domain of `deriv`

Starting point of the iteration

niter : `int`, optional

Number of iterations

line_search : float or *LineSearch*, optional

Strategy to choose the step length. If a float is given, uses it as a fixed step length.

projection : `callable`, optional

Function that can be used to modify the iterates in each iteration, for example enforcing positivity. The function should take one argument and modify it inplace.

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

See also:

odl.solvers.iterative.iterative.landweber Optimized solver for the case `f(x) = ||Ax - b||_2^2`

odl.solvers.iterative.iterative.conjugate_gradient Optimized solver for the case `f(x) = x^T Ax - 2 x^T b`

steplen

Step length computation for optimization schemes.

Classes

BacktrackingLineSearch(function[, tau, c, ...])	Backtracking line search for step length calculation.
BarzilaiBorweinStep(gradf[, step0])	Barzilai-Borwein method to compute a step length.
ConstantLineSearch(constant)	Line search object that returns a constant step length.
LineSearch	Abstract base class for line search step length methods.
StepLength	Abstract base class for step length methods.

BacktrackingLineSearch

class odl.solvers.scalar.steplen.**BacktrackingLineSearch**(*function*, *tau=0.5*, *c=0.01*, *max_num_iter=None*)

Bases: *odl.solvers.scalar.steplen.LineSearch*

Backtracking line search for step length calculation.

This methods approximately finds the longest step length fulfilling the Armijo-Goldstein condition.

The line search algorithm is described in *[BV2004]*, page 464 (book available online) and *[GNS2009]*, pages 378–379. See also Backtracking_line_search.

Methods

__call__(x, direction, dir_derivative)	Calculate the optimal step length along a line.
__eq__	Return self==value.

BacktrackingLineSearch.__call__

BacktrackingLineSearch.**__call__**(*x*, *direction*, *dir_derivative*)

Calculate the optimal step length along a line.

Parametersx : *Operator.domain element*

The current point

direction : *Operator.domain element*

Search direction in which the line search should be computed

dir_derivative : `float`

Directional derivative along the `direction`

Returnsstep : `float`

The computed step length

__init__ (*function*, *tau=0.5*, *c=0.01*, *max_num_iter=None*)

Initialize a new instance.

Parametersfunction : `callable`

The cost function of the optimization problem to be solved.

tau : `float`, optional

The amount the step length is decreased in each iteration, as long as it does not fulfill the decrease condition. The step length is updated as `step_length *= tau`

c : `float`, optional

The 'discount factor' on the `step length * direction derivative`, which the new point needs to be smaller than in order to fulfill the condition and be accepted (see the references).

max_num_iter : `int`, optional

Maximum number of iterations allowed each time the line search method is called. If not set, this number is calculated to allow a shortest step length of 0.0001.

BarzilaiBorweinStep

class `odl.solvers.scalar.steplen.`**BarzilaiBorweinStep** (*gradf*, *step0=0.0005*)

Bases: `object`

Barzilai-Borwein method to compute a step length.

Barzilai-Borwein method to compute a step length for gradient descent methods.

The method is described in *[BB1988]* and *[Ray1997]*.

Methods

__call__(x, x0)	Calculate the step length at a point.
__eq__	Return self==value.

BarzilaiBorweinStep.__call__

`BarzilaiBorweinStep.`**__call__** (*x*, *x0*)

Calculate the step length at a point.

Parametersx : *Operator.domain element*

The current point

x0 : *Operator.domain element*

The previous point

Returnsstep : `float`

The step length

__init__ (*gradf*, *step0=0.0005*)

Initialize a new instance.

Parametersgradf : *Operator*

The gradient of the objective function at a point

step0 : float, optional

Initial step length parameter

ConstantLineSearch

class odl.solvers.scalar.steplen.**ConstantLineSearch**(*constant*)

Bases: *odl.solvers.scalar.steplen.LineSearch*

Line search object that returns a constant step length.

Methods

__call__(x, direction, dir_derivative)	Calculate the step length at a point.
__eq__	Return self==value.

ConstantLineSearch.__call__

ConstantLineSearch.**__call__**(*x*, *direction*, *dir_derivative*)

Calculate the step length at a point.

Parametersx : *Operator.domain element*

The current point

direction : *Operator.domain element*

Search direction in which the line search should be computed

dir_derivative : float

Directional derivative along the direction

Returnsstep : float

The constant step length

__init__(*constant*)

Initialize a new instance.

Parametersconstant : float

The constant step length

LineSearch

class odl.solvers.scalar.steplen.**LineSearch**

Bases: object

Abstract base class for line search step length methods.

Methods

__call__(x, direction, dir_derivative)	Calculate step length in direction.
__eq__	Return self==value.

LineSearch.__call__
LineSearch.**__call__**(*x*, *direction*, *dir_derivative*)
Calculate step length in direction.

Parametersx : *Operator.domain element*

The current point

direction : *Operator.domain element*

Search direction in which the line search should be computed

dir_derivative : float

Directional derivative along the direction

Returnsstep : float

The step length

StepLength

class odl.solvers.scalar.steplen.**StepLength**
Bases: object

Abstract base class for step length methods.

Methods

__call__(x, direction, dir_derivative)	Calculate the step length at a point.
__eq__	Return self==value.

StepLength.__call__
StepLength.**__call__**(*x*, *direction*, *dir_derivative*)
Calculate the step length at a point.

Parametersx : *Operator.domain element*

The current point

direction : *Operator.domain element*

Search direction in which the line search should be computed

dir_derivative : float

Directional derivative along the direction

Returnsstep : float

The step length

8.5.6 util

Modules

partial

Partial objects for per-iterate actions in iterative methods.

Classes

AndPartial(*partials)	Partial used for combining several partials
ForEachPartial(function)	Simple object for applying a function to each iterate.
Partial	Abstract base class for sending partial results of iterations.
PrintIterationPartial([text])	Print the iteration count.
PrintNormPartial()	Print the current norm.
PrintTimingPartial()	Print the time elapsed since the previous iteration.
ShowPartial(**kwargs)	Show the partial result.
StorePartial([results])	Simple object for storing all partial results of the solvers.

AndPartial

class odl.solvers.util.partial.**AndPartial**(**partials*)
Bases: *odl.solvers.util.partial.Partial*

Partial used for combining several partials

Methods

__call__(result)	Apply all partials to result.
__eq__	Return self==value.

AndPartial.__call__
AndPartial.**__call__**(*result*)
Apply all partials to result.
__init__(**partials*)
Initialize an instance.

Parameters*partials : *Partial*'s

Partials to be called in sequence as listed.

ForEachPartial

class odl.solvers.util.partial.**ForEachPartial**(*function*)
Bases: *odl.solvers.util.partial.Partial*

Simple object for applying a function to each iterate.

Methods

__call__(result)	Apply function to result.
__eq__	Return self==value.

ForEachPartial.__call__
ForEachPartial.**__call__**(*result*)
Apply function to result.
__init__(*function*)
Initialize an instance.

Parametersfunction : callable

Function to call for each iteration

Partial

class odl.solvers.util.partial.**Partial**
Bases: object

Abstract base class for sending partial results of iterations.

Methods

__call__(result)	Apply the partial object to result.
__eq__	Return self==value.

Partial.__call__
Partial.**__call__**(*result*)
Apply the partial object to result.

Parametersresult : *LinearSpaceVector*

Partial result after n iterations

ReturnsNone

PrintIterationPartial

class odl.solvers.util.partial.**PrintIterationPartial**(*text=None*)
Bases: *odl.solvers.util.partial.Partial*

Print the iteration count.

Methods

__call__(_)	Print the current iteration.
__eq__	Return self==value.

PrintIterationPartial.__call__
`PrintIterationPartial.__call__(_)`
Print the current iteration.
__init__(*text=None*)
Initialize an instance.

Parameters
text : `str`

Text to display before the iteration count. Default: 'iter ='

PrintNormPartial

class `odl.solvers.util.partial.PrintNormPartial`
Bases: *odl.solvers.util.partial.Partial*

Print the current norm.

Methods

__call__(result)	Print the current norm.
__eq__	Return self==value.

PrintNormPartial.__call__
`PrintNormPartial.__call__(result)`
Print the current norm.
__init__()
Initialize an instance.

PrintTimingPartial

class `odl.solvers.util.partial.PrintTimingPartial`
Bases: *odl.solvers.util.partial.Partial*

Print the time elapsed since the previous iteration.

Methods

__call__(_)	Print time elapsed from the previous iteration.
__eq__	Return self==value.

PrintTimingPartial.__call__
`PrintTimingPartial.__call__(_)`
Print time elapsed from the previous iteration.
__init__()
Initialize an instance.

ShowPartial

class odl.solvers.util.partial.**ShowPartial**(***kwargs*)
Bases: *odl.solvers.util.partial.Partial*

Show the partial result.

Methods

__call__(x)	Show the current iterate.
__eq__	Return self==value.

ShowPartial.__call__
ShowPartial.**__call__**(*x*)
Show the current iterate.
__init__(***kwargs*)
Initialize a new instance.

Parameters are passed through to the vectors show method. Additional parameters included.

Parametersdisplay_step : positive int, optional

Number of iterations between plots. Default: 1

Other Parameterskwargs :

Optional arguments passed on to x.show

StorePartial

class odl.solvers.util.partial.**StorePartial**(*results=None*)
Bases: *odl.solvers.util.partial.Partial*

Simple object for storing all partial results of the solvers.

Attributes

results	The partial results.

StorePartial.results
StorePartial.**results**
The partial results.

Methods

__call__(result)	Append result to results list.
__eq__	Return self==value.
__getitem__(index)	Get partial result.

StorePartial.__call__
StorePartial.**__call__**(*result*)
Append result to results list.

StorePartial.__getitem__
StorePartial.**__getitem__**(*index*)
Get partial result.
__init__(*results=None*)
Initialize an instance.

Parametersresults : list

List in which to store the partial results. Default: new list ([])

8.5.7 vector

Modules

newton

Newton type optimization schemes.

Functions

newtons_method(op, x, line_search[, ...])	Newton's method for solving a system of equations.

newtons_method

odl.solvers.vector.newton.**newtons_method**(*op*, *x*, *line_search*, *num_iter=10*, *cg_iter=None*, *partial=None*)
Newton's method for solving a system of equations.

This is a general and optimized implementation of Newton's method for solving the problem:

```
f(x) = 0
```

of finding a root of a function.

The algorithm is well-known and there is a vast literature about it. Among others, the method is described in *[BV2004]*, Sections 9.5 and 10.2 (book available online), *[GNS2009]*, Section 2.7 for solving nonlinear equations and Section 11.3 for its use in minimization, and wikipedia on Newton's_method.

Parametersop : *Operator*

Gradient of the objective function, x --> grad f(x)

x : element in the domain of op

Starting point of the iteration

line_search : *LineSearch*

Strategy to choose the step length

num_iter : int, optional

Number of iterations

cg_iter : `int`, optional

Number of iterations in the the conjugate gradient solver, for computing the search direction.

partial : *Partial*, optional

Object executing code per iteration, e.g. plotting each iterate

Notes

The algorithm works by iteratively solving

$$\partial f(x_k) p_k = -f(x_k)$$

and then updating as

$$x_{k+1} = x_k + \alpha x_k,$$

where α is a suitable step length (see the references). In this implementation the system of equations are solved using the conjugate gradient method.

8.6 space

Concrete vector spaces.

Modules

8.6.1 base_ntuples

Base classes for implementation of n-tuples.

Classes

FnBase(size, dtype)	Base class for F^n independent of implementation.
FnBaseVector(space, *args, **kwargs)	Abstract class for representation of *FnBase* vectors.
FnWeightingBase(impl[, exponent, ...])	Abstract base class for weighting of *FnBase* spaces.
NtuplesBase(size, dtype)	Base class for sets of n-tuples independent of implementation.
NtuplesBaseVector(space, *args, **kwargs)	Abstract class for representation of *NtuplesBase* elements.

FnBase

class `odl.space.base_ntuples.`**FnBase**(*size*, *dtype*)

Bases: *odl.space.base_ntuples.NtuplesBase*, *odl.set.space.LinearSpace*

Base class for F^n independent of implementation.

Attributes

dtype	The data type of each entry.
element_type	*FnBaseVector*
field	The field of this vector space.
is_cn	Return `True` if the space represents C^n, i.e.
is_rn	Return `True` if the space represents R^n, i.e.
shape	The shape of this space.
size	The number of entries per tuple.

FnBase.dtype

FnBase.**dtype**
The data type of each entry.

FnBase.element_type

FnBase.**element_type**
FnBaseVector

FnBase.field

FnBase.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

FnBase.is_cn

FnBase.**is_cn**
Return `True` if the space represents C^n, i.e. complex tuples.

FnBase.is_rn

FnBase.**is_rn**
Return `True` if the space represents R^n, i.e. real tuples.

FnBase.shape

FnBase.**shape**
The shape of this space.

FnBase.size

FnBase.**size**
The number of entries per tuple.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
_dist(x1, x2)	Calculate the distance between x1 and x2.
_divide(x1, x2, out)	The entry-wise division of two vectors, assigned to `out`.
_inner(x1, x2)	Calculate the inner product of x1 and x2.
_lincomb(a, x1, b, x2, out)	Calculate `out = a*x1 + b*x2`.
_multiply(x1, x2, out)	The entry-wise product of two vectors, assigned to `out`.
_norm(x)	Calculate the norm of x.
astype(dtype)	Return a copy of this space with new `dtype`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp])	Create a *LinearSpaceVector* from `inp` or from scratch.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	Create a vector of ones.
zero()	Create a vector of zeros.

FnBase.__contains__

FnBase.**__contains__**(*other*)
Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *NtuplesBaseVector* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

FnBase.__eq__

FnBase.**__eq__**(*other*)
Return `self == other`.

Returnsequals : `bool`

`True` if `other` is an instance of this space's type with the same *`size`* and *`dtype`*, otherwise `False`.

Examples

```
>>> from odl import Ntuples
>>> int_3 = Ntuples(3, dtype=int)
>>> int_3 == int_3
True
```

Equality is not identity:

```
>>> int_3a, int_3b = Ntuples(3, int), Ntuples(3, int)
>>> int_3a == int_3b
True
>>> int_3a is int_3b
False
```

```
>>> int_3, int_4 = Ntuples(3, int), Ntuples(4, int)
>>> int_3 == int_4
False
>>> int_3, str_3 = Ntuples(3, 'int'), Ntuples(3, 'S2')
>>> int_3 == str_3
False
```

FnBase._dist

FnBase.**_dist**(*x1*, *x2*)
Calculate the distance between x1 and x2.

This method is intended to be private, public callers should resort to *`dist`* which is type-checked.

FnBase._divide

FnBase.**_divide**(*x1*, *x2*, *out*)
The entry-wise division of two vectors, assigned to `out`.

FnBase._inner

FnBase.**_inner**(*x1*, *x2*)
Calculate the inner product of x1 and x2.

This method is intended to be private, public callers should resort to *`inner`* which is type-checked.

FnBase._lincomb

FnBase.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)
Calculate `out = a*x1 + b*x2`.

This method is intended to be private, public callers should resort to *lincomb* which is type-checked.

FnBase._multiply

FnBase.**_multiply**(*x1*, *x2*, *out*)
The entry-wise product of two vectors, assigned to `out`.

FnBase._norm

FnBase.**_norm**(*x*)
Calculate the norm of x.

This method is intended to be private, public callers should resort to *norm* which is type-checked.

FnBase.astype

FnBase.**astype**(*dtype*)
Return a copy of this space with new `dtype`.

Parametersdtype :

Data type of the returned space. Can be given in any way `numpy.dtype` understands, e.g. as string ('complex64') or data type (`complex`).

Returnsnewspace : *FnBase*

The version of this space with given data type

FnBase.contains_all

FnBase.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

FnBase.contains_set

FnBase.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

FnBase.dist

FnBase.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

FnBase.divide

`FnBase.`**`divide`**(*x1*, *x2*, *out=None*)

Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

FnBase.element

`FnBase.`**`element`**(*inp=None*, ***kwargs*)

Create a *LinearSpaceVector* from `inp` or from scratch.

If called without `inp` argument, an arbitrary element of the space is generated without guarantee of its state.

Parametersinp : optional

Input data from which to create the element

kwargs :

Optional further arguments

Returnselement : *LinearSpaceVector*

A vector in this space

FnBase.inner

`FnBase.`**`inner`**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

FnBase.lincomb

FnBase.**lincomb**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

FnBase.multiply

FnBase.**multiply**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

FnBase.norm

`FnBase.`**`norm`**(*x*)
Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

FnBase.one

`FnBase.`**`one`**()
Create a vector of ones.

FnBase.zero

`FnBase.`**`zero`**()
Create a vector of zeros.

`__init__`(*size*, *dtype*)
Initialize a new instance.

Parameterssize : `int`

The number of dimensions of the space

dtype : `object`

The data type of the storage array. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string. Only scalar data types (numbers) are allowed.

FnBaseVector

class `odl.space.base_ntuples.`**`FnBaseVector`**(*space*, **args*, ***kwargs*)
Bases: *odl.space.base_ntuples.NtuplesBaseVector*, *odl.set.space.LinearSpaceVector*

Abstract class for representation of *FnBase* vectors.

Defines abstract attributes and concrete ones which are independent of data representation.

Attributes

T	The transpose of a vector, the functional given by (.
dtype	Length of this vector, equal to space size.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.

Continued on next page

Table 8.159 – continued from previous page

ndim	Number of dimensions, always 1.
shape	Number of entries per axis, equals (size,) for linear storage.
size	Length of this vector, equal to space size.
space	Space to which this vector.
ufunc	*NtuplesBaseUFuncs*, access to numpy style ufuncs.

FnBaseVector.T

FnBaseVector.**T**
The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

FnBaseVector.dtype

FnBaseVector.**dtype**
Length of this vector, equal to space size.

FnBaseVector.itemsize

FnBaseVector.**itemsize**
The size in bytes on one element of this type.

FnBaseVector.nbytes

FnBaseVector.**nbytes**
The number of bytes this vector uses in memory.

FnBaseVector.ndim

FnBaseVector.**ndim**
Number of dimensions, always 1.

FnBaseVector.shape

FnBaseVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

FnBaseVector.size

FnBaseVector.**size**
Length of this vector, equal to space size.

FnBaseVector.space

FnBaseVector.**space**
Space to which this vector.

FnBaseVector.ufunc

FnBaseVector.**ufunc**
NtuplesBaseUFuncs, access to numpy style ufuncs.

These are always available, but may or may not be optimized for the specific space in use.

Methods

__eq__(other)	
__getitem__(indices)	Access values of this vector.
__setitem__(indices, values)	Set values of this vector.
asarray([start, stop, step, out])	Extract the data of this array as a numpy array.
assign(other)	Assign the values of `other` to self.
copy()	
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
set_zero()	Set this vector to zero.
show([title, method, show, fig])	Display the function graphically.

FnBaseVector.__eq__

FnBaseVector.**__eq__**(*other*)

FnBaseVector.__getitem__

FnBaseVector.**__getitem__**(*indices*)
Access values of this vector.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : *NtuplesBase.dtype* or *NtuplesBaseVector*

The value(s) at the index (indices)

FnBaseVector.__setitem__

`FnBaseVector.__setitem__`(*indices*, *values*)

Set values of this vector.

Parametersindices : `int` or `slice`

The position(s) that should be set

values : scalar, *array-like* or *NtuplesBaseVector*

The value(s) that are to be assigned.

If `index` is an integer, `value` must be single value.

If `index` is a slice, `value` must be broadcastable to the size of the slice (same size, shape (1,) or single value).

FnBaseVector.asarray

`FnBaseVector.asarray`(*start=None*, *stop=None*, *step=None*, *out=None*)

Extract the data of this array as a numpy array.

Parametersstart : `int`, optional

Start position. `None` means the first element.

start : `int`, optional

One element past the last element to be extracted. `None` means the last element.

start : `int`, optional

Step length. `None` means 1.

out : `numpy.ndarray`

Array to write result to.

Returnsasarray : `numpy.ndarray`

Numpy array of the same type as the space.

FnBaseVector.assign

`FnBaseVector.assign`(*other*)

Assign the values of `other` to self.

FnBaseVector.copy

`FnBaseVector.copy`()

FnBaseVector.dist

FnBaseVector.**dist**(*other*)
Distance to `other`.

LinearSpace.dist

FnBaseVector.divide

FnBaseVector.**divide**(*x*, *y*)
Divide by `other` inplace.

LinearSpace.divide

FnBaseVector.inner

FnBaseVector.**inner**(*other*)
Inner product with `other`.

LinearSpace.inner

FnBaseVector.lincomb

FnBaseVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

FnBaseVector.multiply

FnBaseVector.**multiply**(*x*, *y*)
Multiply by `other` inplace.

LinearSpace.multiply

FnBaseVector.norm

FnBaseVector.**norm**()
Norm of vector

LinearSpace.norm

FnBaseVector.set_zero

FnBaseVector.**set_zero**()
Set this vector to zero.

LinearSpace.zero

FnBaseVector.show

FnBaseVector.**show**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)
Display the function graphically.

Parameterstitle : str, optional

Set the title of the figure

method : str, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : bool, optional

If the plot should be showed now or deferred until later.

fig : matplotlib.figure.Figure

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that fig is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : matplotlib.figure.Figure

The resulting figure. It is also shown to the user.

See also:

*odl.util.graphics.show_discrete_data*Underlying implementation

__init__(*space*, **args*, ***kwargs*)
Initialize a new instance.

FnWeightingBase

class odl.space.base_ntuples.**FnWeightingBase**(*impl*, *exponent=2.0*, *dist_using_inner=False*)
Bases: object

Abstract base class for weighting of *FnBase* spaces.

This class and its subclasses serve as a simple means to evaluate and compare weighted inner products, norms and metrics semantically rather than by identity on a pure function level.

The functions are implemented similarly to *Operator*, but without extra type checks of input parameters - this is done in the callers of the *LinearSpace* instance where these functions used.

Attributes

exponent	Exponent of this weighting.

Continued on next page

Table 8.161 – continued from previous page

impl	Implementation backend of this weighting.

FnWeightingBase.exponent

FnWeightingBase.**exponent**
Exponent of this weighting.

FnWeightingBase.impl

FnWeightingBase.**impl**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the distance between two vectors.
equiv(other)	Test if `other` is an equivalent inner product.
inner(x1, x2)	Calculate the inner product of two vectors.
norm(x)	Calculate the norm of a vector.

FnWeightingBase.__eq__

FnWeightingBase.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if `other` is a the same weighting, `False` otherwise.

Notes

This operation must be computationally cheap, i.e. no large arrays may be compared element-wise. That is the task of the *equiv* method.

FnWeightingBase.dist

FnWeightingBase.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

This is the standard implementation using *norm*. Subclasses should override it for optimization purposes.

Parametersx1, x2 : *FnBaseVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

FnWeightingBase.equiv

FnWeightingBase.**equiv**(*other*)

Test if `other` is an equivalent inner product.

Should be overwritten, default tests for equality.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise.

FnWeightingBase.inner

FnWeightingBase.**inner**(*x1*, *x2*)

Calculate the inner product of two vectors.

Parametersx1, x2 : *FnBaseVector*

Vectors whose inner product is calculated

Returnsinner : `float` or `complex`

The inner product of the two provided vectors

FnWeightingBase.norm

FnWeightingBase.**norm**(*x*)

Calculate the norm of a vector.

This is the standard implementation using *inner*. Subclasses should override it for optimization purposes.

Parametersx1 : *FnBaseVector*

Vector whose norm is calculated

Returnsnorm : `float`

The norm of the vector

__init__(*impl*, *exponent=2.0*, *dist_using_inner=False*)

Initialize a new instance.

Parametersimpl : `str`

Specifier for the implementation backend

exponent : positive `float`

Exponent of the norm. For values other than 2.0, the inner product is not defined.

dist_using_inner : `bool`, optional

Calculate *dist* using the formula

$\|x - y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y\rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

This option can only be used if `exponent` is 2.0.

Default: `False`.

NtuplesBase

class odl.space.base_ntuples.**NtuplesBase**(*size*, *dtype*)
Bases: *odl.set.sets.Set*

Base class for sets of n-tuples independent of implementation.

Attributes

dtype	The data type of each entry.
element_type	*NtuplesBaseVector*
shape	The shape of this space.
size	The number of entries per tuple.

NtuplesBase.dtype

NtuplesBase.**dtype**
The data type of each entry.

NtuplesBase.element_type

NtuplesBase.**element_type**
NtuplesBaseVector

NtuplesBase.shape

NtuplesBase.**shape**
The shape of this space.

NtuplesBase.size

NtuplesBase.**size**
The number of entries per tuple.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([inp])	Return an element from `inp` or from scratch.

NtuplesBase.__contains__

NtuplesBase.**__contains__**(*other*)
Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *`NtuplesBaseVector`* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

NtuplesBase.__eq__

`NtuplesBase.`**`__eq__`**`(`*`other`*`)`

Return `self == other`.

Returnsequals : `bool`

`True` if `other` is an instance of this space's type with the same *`size`* and *`dtype`*, otherwise `False`.

Examples

```
>>> from odl import Ntuples
>>> int_3 = Ntuples(3, dtype=int)
>>> int_3 == int_3
True
```

Equality is not identity:

```
>>> int_3a, int_3b = Ntuples(3, int), Ntuples(3, int)
>>> int_3a == int_3b
True
>>> int_3a is int_3b
False
```

```
>>> int_3, int_4 = Ntuples(3, int), Ntuples(4, int)
>>> int_3 == int_4
False
>>> int_3, str_3 = Ntuples(3, 'int'), Ntuples(3, 'S2')
>>> int_3 == str_3
False
```

NtuplesBase.contains_all

`NtuplesBase.`**`contains_all`**`(`*`other`*`)`

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

NtuplesBase.contains_set

NtuplesBase.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

NtuplesBase.element

NtuplesBase.**element**(*inp=None*)
Return an element from `inp` or from scratch.

Implementing this method is optional.

__init__(*size*, *dtype*)
Initialize a new instance.

Parameterssize : non-negative int

The number of entries per tuple

dtype :

The data type for each tuple entry. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string.

NtuplesBaseVector

class odl.space.base_ntuples.**NtuplesBaseVector**(*space*, **args*, ***kwargs*)
Bases: `object`

Abstract class for representation of *NtuplesBase* elements.

Defines abstract attributes and concrete ones which are independent of data representation.

Attributes

dtype	Length of this vector, equal to space size.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions, always 1.
shape	Number of entries per axis, equals (size,) for linear storage.
size	Length of this vector, equal to space size.
space	Space to which this vector.
ufunc	*NtuplesBaseUFuncs*, access to numpy style ufuncs.

NtuplesBaseVector.dtype

NtuplesBaseVector.**dtype**
Length of this vector, equal to space size.

NtuplesBaseVector.itemsize

NtuplesBaseVector.**itemsize**
The size in bytes on one element of this type.

NtuplesBaseVector.nbytes

NtuplesBaseVector.**nbytes**
The number of bytes this vector uses in memory.

NtuplesBaseVector.ndim

NtuplesBaseVector.**ndim**
Number of dimensions, always 1.

NtuplesBaseVector.shape

NtuplesBaseVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

NtuplesBaseVector.size

NtuplesBaseVector.**size**
Length of this vector, equal to space size.

NtuplesBaseVector.space

NtuplesBaseVector.**space**
Space to which this vector.

NtuplesBaseVector.ufunc

NtuplesBaseVector.**ufunc**
NtuplesBaseUFuncs, access to numpy style ufuncs.

These are always available, but may or may not be optimized for the specific space in use.

Methods

__eq__(other)	Return `self == other`.
__getitem__(indices)	Access values of this vector.
__setitem__(indices, values)	Set values of this vector.
asarray([start, stop, step, out])	Extract the data of this array as a numpy array.
copy()	Create an identical (deep) copy of this vector.
show([title, method, show, fig])	Display the function graphically.

NtuplesBaseVector.__eq__

NtuplesBaseVector.**__eq__**(*other*)
Return `self == other`.

Returnsequals : `bool`

`True` if all entries of `other` are equal to this vector's entries, `False` otherwise.

NtuplesBaseVector.__getitem__

NtuplesBaseVector.**__getitem__**(*indices*)
Access values of this vector.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : *NtuplesBase.dtype* or *NtuplesBaseVector*

The value(s) at the index (indices)

NtuplesBaseVector.__setitem__

NtuplesBaseVector.**__setitem__**(*indices*, *values*)
Set values of this vector.

Parametersindices : `int` or `slice`

The position(s) that should be set

values : scalar, *array-like* or *NtuplesBaseVector*

The value(s) that are to be assigned.

If `index` is an integer, `value` must be single value.

If `index` is a slice, `value` must be broadcastable to the size of the slice (same size, shape (1,) or single value).

NtuplesBaseVector.asarray

NtuplesBaseVector.**asarray**(*start=None*, *stop=None*, *step=None*, *out=None*)
Extract the data of this array as a numpy array.

Parametersstart : `int`, optional

Start position. `None` means the first element.

start : `int`, optional

One element past the last element to be extracted. `None` means the last element.

start : `int`, optional

Step length. `None` means 1.

out : `numpy.ndarray`

Array to write result to.

Returnsasarray : `numpy.ndarray`

Numpy array of the same type as the space.

NtuplesBaseVector.copy

`NtuplesBaseVector.`**`copy`**`()`
Create an identical (deep) copy of this vector.

NtuplesBaseVector.show

`NtuplesBaseVector.`**`show`**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)
Display the function graphically.

Parameterstitle : `str`, optional

Set the title of the figure

method : `str`, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : `bool`, optional

If the plot should be showed now or deferred until later.

fig : `matplotlib.figure.Figure`

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that `fig` is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : `matplotlib.figure.Figure`

The resulting figure. It is also shown to the user.

See also:

odl.util.graphics.show_discrete_dataUnderlying implementation

`__init__`(*space*, **args*, ***kwargs*)
Initialize a new instance.

8.6.2 cu_ntuples

CUDA implementation of n-dimensional Cartesian spaces.

Classes

CudaFn(size, dtype, **kwargs)	The space *FnBase*, implemented in CUDA.
CudaFnConstWeighting(constant[, exponent])	Weighting of *CudaFn* by a constant.
CudaFnCustomDist(dist)	Custom distance on *CudaFn*, removes `norm` and `inner`.
CudaFnCustomInnerProduct(inner[, ...])	Custom inner product on *CudaFn*.
CudaFnCustomNorm(norm)	Custom norm on *CudaFn*, removes `inner`.
CudaFnNoWeighting([exponent])	Weighting of *CudaFn* with constant 1.
CudaFnVector(space, data)	Representation of a *CudaFn* element.
CudaFnVectorWeighting(vector[, exponent])	Vector weighting for *CudaFn*.
CudaNtuples(size, dtype)	The space *NtuplesBase*, implemented in CUDA.
CudaNtuplesVector(space, data)	Representation of a *CudaNtuples* element.

CudaFn

class `odl.space.cu_ntuples.`**`CudaFn`**(*size*, *dtype*, ***kwargs*)

Bases: *odl.space.base_ntuples.FnBase*, *odl.space.cu_ntuples.CudaNtuples*

The space *FnBase*, implemented in CUDA.

Requires the compiled ODL extension odlpp.

Attributes

dtype	The data type of each entry.
element_type	*CudaFnVector*
exponent	Exponent of the norm and distance.
field	The field of this vector space.
is_cn	Return `True` if the space represents C^n, i.e.
is_rn	Return `True` if the space represents R^n, i.e.
is_weighted	Return `True` if the weighting is not *CudaFnNoWeighting*.
shape	The shape of this space.
size	The number of entries per tuple.
weighting	This space's weighting scheme.

CudaFn.dtype

`CudaFn.`**`dtype`**

The data type of each entry.

CudaFn.element_type

`CudaFn.`**`element_type`**

CudaFnVector

CudaFn.exponent

`CudaFn.`**`exponent`**

Exponent of the norm and distance.

CudaFn.field

CudaFn.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

CudaFn.is_cn

CudaFn.**is_cn**
Return `True` if the space represents C^n, i.e. complex tuples.

CudaFn.is_rn

CudaFn.**is_rn**
Return `True` if the space represents R^n, i.e. real tuples.

CudaFn.is_weighted

CudaFn.**is_weighted**
Return `True` if the weighting is not *CudaFnNoWeighting*.

CudaFn.shape

CudaFn.**shape**
The shape of this space.

CudaFn.size

CudaFn.**size**
The number of entries per tuple.

CudaFn.weighting

CudaFn.**weighting**
This space's weighting scheme.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	s.__eq__(other) <==> s == other.
_dist(x1, x2)	Calculate the distance between two vectors.

Continued on next page

Table 8.169 – continued from previous page

_divide(x1, x2, out)	The pointwise division of two vectors, assigned to `out`.
_inner(x1, x2)	Calculate the inner product of x and y.
_lincomb(a, x1, b, x2, out)	Linear combination of `x1` and `x2`, assigned to `out`.
_multiply(x1, x2, out)	The pointwise product of two vectors, assigned to `out`.
_norm(x)	Calculate the norm of `x`.
astype(dtype)	Return a copy of this space with new `dtype`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
default_dtype(field)	Return the default of *CudaFn* data type for a given field.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp, data_ptr])	Create a new element.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	Create a vector of ones.
zero()	Create a vector of zeros.

CudaFn.__contains__

CudaFn.**__contains__**(*other*)

Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *NtuplesBaseVector* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

CudaFn.__eq__

CudaFn.**__eq__**(*other*)

s.__eq__(other) <==> s == other.

Returnsequals : `bool`

`True` if other is an instance of this space's type with the same `size`, `dtype` and space functions, otherwise `False`.

Examples

```
>>> from numpy.linalg import norm
>>> def dist(x, y, ord):
...     return norm(x - y, ord)
```

```
>>> from functools import partial
>>> dist2 = partial(dist, ord=2)
>>> r3 = CudaRn(3, dist=dist2)
>>> r3_same = CudaRn(3, dist=dist2)
>>> r3  == r3_same
True
```

Different `dist` functions result in different spaces - the same applies for `norm` and `inner`:

```
>>> dist1 = partial(dist, ord=1)
>>> r3_1 = CudaRn(3, dist=dist1)
>>> r3_2 = CudaRn(3, dist=dist2)
>>> r3_1 == r3_2
False
```

Be careful with Lambdas - they result in non-identical function objects:

```
>>> r3_lambda1 = CudaRn(3, dist=lambda x, y: norm(x-y, ord=1))
>>> r3_lambda2 = CudaRn(3, dist=lambda x, y: norm(x-y, ord=1))
>>> r3_lambda1 == r3_lambda2
False
```

CudaFn._dist

CudaFn.**_dist**(*x1*, *x2*)

Calculate the distance between two vectors.

Parametersx1, x2 : *CudaFnVector*

The vectors whose mutual distance is calculated

Returnsdist : `float`

Distance between the vectors

Examples

```
>>> r2 = CudaRn(2)
>>> x = r2.element([3, 8])
>>> y = r2.element([0, 4])
>>> r2.dist(x, y)
5.0
```

CudaFn._divide

CudaFn.**_divide**(*x1*, *x2*, *out*)

The pointwise division of two vectors, assigned to `out`.

This is defined as:

multiply(z, x, y) := [x[0]/y[0], x[1]/y[1], ..., x[n-1]/y[n-1]]

Parametersx1, x2 : *CudaFnVector*

Factors in the product

out : *CudaFnVector*

Element to which the result is written

ReturnsNone

Examples

```
>>> rn = CudaRn(3)
>>> x1 = rn.element([5, 3, 2])
>>> x2 = rn.element([1, 2, 2])
>>> out = rn.element()
>>> rn.divide(x1, x2, out)  # out is returned
CudaRn(3).element([5.0, 1.5, 1.0])
>>> out
CudaRn(3).element([5.0, 1.5, 1.0])
```

CudaFn._inner

CudaFn.**_inner**(*x1*, *x2*)

Calculate the inner product of x and y.

Parametersx1, x2 : *CudaFnVector*

Returnsinner: `float` or `complex`

The inner product of x and y

Examples

```
>>> uc3 = CudaFn(3, 'uint8')
>>> x = uc3.element([1, 2, 3])
>>> y = uc3.element([3, 1, 5])
>>> uc3.inner(x, y)
20.0
```

CudaFn._lincomb

CudaFn.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)

Linear combination of `x1` and `x2`, assigned to `out`.

Calculate `z = a * x + b * y` using optimized CUDA routines.

Parametersa, b : *LinearSpace.field element*

Scalar to multiply `x` and `y` with.

x, y : *CudaFnVector*

The summands

out : *CudaFnVector*

The Vector that the result is written to.

Returns None

Examples

```
>>> r3 = CudaRn(3)
>>> x = r3.element([1, 2, 3])
>>> y = r3.element([4, 5, 6])
>>> out = r3.element()
>>> r3.lincomb(2, x, 3, y, out)  # out is returned
CudaRn(3).element([14.0, 19.0, 24.0])
>>> out
CudaRn(3).element([14.0, 19.0, 24.0])
```

CudaFn._multiply

CudaFn.**_multiply**(*x1*, *x2*, *out*)

The pointwise product of two vectors, assigned to `out`.

This is defined as:

multiply(x, y, out) := [x[0]*y[0], x[1]*y[1], ..., x[n-1]*y[n-1]]

Parameters **x1, x2** : *CudaFnVector*

Factors in product

out : *CudaFnVector*

Element to which the result is written

Returns None

Examples

```
>>> rn = CudaRn(3)
>>> x1 = rn.element([5, 3, 2])
>>> x2 = rn.element([1, 2, 3])
>>> out = rn.element()
>>> rn.multiply(x1, x2, out)  # out is returned
CudaRn(3).element([5.0, 6.0, 6.0])
>>> out
CudaRn(3).element([5.0, 6.0, 6.0])
```

CudaFn._norm

CudaFn.**_norm**(*x*)

Calculate the norm of `x`.

This method is implemented separately from `sqrt(inner(x,x))` for efficiency reasons.

Parameters **x** : *CudaFnVector*

Returns **norm** : `float`

The norm of x

Examples

```
>>> uc3 = CudaFn(3, 'uint8')
>>> x = uc3.element([2, 3, 6])
>>> uc3.norm(x)
7.0
```

CudaFn.astype

CudaFn.**astype**(*dtype*)

Return a copy of this space with new `dtype`.

Parametersdtype :

Data type of the returned space. Can be given in any way `numpy.dtype` understands, e.g. as string ('complex64') or data type (`complex`).

Returnsnewspace : *FnBase*

The version of this space with given data type

CudaFn.contains_all

CudaFn.**contains_all**(*other*)

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

CudaFn.contains_set

CudaFn.**contains_set**(*other*)

Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

CudaFn.default_dtype

static CudaFn.**default_dtype**(*field*)

Return the default of *CudaFn* data type for a given field.

Parametersfield : *Field*

Set of numbers to be represented by a data type. Currently supported: *RealNumbers*.

Returnsdtype : `type`

Numpy data type specifier. The returned defaults are:

`RealNumbers() : , np.dtype('float32')`

CudaFn.dist

CudaFn.**dist**(*x1*, *x2*)

Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

CudaFn.divide

`CudaFn.`**`divide`**(*x1*, *x2*, *out=None*)

Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

CudaFn.element

`CudaFn.`**`element`**(*inp=None*, *data_ptr=None*)

Create a new element.

Parametersinp : *array-like* or scalar, optional

Input to initialize the new element.

If `inp` is a `numpy.ndarray` of shape `(size,)` and the same data type as this space, the array is wrapped, not copied. Other array-like objects are copied (with broadcasting if necessary).

If a single value is given, it is copied to all entries.

If both `inp` and `data_ptr` are `None`, an empty element is created with no guarantee of its state (memory allocation only).

data_ptr : `int`, optional

Memory address of a CUDA array container

Cannot be combined with `inp`.

Returnselement : *CudaNtuplesVector*

The new element

Notes

This method preserves "array views" of correct size and type, see the examples below.

TODO: No, it does not yet!

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> x = uc3.element(np.array([1, 2, 3], dtype='uint8'))
>>> x
CudaNtuples(3, 'uint8').element([1, 2, 3])
>>> y = uc3.element([1, 2, 3])
>>> y
CudaNtuples(3, 'uint8').element([1, 2, 3])
```

CudaFn.inner

CudaFn.**inner**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

CudaFn.lincomb

CudaFn.**lincomb**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

CudaFn.multiply

CudaFn.**multiply**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

CudaFn.norm

CudaFn.**norm**(*x*)

Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

CudaFn.one

CudaFn.**one**()

Create a vector of ones.

CudaFn.zero

CudaFn.**zero**()

Create a vector of zeros.

__init__(*size*, *dtype*, ***kwargs*)

Initialize a new instance.

Parameterssize : positive `int`

The number of dimensions of the space

dtype : `object`

The data type of the storage array. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string.

Only scalar data types are allowed.

weight : optional

Use weighted inner product, norm, and dist. The following types are supported as `weight`:

`FnWeightingBase` : Use this weighting as-is. Compatibility with this space's elements is not checked during init.

`float` : Weighting by a constant

`array-like` : Weighting by a vector (1-dim. array, corresponds to a diagonal matrix). Note that the array is stored in main memory, which results in slower space functions due to a copy during evaluation.

`CudaFnVector` : same as 1-dim. array-like, except that copying is avoided if the `dtype` of the vector is the same as this space's `dtype`.

Default: no weighting

This option cannot be combined with `dist`, `norm` or `inner`.

exponent : positive `float`, optional

Exponent of the norm. For values other than 2.0, no inner product is defined.

This option is ignored if `dist`, `norm` or `inner` is given.

Default: 2.0

dist : `callable`, optional

The distance function defining a metric on *`CudaFn`*. It must accept two *`CudaFnVector`* arguments, return a `float` and fulfill the following mathematical conditions for any three vectors `x, y, z`:

- $d(x, y) = d(y, x)$
- $d(x, y) \geq 0$
- $d(x, y) = 0 \Leftrightarrow x = y$
- $d(x, y) \geq d(x, z) + d(z, y)$

By default, `dist(x, y)` is calculated as `norm(x - y)`. This creates an intermediate array `x-y`, which can be avoided by choosing `dist_using_inner=True`.

This option cannot be combined with `weight`, `norm` or `inner`.

norm : `callable`, optional

The norm implementation. It must accept an *`CudaFnVector`* argument, return a `float` and satisfy the following conditions for all vectors x, y and scalars s:

- $\|x\| \geq 0$
- $\|x\| = 0 \Leftrightarrow x = 0$
- $\|sx\| = |s|\|x\|$
- $\|x + y\| \leq \|x\| + \|y\|$.

By default, `norm(x)` is calculated as `inner(x, x)`.

This option cannot be combined with `weight`, `dist` or `inner`.

inner : `callable`, optional

The inner product implementation. It must accept two *CudaFnVector* arguments, return an element from the field of the space (real or complex number) and satisfy the following conditions for all vectors x, y, z and scalars s:

- $\langle x, y\rangle = \overline{\langle y, x\rangle}$
- $\langle sx, y\rangle = s\langle x, y\rangle$
- $\langle x + z, y\rangle = \langle x, y\rangle + \langle z, y\rangle$
- $\langle x, x\rangle = 0 \Leftrightarrow x = 0$

This option cannot be combined with `weight`, `dist` or `norm`.

CudaFnConstWeighting

class `odl.space.cu_ntuples.`**`CudaFnConstWeighting`**(*constant*, *exponent=2.0*)

Bases: *odl.space.base_ntuples.FnWeightingBase*

Weighting of *CudaFn* by a constant.

For exponent 2.0, a new weighted inner product with constant c is defined as

$\langle a, b\rangle_c := c\, b^H a$

with b^H standing for transposed complex conjugate.

For other exponents, only norm and dist are defined. In the case of exponent `inf`, the weighted norm is defined as

$\|a\|_{c,\infty} := c\|a\|_\infty$,

otherwise it is

$\|a\|_{c,p} := c^{1/p}\|a\|_p$.

Not that this definition does **not** fulfill the limit property in p, i.e.

$\lim_{p\to\infty}\|a\|_{c,p} = \|a\|_\infty \neq \|a\|_{c,\infty}$

unless $c = 1$.

The constant c must be positive.

Attributes

const	Weighting constant of this inner product.
exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

CudaFnConstWeighting.const

`CudaFnConstWeighting.`**`const`**

Weighting constant of this inner product.

CudaFnConstWeighting.exponent

CudaFnConstWeighting.**exponent**
Exponent of this weighting.

CudaFnConstWeighting.impl

CudaFnConstWeighting.**impl**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the constant-weighted distance between two vectors.
equiv(other)	Test if `other` is an equivalent weighting.
inner(x1, x2)	Calculate the constant-weighted inner product of two vectors.
norm(x)	Calculate the constant-weighted norm of a vector.

CudaFnConstWeighting.__eq__

CudaFnConstWeighting.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if `other` is a *CudaFnConstWeighting* instance with the same constant, `False` otherwise.

CudaFnConstWeighting.dist

CudaFnConstWeighting.**dist**(*x1*, *x2*)
Calculate the constant-weighted distance between two vectors.

Parametersx1, x2 : *CudaFnVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

CudaFnConstWeighting.equiv

CudaFnConstWeighting.**equiv**(*other*)
Test if `other` is an equivalent weighting.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance with the same *FnWeightingBase.impl*, which yields the same result as this inner product for any input, `False` otherwise. This is the same as equality if `other` is a

CudaFnConstWeighting instance, otherwise by entry-wise comparison of this inner product's constant with the matrix of `other`.

CudaFnConstWeighting.inner

`CudaFnConstWeighting.`**`inner`**(*x1*, *x2*)

Calculate the constant-weighted inner product of two vectors.

Parametersx1, x2 : *CudaFnVector*

Vectors whose inner product is calculated

Returnsinner : `float` or `complex`

The inner product of the two vectors

CudaFnConstWeighting.norm

`CudaFnConstWeighting.`**`norm`**(*x*)

Calculate the constant-weighted norm of a vector.

Parametersx1 : *CudaFnVector*

Vector whose norm is calculated

Returnsnorm : `float`

The norm of the vector

`__init__`(*constant*, *exponent=2.0*)

Initialize a new instance.

Parametersconstant : positive finite `float`

Weighting constant of the inner product.

exponent : positive `float`

Exponent of the norm. For values other than 2.0, the inner product is not defined.

CudaFnCustomDist

class `odl.space.cu_ntuples.`**`CudaFnCustomDist`**(*dist*)

Bases: *odl.space.base_ntuples.FnWeightingBase*

Custom distance on *CudaFn*, removes `norm` and `inner`.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

CudaFnCustomDist.exponent

`CudaFnCustomDist.`**`exponent`**

Exponent of this weighting.

CudaFnCustomDist.impl

CudaFnCustomDist.**impl**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Custom distance of this instance..
equiv(other)	Test if `other` is an equivalent inner product.
inner(x1, x2)	Inner product is not defined for custom distance.
norm(x)	Norm is not defined for custom distance.

CudaFnCustomDist.__eq__

CudaFnCustomDist.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if `other` is a *CudaFnCustomDist* instance with the same norm, `False` otherwise.

CudaFnCustomDist.dist

CudaFnCustomDist.**dist**(*x1*, *x2*)
Custom distance of this instance..

CudaFnCustomDist.equiv

CudaFnCustomDist.**equiv**(*other*)
Test if `other` is an equivalent inner product.

Should be overwritten, default tests for equality.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise.

CudaFnCustomDist.inner

CudaFnCustomDist.**inner**(*x1*, *x2*)
Inner product is not defined for custom distance.

CudaFnCustomDist.norm

CudaFnCustomDist.**norm**(*x*)
Norm is not defined for custom distance.

__init__ (*dist*)
Initialize a new instance.

Parametersdist : `callable`

The distance function defining a metric on $\mathbb{F}^n$. It must accept two *CudaFnVector* arguments and fulfill the following mathematical conditions for any three vectors x, y, z:

- $d(x, y) = d(y, x)$
- $d(x, y) \geq 0$
- $d(x, y) = 0 \Leftrightarrow x = y$
- $d(x, y) \geq d(x, z) + d(z, y)$

CudaFnCustomInnerProduct

class odl.space.cu_ntuples.**CudaFnCustomInnerProduct** (*inner*, *dist_using_inner=True*)
Bases: *odl.space.base_ntuples.FnWeightingBase*

Custom inner product on *CudaFn*.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

CudaFnCustomInnerProduct.exponent

CudaFnCustomInnerProduct.**exponent**
Exponent of this weighting.

CudaFnCustomInnerProduct.impl

CudaFnCustomInnerProduct.**impl**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the distance between two vectors.
equiv(other)	Test if `other` is an equivalent inner product.
inner(x1, x2)	Custom inner product of this instance..
norm(x)	Calculate the norm of a vector.

CudaFnCustomInnerProduct.__eq__

CudaFnCustomInnerProduct.**__eq__** (*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if `other` is a *CudaFnCustomInnerProduct* instance with the same inner product, `False` otherwise.

CudaFnCustomInnerProduct.dist

`CudaFnCustomInnerProduct.`**`dist`**(*x1*, *x2*)

Calculate the distance between two vectors.

This is the standard implementation using *norm*. Subclasses should override it for optimization purposes.

Parametersx1, x2 : *FnBaseVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

CudaFnCustomInnerProduct.equiv

`CudaFnCustomInnerProduct.`**`equiv`**(*other*)

Test if `other` is an equivalent inner product.

Should be overwritten, default tests for equality.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise.

CudaFnCustomInnerProduct.inner

`CudaFnCustomInnerProduct.`**`inner`**(*x1*, *x2*)

Custom inner product of this instance..

CudaFnCustomInnerProduct.norm

`CudaFnCustomInnerProduct.`**`norm`**(*x*)

Calculate the norm of a vector.

This is the standard implementation using *inner*. Subclasses should override it for optimization purposes.

Parametersx1 : *FnBaseVector*

Vector whose norm is calculated

Returnsnorm : `float`

The norm of the vector

`__init__`(*inner*, *dist_using_inner=True*)

Initialize a new instance.

Parametersinner : `callable`

The inner product implementation. It must accept two *CudaFnVector* arguments, return a complex number and satisfy the following conditions for all vectors x, y, z and scalars s:

- $\langle x, y \rangle = \overline{\langle y, x \rangle}$
- $\langle sx, y \rangle = s\langle x, y \rangle$
- $\langle x + z, y \rangle = \langle x, y \rangle + \langle z, y \rangle$
- $\langle x, x \rangle = 0 \Leftrightarrow x = 0$

dist_using_inner : `bool`, optional

Calculate `dist` using the formula

$\|x - y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y \rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

CudaFnCustomNorm

class `odl.space.cu_ntuples.`**CudaFnCustomNorm**(*norm*)

Bases: *odl.space.base_ntuples.FnWeightingBase*

Custom norm on *CudaFn*, removes `inner`.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

CudaFnCustomNorm.exponent

`CudaFnCustomNorm.`**exponent**

Exponent of this weighting.

CudaFnCustomNorm.impl

`CudaFnCustomNorm.`**impl**

Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the distance between two vectors.
equiv(other)	Test if `other` is an equivalent inner product.
inner(x1, x2)	Inner product is not defined for custom distance.
norm(x)	Custom norm of this instance..

CudaFnCustomNorm.__eq__

CudaFnCustomNorm.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if `other` is a *CudaFnCustomNorm* instance with the same norm, `False` otherwise.

CudaFnCustomNorm.dist

CudaFnCustomNorm.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

This is the standard implementation using *norm*. Subclasses should override it for optimization purposes.

Parametersx1, x2 : *FnBaseVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

CudaFnCustomNorm.equiv

CudaFnCustomNorm.**equiv**(*other*)
Test if `other` is an equivalent inner product.

Should be overwritten, default tests for equality.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise.

CudaFnCustomNorm.inner

CudaFnCustomNorm.**inner**(*x1*, *x2*)
Inner product is not defined for custom distance.

CudaFnCustomNorm.norm

CudaFnCustomNorm.**norm**(*x*)
Custom norm of this instance..

__init__(*norm*)
Initialize a new instance.

Parametersnorm : `callable`

The norm implementation. It must accept an *CudaFnVector* argument, return a `float` and satisfy the following conditions for all vectors x, y and scalars s:

- $\|x\| \geq 0$

- $\|x\| = 0 \Leftrightarrow x = 0$
- $\|sx\| = |s|\|x\|$
- $\|x + y\| \leq \|x\| + \|y\|$.

CudaFnNoWeighting

class odl.space.cu_ntuples.**CudaFnNoWeighting**(*exponent=2.0*)
Bases: *odl.space.cu_ntuples.CudaFnConstWeighting*

Weighting of *CudaFn* with constant 1.

For exponent 2.0, the unweighted inner product is defined as

$\langle a, b \rangle := b^H a$

with b^H standing for transposed complex conjugate.

For other exponents, only norm and dist are defined.

Attributes

const	Weighting constant of this inner product.
exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

CudaFnNoWeighting.const

CudaFnNoWeighting.**const**
Weighting constant of this inner product.

CudaFnNoWeighting.exponent

CudaFnNoWeighting.**exponent**
Exponent of this weighting.

CudaFnNoWeighting.impl

CudaFnNoWeighting.**impl**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the constant-weighted distance between two vectors.
equiv(other)	Test if `other` is an equivalent weighting.
inner(x1, x2)	Calculate the constant-weighted inner product of two vectors.
norm(x)	Calculate the constant-weighted norm of a vector.

CudaFnNoWeighting.__eq__

CudaFnNoWeighting.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if `other` is a *CudaFnConstWeighting* instance with the same constant, `False` otherwise.

CudaFnNoWeighting.dist

CudaFnNoWeighting.**dist**(*x1*, *x2*)
Calculate the constant-weighted distance between two vectors.

Parametersx1, x2 : *CudaFnVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

CudaFnNoWeighting.equiv

CudaFnNoWeighting.**equiv**(*other*)
Test if `other` is an equivalent weighting.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance with the same *FnWeightingBase.impl*, which yields the same result as this inner product for any input, `False` otherwise. This is the same as equality if `other` is a *CudaFnConstWeighting* instance, otherwise by entry-wise comparison of this inner product's constant with the matrix of `other`.

CudaFnNoWeighting.inner

CudaFnNoWeighting.**inner**(*x1*, *x2*)
Calculate the constant-weighted inner product of two vectors.

Parametersx1, x2 : *CudaFnVector*

Vectors whose inner product is calculated

Returnsinner : `float` or `complex`

The inner product of the two vectors

CudaFnNoWeighting.norm

CudaFnNoWeighting.**norm**(*x*)
Calculate the constant-weighted norm of a vector.

Parametersx1 : *CudaFnVector*

Vector whose norm is calculated

Returnsnorm : `float`

The norm of the vector

__init__(*exponent=2.0*)
Initialize a new instance.

CudaFnVector

class odl.space.cu_ntuples.**CudaFnVector**(*space*, *data*)
Bases: *odl.space.base_ntuples.FnBaseVector*, *odl.space.cu_ntuples.CudaNtuplesVector*

Representation of a *CudaFn* element.

Attributes

T	The transpose of a vector, the functional given by (.
data	The data of this vector.
data_ptr	A raw pointer to the data of this vector.
dtype	Length of this vector, equal to space size.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions, always 1.
shape	Number of entries per axis, equals (size,) for linear storage.
size	Length of this vector, equal to space size.
space	Space to which this vector.
ufunc	*CudaNtuplesUFuncs*, access to numpy style ufuncs.

CudaFnVector.T

CudaFnVector.**T**
The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

CudaFnVector.data

CudaFnVector.**data**
The data of this vector.

ParametersNone

Returnsptr : CudaFnVectorImpl

Underlying cuda data representation

CudaFnVector.data_ptr

CudaFnVector.**data_ptr**
A raw pointer to the data of this vector.

CudaFnVector.dtype

CudaFnVector.**dtype**
Length of this vector, equal to space size.

CudaFnVector.itemsize

CudaFnVector.**itemsize**
The size in bytes on one element of this type.

CudaFnVector.nbytes

CudaFnVector.**nbytes**
The number of bytes this vector uses in memory.

CudaFnVector.ndim

CudaFnVector.**ndim**
Number of dimensions, always 1.

CudaFnVector.shape

CudaFnVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

CudaFnVector.size

CudaFnVector.**size**
Length of this vector, equal to space size.

CudaFnVector.space

CudaFnVector.**space**
Space to which this vector.

CudaFnVector.ufunc

CudaFnVector.**ufunc**
CudaNtuplesUFuncs, access to numpy style ufuncs.

See also:

odl.util.ufuncs.NtuplesBaseUFuncsBase class for ufuncs in *NtuplesBase* spaces.

Notes

Not all ufuncs are currently optimized, some use the default numpy implementation. This can be improved in the future.

Examples

```
>>> r2 = CudaRn(2)
>>> x = r2.element([1, -2])
>>> x.ufunc.absolute()
CudaRn(2).element([1.0, 2.0])
```

These functions can also be used with broadcasting

```
>>> x.ufunc.add(3)
CudaRn(2).element([4.0, 1.0])
```

and non-space elements

```
>>> x.ufunc.subtract([3, 3])
CudaRn(2).element([-2.0, -5.0])
```

There is also support for various reductions (sum, prod, min, max)

```
>>> x.ufunc.sum()
-1.0
```

Also supports out parameter

```
>>> y = r2.element([3, 4])
>>> out = r2.element()
>>> result = x.ufunc.add(y, out=out)
>>> result
CudaRn(2).element([4.0, 2.0])
>>> result is out
True
```

Methods

__eq__(other)	
__getitem__(indices)	Access values of this vector.
__setitem__(indices, values)	Set values of this vector.
asarray([start, stop, step, out])	Extract the data of this array as a numpy array.
assign(other)	Assign the values of `other` to self.
copy()	
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
set_zero()	Set this vector to zero.
show([title, method, show, fig])	Display the function graphically.

CudaFnVector.__eq__

CudaFnVector.**__eq__**(*other*)

CudaFnVector.__getitem__

CudaFnVector.**__getitem__**(*indices*)

Access values of this vector.

This will cause the values to be copied to CPU which is a slow operation.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : scalar or *CudaNtuplesVector*

The value(s) at the index (indices)

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> y = uc3.element([1, 2, 3])
>>> y[0]
1
>>> z = y[1:3]
>>> z
CudaNtuples(2, 'uint8').element([2, 3])
>>> y[::2]
CudaNtuples(2, 'uint8').element([1, 3])
>>> y[::-1]
CudaNtuples(3, 'uint8').element([3, 2, 1])
```

The returned value is a view, modifications are reflected in the original data:

```
>>> z[:] = [4, 5]
>>> y
CudaNtuples(3, 'uint8').element([1, 4, 5])
```

CudaFnVector.__setitem__

CudaFnVector.**__setitem__**(*indices*, *values*)

Set values of this vector.

This will cause the values to be copied to CPU which is a slow operation.

Parametersindices : int or slice

The position(s) that should be set

values : scalar, *array-like* or *CudaNtuplesVector*

The value(s) that are to be assigned.

If index is an int, value must be single value.

If index is a slice, value must be broadcastable to the size of the slice (same size, shape (1,) or single value).

ReturnsNone

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> y = uc3.element([1, 2, 3])
>>> y[0] = 5
>>> y
CudaNtuples(3, 'uint8').element([5, 2, 3])
>>> y[1:3] = [7, 8]
>>> y
CudaNtuples(3, 'uint8').element([5, 7, 8])
>>> y[:] = np.array([0, 0, 0])
>>> y
CudaNtuples(3, 'uint8').element([0, 0, 0])
```

Scalar assignment

```
>>> y[:] = 5
>>> y
CudaNtuples(3, 'uint8').element([5, 5, 5])
```

CudaFnVector.asarray

CudaFnVector.**asarray**(*start=None*, *stop=None*, *step=None*, *out=None*)

Extract the data of this array as a numpy array.

Parametersstart : int, optional

Start position. None means the first element.

start : int, optional

One element past the last element to be extracted. None means the last element.

start : int, optional

Step length. None means 1.

out : numpy.ndarray

Array in which the result should be written in-place. Has to be contiguous and of the correct dtype.

Returnsasarray : `numpy.ndarray`

Numpy array of the same type as the space.

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> y = uc3.element([1, 2, 3])
>>> y.asarray()
array([1, 2, 3], dtype=uint8)
>>> y.asarray(1, 3)
array([2, 3], dtype=uint8)
```

Using the out parameter

```
>>> out = np.empty((3,), dtype='uint8')
>>> result = y.asarray(out=out)
>>> out
array([1, 2, 3], dtype=uint8)
>>> result is out
True
```

CudaFnVector.assign

`CudaFnVector.`**`assign`**(*other*)

Assign the values of `other` to self.

CudaFnVector.copy

`CudaFnVector.`**`copy`**()

CudaFnVector.dist

`CudaFnVector.`**`dist`**(*other*)

Distance to `other`.

`LinearSpace.dist`

CudaFnVector.divide

`CudaFnVector.`**`divide`**(*x*, *y*)

Divide by `other` inplace.

`LinearSpace.divide`

CudaFnVector.inner

CudaFnVector.**inner**(*other*)
Inner product with `other`.

LinearSpace.inner

CudaFnVector.lincomb

CudaFnVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

CudaFnVector.multiply

CudaFnVector.**multiply**(*x*, *y*)
Multiply by `other` inplace.

LinearSpace.multiply

CudaFnVector.norm

CudaFnVector.**norm**()
Norm of vector

LinearSpace.norm

CudaFnVector.set_zero

CudaFnVector.**set_zero**()
Set this vector to zero.

LinearSpace.zero

CudaFnVector.show

CudaFnVector.**show**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)
Display the function graphically.

Parameters

title : `str`, optional

Set the title of the figure

method : `str`, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : `bool`, optional

If the plot should be showed now or deferred until later.

fig : `matplotlib.figure.Figure`

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that `fig` is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : `matplotlib.figure.Figure`

The resulting figure. It is also shown to the user.

See also:

odl.util.graphics.show_discrete_data Underlying implementation

__init__ (*space*, *data*)
Initialize a new instance.

CudaFnVectorWeighting

class `odl.space.cu_ntuples.`**CudaFnVectorWeighting** (*vector*, *exponent=2.0*)
Bases: *odl.space.base_ntuples.FnWeightingBase*

Vector weighting for *CudaFn*.

For exponent 2.0, a new weighted inner product with vector w is defined as

$\langle a, b \rangle_w := b^H (w \odot a)$

with b^H standing for transposed complex conjugate, and $w \odot a$ being element-wise multiplication.

For other exponents, only norm and dist are defined. In the case of exponent `inf`, the weighted norm is

$\|a\|_{w,\infty} := \|w \odot a\|_\infty$,

otherwise it is

$\|a\|_{w,p} := \|w^{1/p} \odot a\|_p$.

Not that this definition does **not** fulfill the limit property in p, i.e.

$\lim_{p \to \infty} \|a\|_{w,p} = \|a\|_\infty \neq \|a\|_{w,\infty}$

unless $w = (1, \ldots, 1)$.

The vector may only have positive entries, otherwise it does not define an inner product or norm, respectively. This is not checked during initialization.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.
vector	Weighting vector of this inner product.

CudaFnVectorWeighting.exponent

CudaFnVectorWeighting.**exponent**
Exponent of this weighting.

CudaFnVectorWeighting.impl

CudaFnVectorWeighting.**impl**
Implementation backend of this weighting.

CudaFnVectorWeighting.vector

CudaFnVectorWeighting.**vector**
Weighting vector of this inner product.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the vector-weighted distance between two vectors.
equiv(other)	Test if `other` is an equivalent weighting.
inner(x1, x2)	Calculate the vector weighted inner product of two vectors.
norm(x)	Calculate the vector-weighted norm of a vector.
vector_is_valid()	Test if the vector is a valid weight, i.e.

CudaFnVectorWeighting.__eq__

CudaFnVectorWeighting.**__eq__**(*other*)
Return `self == other`.

Returnsequals : `bool`

`True` if `other` is a *CudaFnVectorWeighting* instance with **identical** vector, `False` otherwise.

See also:

equivtest for equivalent inner products

CudaFnVectorWeighting.dist

CudaFnVectorWeighting.**dist**(*x1*, *x2*)
Calculate the vector-weighted distance between two vectors.

Parametersx1, x2 : *CudaFnVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

CudaFnVectorWeighting.equiv

CudaFnVectorWeighting.**equiv**(*other*)
Test if `other` is an equivalent weighting.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise. This is checked by entry-wise comparison of matrices/vectors/constant of this inner product and `other`.

CudaFnVectorWeighting.inner

CudaFnVectorWeighting.**inner**(*x1*, *x2*)
Calculate the vector weighted inner product of two vectors.

Parametersx1, x2 : *CudaFnVector*

Vectors whose inner product is calculated

Returnsinner : `float` or `complex`

The inner product of the two provided vectors

CudaFnVectorWeighting.norm

CudaFnVectorWeighting.**norm**(*x*)
Calculate the vector-weighted norm of a vector.

Parametersx : *CudaFnVector*

Vector whose norm is calculated

Returnsnorm : `float`

The norm of the provided vector

CudaFnVectorWeighting.vector_is_valid

CudaFnVectorWeighting.**vector_is_valid**()
Test if the vector is a valid weight, i.e. positive.

Notes

This operation copies the vector to the CPU memory if necessary and uses `numpy.all`, which can be very time-consuming in total.

__init__(*vector*, *exponent=2.0*)
Initialize a new instance.

Parametersvector : *array-like*, one-dim.

Weighting vector of the inner product

exponent : positive `float`

Exponent of the norm. For values other than 2.0, the inner product is not defined.

CudaNtuples

class odl.space.cu_ntuples.**CudaNtuples**(*size*, *dtype*)
Bases: *odl.space.base_ntuples.NtuplesBase*

The space *NtuplesBase*, implemented in CUDA.

Attributes

dtype	The data type of each entry.
element_type	*CudaNtuplesVector*
shape	The shape of this space.
size	The number of entries per tuple.

CudaNtuples.dtype

CudaNtuples.**dtype**
The data type of each entry.

CudaNtuples.element_type

CudaNtuples.**element_type**
CudaNtuplesVector

CudaNtuples.shape

CudaNtuples.**shape**
The shape of this space.

CudaNtuples.size

CudaNtuples.**size**
The number of entries per tuple.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([inp, data_ptr])	Create a new element.

CudaNtuples.__contains__

CudaNtuples.**__contains__**(*other*)
Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *`NtuplesBaseVector`* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

CudaNtuples.__eq__

`CudaNtuples.`**`__eq__`**`(`*`other`*`)`

Return `self == other`.

Returnsequals : `bool`

`True` if `other` is an instance of this space's type with the same *`size`* and *`dtype`*, otherwise `False`.

Examples

```
>>> from odl import Ntuples
>>> int_3 = Ntuples(3, dtype=int)
>>> int_3 == int_3
True
```

Equality is not identity:

```
>>> int_3a, int_3b = Ntuples(3, int), Ntuples(3, int)
>>> int_3a == int_3b
True
>>> int_3a is int_3b
False
```

```
>>> int_3, int_4 = Ntuples(3, int), Ntuples(4, int)
>>> int_3 == int_4
False
>>> int_3, str_3 = Ntuples(3, 'int'), Ntuples(3, 'S2')
>>> int_3 == str_3
False
```

CudaNtuples.contains_all

`CudaNtuples.`**`contains_all`**`(`*`other`*`)`

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

CudaNtuples.contains_set

CudaNtuples.**contains_set**(*other*)

Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

CudaNtuples.element

CudaNtuples.**element**(*inp=None*, *data_ptr=None*)

Create a new element.

Parametersinp : *array-like* or scalar, optional

Input to initialize the new element.

If `inp` is a `numpy.ndarray` of shape `(size,)` and the same data type as this space, the array is wrapped, not copied. Other array-like objects are copied (with broadcasting if necessary).

If a single value is given, it is copied to all entries.

If both `inp` and `data_ptr` are `None`, an empty element is created with no guarantee of its state (memory allocation only).

data_ptr : `int`, optional

Memory address of a CUDA array container

Cannot be combined with `inp`.

Returnselement : *CudaNtuplesVector*

The new element

Notes

This method preserves "array views" of correct size and type, see the examples below.

TODO: No, it does not yet!

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> x = uc3.element(np.array([1, 2, 3], dtype='uint8'))
>>> x
CudaNtuples(3, 'uint8').element([1, 2, 3])
>>> y = uc3.element([1, 2, 3])
>>> y
CudaNtuples(3, 'uint8').element([1, 2, 3])
```

__init__(*size*, *dtype*)

Initialize a new instance.

Parameterssize : `int`

The number entries per tuple

dtype : `object`

The data type for each tuple entry. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string.

Check `CUDA_DTYPES` for a list of available data types.

CudaNtuplesVector

class `odl.space.cu_ntuples.`**`CudaNtuplesVector`**(*space*, *data*)

Bases: *odl.space.base_ntuples.NtuplesBaseVector*, *odl.set.space.LinearSpaceVector*

Representation of a *CudaNtuples* element.

Attributes

T	The transpose of a vector, the functional given by (.
data	The data of this vector.
data_ptr	A raw pointer to the data of this vector.
dtype	Length of this vector, equal to space size.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions, always 1.
shape	Number of entries per axis, equals (size,) for linear storage.
size	Length of this vector, equal to space size.
space	Space to which this vector.
ufunc	*CudaNtuplesUFuncs*, access to numpy style ufuncs.

CudaNtuplesVector.T

`CudaNtuplesVector.`**`T`**

The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

CudaNtuplesVector.data

CudaNtuplesVector.**data**
The data of this vector.

ParametersNone

Returnsptr : CudaFnVectorImpl

Underlying cuda data representation

CudaNtuplesVector.data_ptr

CudaNtuplesVector.**data_ptr**
A raw pointer to the data of this vector.

CudaNtuplesVector.dtype

CudaNtuplesVector.**dtype**
Length of this vector, equal to space size.

CudaNtuplesVector.itemsize

CudaNtuplesVector.**itemsize**
The size in bytes on one element of this type.

CudaNtuplesVector.nbytes

CudaNtuplesVector.**nbytes**
The number of bytes this vector uses in memory.

CudaNtuplesVector.ndim

CudaNtuplesVector.**ndim**
Number of dimensions, always 1.

CudaNtuplesVector.shape

CudaNtuplesVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

CudaNtuplesVector.size

CudaNtuplesVector.**size**
Length of this vector, equal to space size.

CudaNtuplesVector.space

CudaNtuplesVector.**space**
Space to which this vector.

CudaNtuplesVector.ufunc

CudaNtuplesVector.**ufunc**
CudaNtuplesUFuncs, access to numpy style ufuncs.

See also:

odl.util.ufuncs.NtuplesBaseUFuncsBase class for ufuncs in *NtuplesBase* spaces.

Notes

Not all ufuncs are currently optimized, some use the default numpy implementation. This can be improved in the future.

Examples

```
>>> r2 = CudaRn(2)
>>> x = r2.element([1, -2])
>>> x.ufunc.absolute()
CudaRn(2).element([1.0, 2.0])
```

These functions can also be used with broadcasting

```
>>> x.ufunc.add(3)
CudaRn(2).element([4.0, 1.0])
```

and non-space elements

```
>>> x.ufunc.subtract([3, 3])
CudaRn(2).element([-2.0, -5.0])
```

There is also support for various reductions (sum, prod, min, max)

```
>>> x.ufunc.sum()
-1.0
```

Also supports out parameter

```
>>> y = r2.element([3, 4])
>>> out = r2.element()
>>> result = x.ufunc.add(y, out=out)
>>> result
CudaRn(2).element([4.0, 2.0])
>>> result is out
True
```

Methods

__eq__(other)	Return `self == other`.
__getitem__(indices)	Access values of this vector.
__setitem__(indices, values)	Set values of this vector.
asarray([start, stop, step, out])	Extract the data of this array as a numpy array.
assign(other)	Assign the values of `other` to self.
copy()	Create an identical (deep) copy of this vector.
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
set_zero()	Set this vector to zero.
show([title, method, show, fig])	Display the function graphically.

CudaNtuplesVector.__eq__

CudaNtuplesVector.**__eq__**(*other*)

Return `self == other`.

Returnsequals : `bool`

`True` if all elements of `other` are equal to this vector's elements, `False` otherwise

Examples

```
>>> r3 = CudaNtuples(3, 'float32')
>>> x = r3.element([1, 2, 3])
>>> x == x
True
>>> y = r3.element([1, 2, 3])
>>> x == y
True
>>> y = r3.element([0, 0, 0])
>>> x == y
False
>>> r3_2 = CudaNtuples(3, 'uint8')
>>> z = r3_2.element([1, 2, 3])
>>> x != z
True
```

CudaNtuplesVector.__getitem__

CudaNtuplesVector.**__getitem__**(*indices*)

Access values of this vector.

This will cause the values to be copied to CPU which is a slow operation.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : scalar or *CudaNtuplesVector*

The value(s) at the index (indices)

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> y = uc3.element([1, 2, 3])
>>> y[0]
1
>>> z = y[1:3]
>>> z
CudaNtuples(2, 'uint8').element([2, 3])
>>> y[::2]
CudaNtuples(2, 'uint8').element([1, 3])
>>> y[::-1]
CudaNtuples(3, 'uint8').element([3, 2, 1])
```

The returned value is a view, modifications are reflected in the original data:

```
>>> z[:] = [4, 5]
>>> y
CudaNtuples(3, 'uint8').element([1, 4, 5])
```

CudaNtuplesVector.__setitem__

CudaNtuplesVector.**__setitem__**(*indices*, *values*)

Set values of this vector.

This will cause the values to be copied to CPU which is a slow operation.

Parameters

indices : `int` or `slice`

The position(s) that should be set

values : scalar, *array-like* or *CudaNtuplesVector*

The value(s) that are to be assigned.

If `index` is an `int`, `value` must be single value.

If `index` is a `slice`, `value` must be broadcastable to the size of the slice (same size, shape (1,) or single value).

Returns

`None`

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> y = uc3.element([1, 2, 3])
>>> y[0] = 5
>>> y
CudaNtuples(3, 'uint8').element([5, 2, 3])
>>> y[1:3] = [7, 8]
>>> y
CudaNtuples(3, 'uint8').element([5, 7, 8])
>>> y[:] = np.array([0, 0, 0])
>>> y
CudaNtuples(3, 'uint8').element([0, 0, 0])
```

Scalar assignment

```
>>> y[:] = 5
>>> y
CudaNtuples(3, 'uint8').element([5, 5, 5])
```

CudaNtuplesVector.asarray

CudaNtuplesVector.**asarray**(*start=None*, *stop=None*, *step=None*, *out=None*)

Extract the data of this array as a numpy array.

Parametersstart : int, optional

Start position. None means the first element.

start : int, optional

One element past the last element to be extracted. None means the last element.

start : int, optional

Step length. None means 1.

out : numpy.ndarray

Array in which the result should be written in-place. Has to be contiguous and of the correct dtype.

Returnsasarray : numpy.ndarray

Numpy array of the same type as the space.

Examples

```
>>> uc3 = CudaNtuples(3, 'uint8')
>>> y = uc3.element([1, 2, 3])
>>> y.asarray()
array([1, 2, 3], dtype=uint8)
>>> y.asarray(1, 3)
array([2, 3], dtype=uint8)
```

Using the out parameter

```
>>> out = np.empty((3,), dtype='uint8')
>>> result = y.asarray(out=out)
>>> out
array([1, 2, 3], dtype=uint8)
>>> result is out
True
```

CudaNtuplesVector.assign

CudaNtuplesVector.**assign**(*other*)

Assign the values of other to self.

CudaNtuplesVector.copy

CudaNtuplesVector.**copy**()
Create an identical (deep) copy of this vector.

Returnscopy : *CudaNtuplesVector*

The deep copy

Examples

```
>>> vec1 = CudaNtuples(3, 'uint8').element([1, 2, 3])
>>> vec2 = vec1.copy()
>>> vec2
CudaNtuples(3, 'uint8').element([1, 2, 3])
>>> vec1 == vec2
True
>>> vec1 is vec2
False
```

CudaNtuplesVector.dist

CudaNtuplesVector.**dist**(*other*)
Distance to `other`.

LinearSpace.dist

CudaNtuplesVector.divide

CudaNtuplesVector.**divide**(*x*, *y*)
Divide by `other` inplace.

LinearSpace.divide

CudaNtuplesVector.inner

CudaNtuplesVector.**inner**(*other*)
Inner product with `other`.

LinearSpace.inner

CudaNtuplesVector.lincomb

CudaNtuplesVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

CudaNtuplesVector.multiply

CudaNtuplesVector.**multiply**(*x*, *y*)
Multiply by `other` inplace.

LinearSpace.multiply

CudaNtuplesVector.norm

CudaNtuplesVector.**norm**()
Norm of vector

LinearSpace.norm

CudaNtuplesVector.set_zero

CudaNtuplesVector.**set_zero**()
Set this vector to zero.

LinearSpace.zero

CudaNtuplesVector.show

CudaNtuplesVector.**show**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)
Display the function graphically.

Parameterstitle : `str`, optional

Set the title of the figure

method : `str`, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : `bool`, optional

If the plot should be showed now or deferred until later.

fig : `matplotlib.figure.Figure`

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that `fig` is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : `matplotlib.figure.Figure`

The resulting figure. It is also shown to the user.

See also:

odl.util.graphics.show_discrete_dataUnderlying implementation

__init__ (*space*, *data*)
Initialize a new instance.

Functions

CudaRn(size[, dtype])	The real space R^n, implemented in CUDA.
cu_weighted_dist(weight[, exponent])	Weighted distance on *CudaFn* spaces as free function.
cu_weighted_inner(weight)	Weighted inner product on *CudaFn* spaces as free function.
cu_weighted_norm(weight[, exponent])	Weighted norm on *CudaFn* spaces as free function.

CudaRn

odl.space.cu_ntuples.**CudaRn** (*size*, *dtype='float32'*, ***kwargs*)
The real space R^n, implemented in CUDA.

Requires the compiled ODL extension odlpp.

Parameterssize : positive `int`

The number of dimensions of the space

dtype : optional

The data type of the storage array. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string.

Only real floating-point data types are allowed.

kwargs : {'weight', 'exponent', 'dist', 'norm', 'inner'}

See *CudaFn*

cu_weighted_dist

odl.space.cu_ntuples.**cu_weighted_dist** (*weight*, *exponent=2.0*)
Weighted distance on *CudaFn* spaces as free function.

Parametersweight : scalar, *array-like* or *CudaFnVector*

Weight of the inner product. A scalar is interpreted as a constant weight and a 1-dim. array or a *CudaFnVector* as a weighting vector.

exponent : positive `float`

Exponent of the distance

Returnsdist : `callable`

Distance function with given weight. Constant weightings are applicable to spaces of any size, for arrays the sizes of the weighting and the space must match.

See also:

CudaFnConstWeighting, *CudaFnVectorWeighting*

cu_weighted_inner

odl.space.cu_ntuples.**cu_weighted_inner**(*weight*)
Weighted inner product on *CudaFn* spaces as free function.

Parameters
weight : scalar, *array-like* or *CudaFnVector*

Weight of the inner product. A scalar is interpreted as a constant weight and a 1-dim. array or a *CudaFnVector* as a weighting vector.

Returns
inner : callable

Inner product function with given weight. Constant weightings are applicable to spaces of any size, for arrays the sizes of the weighting and the space must match.

See also:

CudaFnConstWeighting, *CudaFnVectorWeighting*

cu_weighted_norm

odl.space.cu_ntuples.**cu_weighted_norm**(*weight*, *exponent=2.0*)
Weighted norm on *CudaFn* spaces as free function.

Parameters
weight : scalar, *array-like* or *CudaFnVector*

Weight of the inner product. A scalar is interpreted as a constant weight and a 1-dim. array or a *CudaFnVector* as a weighting vector.

exponent : positive `float`

Exponent of the norm. If `weight` is a sparse matrix, only 1.0, 2.0 and `inf` are allowed.

Returns
norm : callable

Norm function with given weight. Constant weightings are applicable to spaces of any size, for arrays the sizes of the weighting and the space must match.

See also:

CudaFnConstWeighting, *CudaFnVectorWeighting*

8.6.3 fspace

Spaces of functions with common domain and range.

Classes

FunctionSet(domain, range[, out_dtype])	A general set of functions with common domain and range.
FunctionSetVector(fset, fcall[, out_dtype])	Representation of a *FunctionSet* element.
FunctionSpace(domain[, field, out_dtype])	A vector space of functions.
FunctionSpaceVector(fspace, fcall)	Representation of a *FunctionSpace* element.

FunctionSet

class odl.space.fspace.**FunctionSet**(*domain*, *range*, *out_dtype=None*)
Bases: *odl.set.sets.Set*

A general set of functions with common domain and range.

Attributes

domain	Common domain of all functions in this set.
element_type	*FunctionSetVector*
out_dtype	Output data type of functions in this space.
range	Common range of all functions in this set.

FunctionSet.domain

FunctionSet.**domain**
Common domain of all functions in this set.

FunctionSet.element_type

FunctionSet.**element_type**
FunctionSetVector

FunctionSet.out_dtype

FunctionSet.**out_dtype**
Output data type of functions in this space.

FunctionSet.range

FunctionSet.**range**
Common range of all functions in this set.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([fcall, vectorized])	Create a *FunctionSet* element.

FunctionSet.__contains__

FunctionSet.**__contains__**(*other*)
Return `other in self`.

Returnsequals : `bool`

`True` if `other` is a *FunctionSetVector* whose *FunctionSetVector.space* attribute equals this space, `False` otherwise.

FunctionSet.__eq__

FunctionSet.**__eq__**(*other*)
Return `self == other`.

Returnsequals : `bool`

`True` if `other` is a *FunctionSet* with same *FunctionSet.domain* and *FunctionSet.range*, `False` otherwise.

FunctionSet.contains_all

FunctionSet.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

FunctionSet.contains_set

FunctionSet.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

FunctionSet.element

FunctionSet.**element**(*fcall=None*, *vectorized=True*)
Create a *FunctionSet* element.

Parametersfcall : `callable`, optional

The actual instruction for out-of-place evaluation. It must return an *FunctionSet.range* element or a `numpy.ndarray` of such (vectorized call).

vectorized : bool

Whether `fcall` supports vectorized evaluation.

Returnselement : *FunctionSetVector*

The new element, always supports vectorization

See also:

odl.discr.grid.TensorGrid.meshgridefficient grids for function evaluation

__init__(*domain*, *range*, *out_dtype=None*)
Initialize a new instance.

Parametersdomain : *Set*

The domain of the functions.

range : *Set*

The range of the functions.

out_dtype : optional

Data type of the return value of a function in this space. Can be given in any way `numpy.dtype` understands, e.g. as string ('bool') or data type (`bool`). If no data type is given, a "lazy" evaluation is applied, i.e. an adequate data type is inferred during function evaluation.

FunctionSetVector

class `odl.space.fspace.`**`FunctionSetVector`**(*fset*, *fcall*, *out_dtype=None*)

Bases: *odl.operator.operator.Operator*

Representation of a *FunctionSet* element.

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.
space	The space or set this function belongs to.

FunctionSetVector.adjoint

`FunctionSetVector.`**`adjoint`**

The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

FunctionSetVector.domain

`FunctionSetVector.`**`domain`**

Set of objects on which this operator can be evaluated.

FunctionSetVector.inverse

`FunctionSetVector.`**`inverse`**

Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

FunctionSetVector.is_functional

`FunctionSetVector.`**`is_functional`**

`True` if the this operator's range is a *Field*.

FunctionSetVector.is_linear

FunctionSetVector.**is_linear**
`True` if this operator is linear.

FunctionSetVector.range

FunctionSetVector.**range**
Set in which the result of an evaluation of this operator lies.

FunctionSetVector.space

FunctionSetVector.**space**
The space or set this function belongs to.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__(other)	Returns `vec == other`.
_call(x[, out])	Raw evaluation method.
assign(other)	Assign `other` to this vector.
copy()	Create an identical (deep) copy of this vector.
derivative(point)	Return the operator derivative at `point`.

FunctionSetVector.__call__

FunctionSetVector.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Parametersx : domain *element-like*, *meshgrid* or `numpy.ndarray`

Input argument for the function evaluation. Conditions on `x` depend on its type:

element-like: must be a castable to a domain element

meshgrid: length must be `space.ndim`, and the arrays must be broadcastable against each other.

array: shape must be `(d, N)`, where `d` is the number of dimensions of the function domain

out : `numpy.ndarray`, optional

Output argument holding the result of the function evaluation, can only be used for vectorized functions. Its shape must be equal to `np.broadcast(*x).shape`.

bounds_check : `bool`

If `True`, check if all input points lie in the function domain in the case of vectorized evaluation. This requires the domain to implement *Set.contains_all*. Default: `True`

Returnsout : range element or array of elements

Result of the function evaluation. If `out` was provided, the returned object is a reference to it.

RaisesTypeError

If `x` is not a valid vectorized evaluation argument

If `out` is not a range element or a `numpy.ndarray` of range elements

ValueError

If evaluation points fall outside the valid domain

FunctionSetVector.__eq__

`FunctionSetVector.__eq__`(*other*)

Returns `vec == other`.

Returnsequals : `bool`

`True` if `other` is a *FunctionSetVector* with `other.space` equal to this vector's space and evaluation function of `other` and this vector is equal. `False` otherwise.

FunctionSetVector._call

`FunctionSetVector._call`(*x*, *out=None*, ***kwargs*)

Raw evaluation method.

FunctionSetVector.assign

`FunctionSetVector.assign`(*other*)

Assign `other` to this vector.

This is implemented without *FunctionSpace.lincomb* to ensure that `vec == other` evaluates to `True` after `vec.assign(other)`.

FunctionSetVector.copy

`FunctionSetVector.copy`()

Create an identical (deep) copy of this vector.

FunctionSetVector.derivative

`FunctionSetVector.derivative`(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*fset*, *fcall*, *out_dtype=None*)

Initialize a new instance.

Parametersfset : *FunctionSet*

The set of functions this element lives in

fcall : `callable`

The actual instruction for out-of-place evaluation. It must return an *FunctionSet.range* element or a `numpy.ndarray` of such (vectorized call).

out_d

FunctionSpace

class `odl.space.fspace.`**FunctionSpace**(*domain*, *field=None*, *out_dtype=None*)

Bases: *odl.space.fspace.FunctionSet*, *odl.set.space.LinearSpace*

A vector space of functions.

Attributes

domain	Common domain of all functions in this set.
element_type	*FunctionSpaceVector*
field	The field of this vector space.
out_dtype	Output data type of functions in this space.
range	Common range of all functions in this set.

FunctionSpace.domain

`FunctionSpace.`**domain**

Common domain of all functions in this set.

FunctionSpace.element_type

`FunctionSpace.`**element_type**

FunctionSpaceVector

FunctionSpace.field

`FunctionSpace.`**field**

The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

FunctionSpace.out_dtype

`FunctionSpace.`**out_dtype**

Output data type of functions in this space.

FunctionSpace.range

FunctionSpace.**range**
Common range of all functions in this set.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Returns `s == other`.
_dist(x1, x2)	Calculate the distance between x1 and x2.
_divide(x1, x2, out)	Raw pointwise division of two functions.
_inner(x1, x2)	Calculate the inner product of x1 and x2.
_lincomb(a, x1, b, x2, out)	Raw linear combination of `x1` and `x2`.
_multiply(x1, x2, out)	Raw pointwise multiplication of two functions.
_norm(x)	Calculate the norm of x.
astype(out_dtype)	Return a copy of this space with new `out_dtype`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([fcall, vectorized])	Create a *FunctionSpace* element.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	The function mapping everything to one.
zero()	The function mapping everything to zero.

FunctionSpace.__contains__

FunctionSpace.**__contains__**(*other*)
Return `other in self`.

Returnsequals : `bool`

`True` if `other` is a *FunctionSetVector* whose *FunctionSetVector.space* attribute equals this space, `False` otherwise.

FunctionSpace.__eq__

FunctionSpace.**__eq__**(*other*)
Returns `s == other`.

Returnsequals : `bool`

`True` if `other` is a *FunctionSpace* with same *FunctionSpace.domain* and *FunctionSpace.range*, `False` otherwise.

FunctionSpace._dist

FunctionSpace.**_dist**(*x1*, *x2*)
Calculate the distance between x1 and x2.

This method is intended to be private, public callers should resort to *dist* which is type-checked.

FunctionSpace._divide

FunctionSpace.**_divide**(*x1*, *x2*, *out*)
Raw pointwise division of two functions.

FunctionSpace._inner

FunctionSpace.**_inner**(*x1*, *x2*)
Calculate the inner product of x1 and x2.

This method is intended to be private, public callers should resort to *inner* which is type-checked.

FunctionSpace._lincomb

FunctionSpace.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)
Raw linear combination of `x1` and `x2`.

Notes

The additions and multiplications are implemented via simple Python functions, so non-vectorized versions are slow.

FunctionSpace._multiply

FunctionSpace.**_multiply**(*x1*, *x2*, *out*)
Raw pointwise multiplication of two functions.

Notes

The multiplication is implemented with a simple Python function, so the non-vectorized versions are slow.

FunctionSpace._norm

FunctionSpace.**_norm**(*x*)
Calculate the norm of x.

This method is intended to be private, public callers should resort to *norm* which is type-checked.

FunctionSpace.astype

FunctionSpace.**astype**(*out_dtype*)

Return a copy of this space with new `out_dtype`.

Parametersout_dtype : optional

Output data type of the returned space. Can be given in any way `numpy.dtype` understands, e.g. as string ('complex64') or data type (`complex`). `None` is interpreted as 'float64'.

Returnsnewspace : *FunctionSpace*

The version of this space with given data type

FunctionSpace.contains_all

FunctionSpace.**contains_all**(*other*)

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

FunctionSpace.contains_set

FunctionSpace.**contains_set**(*other*)

Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

FunctionSpace.dist

FunctionSpace.**dist**(*x1*, *x2*)

Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

FunctionSpace.divide

FunctionSpace.**divide**(*x1*, *x2*, *out=None*)

Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

FunctionSpace.element

`FunctionSpace.`**`element`**(*fcall=None*, *vectorized=True*)

Create a *FunctionSpace* element.

Parametersfcall : `callable`, optional

The actual instruction for out-of-place evaluation. It must return an *FunctionSet.range* element or a `numpy.ndarray` of such (vectorized call).

If fcall is a *FunctionSetVector*, it is wrapped as a new *FunctionSpaceVector*.

vectorized : bool

Whether `fcall` supports vectorized evaluation.

Returnselement : *FunctionSpaceVector*

The new element, always supports vectorization

Notes

If you specify `vectorized=False`, the function is decorated with a vectorizer, which makes two elements created this way from the same function being regarded as *not equal*.

FunctionSpace.inner

`FunctionSpace.`**`inner`**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

FunctionSpace.lincomb

`FunctionSpace.`**`lincomb`**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

FunctionSpace.multiply

`FunctionSpace.`**`multiply`**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

FunctionSpace.norm

`FunctionSpace.`**`norm`**(*x*)

Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

FunctionSpace.one

`FunctionSpace.`**`one`**`()`
The function mapping everything to one.

This function is the multiplicative unit in the function space.

FunctionSpace.zero

`FunctionSpace.`**`zero`**`()`
The function mapping everything to zero.

This function is the additive unit in the function space.

Since *`FunctionSpace.lincomb`* may be slow, we implement this function directly.

`__init__`(*domain*, *field=None*, *out_dtype=None*)
Initialize a new instance.

Parametersdomain : *`Set`*

The domain of the functions

field : *`Field`*, optional

The range of the functions, usually the *`RealNumbers`* or *`ComplexNumbers`*. If not given, the field is either inferred from `out_dtype`, or, if the latter is also `None`, set to `RealNumbers()`.

out_dtype : optional

Data type of the return value of a function in this space. Can be given in any way `numpy.dtype` understands, e.g. as string ('float64') or data type (`float`). By default, 'float64' is used for real and 'complex128' for complex spaces.

FunctionSpaceVector

class `odl.space.fspace.`**`FunctionSpaceVector`**(*fspace*, *fcall*)
Bases: *`odl.set.space.LinearSpaceVector`*, *`odl.space.fspace.FunctionSetVector`*

Representation of a *`FunctionSpace`* element.

Attributes

`T`	The transpose of a vector, the functional given by (.
`adjoint`	The operator adjoint (abstract).
`domain`	Set of objects on which this operator can be evaluated.
`imag`	Pointwise imaginary part of this function.
`inverse`	Return the operator inverse.
`is_functional`	`True` if the this operator's range is a *`Field`*.
`is_linear`	`True` if this operator is linear.
`range`	Set in which the result of an evaluation of this operator lies.

Continued on next page

Table 8.196 – continued from previous page

real	Pointwise real part of this function.
space	Space to which this vector belongs.

FunctionSpaceVector.T

FunctionSpaceVector.**T**
The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

FunctionSpaceVector.adjoint

FunctionSpaceVector.**adjoint**
The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

FunctionSpaceVector.domain

FunctionSpaceVector.**domain**
Set of objects on which this operator can be evaluated.

FunctionSpaceVector.imag

FunctionSpaceVector.**imag**
Pointwise imaginary part of this function.

FunctionSpaceVector.inverse

FunctionSpaceVector.**inverse**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

FunctionSpaceVector.is_functional

FunctionSpaceVector.**is_functional**
`True` if the this operator's range is a *Field*.

FunctionSpaceVector.is_linear

FunctionSpaceVector.**is_linear**
`True` if this operator is linear.

FunctionSpaceVector.range

FunctionSpaceVector.**range**
Set in which the result of an evaluation of this operator lies.

FunctionSpaceVector.real

FunctionSpaceVector.**real**
Pointwise real part of this function.

FunctionSpaceVector.space

FunctionSpaceVector.**space**
Space to which this vector belongs.

LinearSpace

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__(other)	Returns `vec == other`.
_call(x[, out])	Raw evaluation method.
assign(other)	Assign `other` to this vector.
conj()	Pointwise complex conjugate of this function.
copy()	Create an identical (deep) copy of this vector.
derivative(point)	Return the operator derivative at `point`.
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.

Continued on next page

Table 8.197 – continued from previous page

lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
set_zero()	Set this vector to zero.

FunctionSpaceVector.__call__

`FunctionSpaceVector.__call__`(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Parametersx : domain *element-like*, *meshgrid* or `numpy.ndarray`

Input argument for the function evaluation. Conditions on `x` depend on its type:

element-like: must be a castable to a domain element

meshgrid: length must be `space.ndim`, and the arrays must be broadcastable against each other.

array: shape must be `(d, N)`, where `d` is the number of dimensions of the function domain

out : `numpy.ndarray`, optional

Output argument holding the result of the function evaluation, can only be used for vectorized functions. Its shape must be equal to `np.broadcast(*x).shape`.

bounds_check : `bool`

If `True`, check if all input points lie in the function domain in the case of vectorized evaluation. This requires the domain to implement *Set.contains_all*. Default: `True`

Returnsout : range element or array of elements

Result of the function evaluation. If `out` was provided, the returned object is a reference to it.

RaisesTypeError

If `x` is not a valid vectorized evaluation argument

If `out` is not a range element or a `numpy.ndarray` of range elements

ValueError

If evaluation points fall outside the valid domain

FunctionSpaceVector.__eq__

`FunctionSpaceVector.__eq__`(*other*)

Returns `vec == other`.

Returnsequals : `bool`

`True` if `other` is a *FunctionSetVector* with `other.space` equal to this vector's space and evaluation function of `other` and this vector is equal. `False` otherwise.

FunctionSpaceVector._call

FunctionSpaceVector.**_call**(*x*, *out=None*, ***kwargs*)
Raw evaluation method.

FunctionSpaceVector.assign

FunctionSpaceVector.**assign**(*other*)
Assign `other` to this vector.

This is implemented without *FunctionSpace.lincomb* to ensure that `vec == other` evaluates to `True` after `vec.assign(other)`.

FunctionSpaceVector.conj

FunctionSpaceVector.**conj**()
Pointwise complex conjugate of this function.

FunctionSpaceVector.copy

FunctionSpaceVector.**copy**()
Create an identical (deep) copy of this vector.

FunctionSpaceVector.derivative

FunctionSpaceVector.**derivative**(*point*)
Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

FunctionSpaceVector.dist

FunctionSpaceVector.**dist**(*other*)
Distance to `other`.

LinearSpace.dist

FunctionSpaceVector.divide

FunctionSpaceVector.**divide**(*x*, *y*)
Divide by `other` inplace.

LinearSpace.divide

FunctionSpaceVector.inner

FunctionSpaceVector.**inner**(*other*)
Inner product with `other`.

LinearSpace.inner

FunctionSpaceVector.lincomb

FunctionSpaceVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)
Assign a linear combination to this vector.

Implemented as `space.lincomb(a, x1, b, x2, out=self)`.

LinearSpace.lincomb

FunctionSpaceVector.multiply

FunctionSpaceVector.**multiply**(*x*, *y*)
Multiply by `other` inplace.

LinearSpace.multiply

FunctionSpaceVector.norm

FunctionSpaceVector.**norm**()
Norm of vector

LinearSpace.norm

FunctionSpaceVector.set_zero

FunctionSpaceVector.**set_zero**()
Set this vector to zero.

LinearSpace.zero

__init__(*fspace*, *fcall*)
Initialize a new instance.

Parametersfspace : *FunctionSpace*

The set of functions this element lives in

fcall : `callable`

The actual instruction for out-of-place evaluation. It must return an *FunctionSet.range* element or a `numpy.ndarray` of such (vectorized call).

8.6.4 ntuples

CPU implementations of `n`-dimensional Cartesian spaces.

Classes

Fn(size, dtype, **kwargs)	The vector space F^n with vector multiplication.
FnConstWeighting(constant[, exponent, ...])	Weighting of *Fn* by a constant.
FnCustomDist(dist)	Custom distance on *Fn*, removes `norm` and `inner`.
FnCustomInnerProduct(inner[, dist_using_inner])	Custom inner product on *Fn*.
FnCustomNorm(norm)	Custom norm on *Fn*, removes `inner`.
FnMatrixWeighting(matrix[, exponent, ...])	Matrix weighting for *Fn*.
FnNoWeighting([exponent, dist_using_inner])	Weighting of *Fn* with constant 1.
FnVector(space, data)	Representation of an *Fn* element.
FnVectorWeighting(vector[, exponent, ...])	Vector weighting for *Fn*.
MatVecOperator(matrix[, dom, ran])	Matrix multiply operator $\mathbb{F}^n -> \mathbb{F}^m$.
Ntuples(size, dtype)	The set of n-tuples of arbitrary type.
NtuplesVector(space, data)	Representation of an *Ntuples* element.

Fn

class `odl.space.ntuples.`**`Fn`**(*size*, *dtype*, ***kwargs*)

Bases: *odl.space.base_ntuples.FnBase*, *odl.space.ntuples.Ntuples*

The vector space F^n with vector multiplication.

This space implements n-tuples of elements from a *Field* `F`, which is usually the real or complex numbers.

Its elements are represented as instances of the *FnVector* class.

Attributes

dtype	The data type of each entry.
element_type	Return *FnVector*.
exponent	Exponent of the norm and distance.
field	The field of this vector space.
is_cn	Return `True` if the space represents C^n, i.e.
is_rn	Return `True` if the space represents R^n, i.e.
is_weighted	Return `True` if the weighting is not *FnNoWeighting*.
shape	The shape of this space.
size	The number of entries per tuple.
weighting	This space's weighting scheme.

Fn.dtype

`Fn.`**`dtype`**

The data type of each entry.

Fn.element_type

`Fn.`**`element_type`**

Return *FnVector*.

Fn.exponent

Fn.**exponent**
Exponent of the norm and distance.

Fn.field

Fn.**field**
The field of this vector space.

The field is the set of scalars of the space, that is numbers that the vectors in the space can be multiplied with.

Returnsfield : *Field*

The underlying field.

Fn.is_cn

Fn.**is_cn**
Return `True` if the space represents C^n, i.e. complex tuples.

Fn.is_rn

Fn.**is_rn**
Return `True` if the space represents R^n, i.e. real tuples.

Fn.is_weighted

Fn.**is_weighted**
Return `True` if the weighting is not *FnNoWeighting*.

Fn.shape

Fn.**shape**
The shape of this space.

Fn.size

Fn.**size**
The number of entries per tuple.

Fn.weighting

Fn.**weighting**
This space's weighting scheme.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
_dist(x1, x2)	Calculate the distance between two vectors.
_divide(x1, x2, out)	The entry-wise division of two vectors, assigned to out.
_inner(x1, x2)	Raw inner product of two vectors.
_lincomb(a, x1, b, x2, out)	Linear combination of `x1` and `x2`.
_multiply(x1, x2, out)	The entry-wise product of two vectors, assigned to out.
_norm(x)	Calculate the norm of a vector.
astype(dtype)	Return a copy of this space with new `dtype`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
default_dtype(field)	Return the default of *Fn* data type for a given field.
dist(x1, x2)	Calculate the distance between two vectors.
divide(x1, x2[, out])	Calculate the pointwise division of `x1` and `x2`
element([inp, data_ptr])	Create a new element.
inner(x1, x2)	Calculate the inner product of `x1` and `x2`.
lincomb(a, x1[, b, x2, out])	Linear combination of vectors.
multiply(x1, x2[, out])	Calculate the pointwise product of `x1` and `x2`.
norm(x)	Calculate the norm of a vector.
one()	Create a vector of ones.
zero()	Create a vector of zeros.

Fn.__contains__

Fn.**__contains__**(*other*)
Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *NtuplesBaseVector* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

Fn.__eq__

Fn.**__eq__**(*other*)
Return `self == other`.

Returnsequals : `bool`

`True` if other is an instance of this space's type with the same *NtuplesBase.size* and *NtuplesBase.dtype*, and identical distance function, otherwise `False`.

Examples

```
>>> from numpy.linalg import norm
>>> def dist(x, y, ord):
...     return norm(x - y, ord)
```

```
>>> from functools import partial
>>> dist2 = partial(dist, ord=2)
>>> c3 = Cn(3, dist=dist2)
>>> c3_same = Cn(3, dist=dist2)
>>> c3  == c3_same
True
```

Different `dist` functions result in different spaces - the same applies for `norm` and `inner`:

```
>>> dist1 = partial(dist, ord=1)
>>> c3_1 = Cn(3, dist=dist1)
>>> c3_2 = Cn(3, dist=dist2)
>>> c3_1 == c3_2
False
```

Be careful with Lambdas - they result in non-identical function objects:

```
>>> c3_lambda1 = Cn(3, dist=lambda x, y: norm(x-y, ord=1))
>>> c3_lambda2 = Cn(3, dist=lambda x, y: norm(x-y, ord=1))
>>> c3_lambda1 == c3_lambda2
False
```

An *Fn* space with the same data type is considered equal:

```
>>> c3 = Cn(3)
>>> f3_cdouble = Fn(3, dtype='complex128')
>>> c3 == f3_cdouble
True
```

Fn._dist

`Fn.`**`_dist`**(*x1*, *x2*)

Calculate the distance between two vectors.

Parametersx1, x2 : *FnVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

Distance between the vectors

Examples

```
>>> from numpy.linalg import norm
>>> c2_2 = Cn(2, dist=lambda x, y: norm(x - y, ord=2))
>>> x = c2_2.element([3+1j, 4])
>>> y = c2_2.element([1j, 4-4j])
>>> c2_2.dist(x, y)
5.0
```

```
>>> c2_2 = Cn(2, dist=lambda x, y: norm(x - y, ord=1))
>>> x = c2_2.element([3+1j, 4])
>>> y = c2_2.element([1j, 4-4j])
>>> c2_2.dist(x, y)
7.0
```

Fn._divide

Fn.**_divide**(*x1*, *x2*, *out*)

The entry-wise division of two vectors, assigned to out.

Parametersx1, x2 : *FnVector*

Dividend and divisor in the quotient

out : *FnVector*

Vector to which the result is written

ReturnsNone

Examples

```
>>> r3 = Rn(3)
>>> x = r3.element([3, 5, 6])
>>> y = r3.element([1, 2, 2])
>>> out = r3.element()
>>> r3.divide(x, y, out)  # out is returned
Rn(3).element([3.0, 2.5, 3.0])
>>> out
Rn(3).element([3.0, 2.5, 3.0])
```

Fn._inner

Fn.**_inner**(*x1*, *x2*)

Raw inner product of two vectors.

Parametersx1, x2 : *FnVector*

The vectors whose inner product is calculated

Returnsinner : *field element*

Inner product of the vectors

Examples

```
>>> import numpy as np
>>> c3 = Cn(2, inner=lambda x, y: np.vdot(y, x))
>>> x = c3.element([5+1j, -2j])
>>> y = c3.element([1, 1+1j])
>>> c3.inner(x, y) == (5+1j)*1 + (-2j)*(1-1j)
True
```

Define a space with custom inner product:

```
>>> weights = np.array([1., 2.])
>>> def weighted_inner(x, y):
...     return np.vdot(weights * y.data, x.data)
```

```
>>> c3w = Cn(2, inner=weighted_inner)
>>> x = c3w.element(x)  # elements must be cast (no copy)
>>> y = c3w.element(y)
>>> c3w.inner(x, y) == 1*(5+1j)*1 + 2*(-2j)*(1-1j)
True
```

Fn._lincomb

Fn.**_lincomb**(*a*, *x1*, *b*, *x2*, *out*)

Linear combination of `x1` and `x2`.

Calculate `out = a*x1 + b*x2` using optimized BLAS routines if possible.

Parametersa, b : *FnBase.field*

Scalars to multiply `x1` and `x2` with

x1, x2 : *FnVector*

Summands in the linear combination

out : *FnVector*

Vector to which the result is written

ReturnsNone

Examples

```
>>> c3 = Cn(3)
>>> x = c3.element([1+1j, 2-1j, 3])
>>> y = c3.element([4+0j, 5, 6+0.5j])
>>> out = c3.element()
>>> c3.lincomb(2j, x, 3-1j, y, out)  # out is returned
Cn(3).element([(10-2j), (17-1j), (18.5+1.5j)])
>>> out
Cn(3).element([(10-2j), (17-1j), (18.5+1.5j)])
```

Fn._multiply

Fn.**_multiply**(*x1*, *x2*, *out*)

The entry-wise product of two vectors, assigned to out.

Parametersx1, x2 : *FnVector*

Factors in the product

out : *FnVector*

Vector to which the result is written

ReturnsNone

Examples

```
>>> c3 = Cn(3)
>>> x = c3.element([5+1j, 3, 2-2j])
>>> y = c3.element([1, 2+1j, 3-1j])
>>> out = c3.element()
>>> c3.multiply(x, y, out)  # out is returned
Cn(3).element([(5+1j), (6+3j), (4-8j)])
>>> out
Cn(3).element([(5+1j), (6+3j), (4-8j)])
```

Fn._norm

`Fn.`**`_norm`**`(`*x*`)`

Calculate the norm of a vector.

Parametersx : *FnVector*

The vector whose norm is calculated

Returnsnorm : `float`

Norm of the vector

Examples

```
>>> import numpy as np
>>> c2_2 = Cn(2, norm=np.linalg.norm)  # 2-norm
>>> x = c2_2.element([3+1j, 1-5j])
>>> c2_2.norm(x)
6.0
```

```
>>> from functools import partial
>>> c2_1 = Cn(2, norm=partial(np.linalg.norm, ord=1))
>>> x = c2_1.element([3-4j, 12+5j])
>>> c2_1.norm(x)
18.0
```

Fn.astype

`Fn.`**`astype`**`(`*dtype*`)`

Return a copy of this space with new `dtype`.

Parametersdtype :

Data type of the returned space. Can be given in any way `numpy.dtype` understands, e.g. as string ('complex64') or data type (`complex`).

Returnsnewspace : *FnBase*

The version of this space with given data type

Fn.contains_all

Fn.**contains_all**(*other*)
Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

Fn.contains_set

Fn.**contains_set**(*other*)
Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

Fn.default_dtype

static Fn.**default_dtype**(*field*)
Return the default of *Fn* data type for a given field.

Parametersfield : *Field*

Set of numbers to be represented by a data type. Currently supported : *RealNumbers*, *ComplexNumbers*

Returnsdtype : `type`

Numpy data type specifier. The returned defaults are:

`RealNumbers()` : `np.dtype('float64')`

`ComplexNumbers()` : `np.dtype('complex128')`

Fn.dist

Fn.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

Parametersx1, x2 : *LinearSpaceVector*

Vectors whose distance to compute

Returnsdist : `float`

Distance between vectors

Fn.divide

Fn.**divide**(*x1*, *x2*, *out=None*)
Calculate the pointwise division of `x1` and `x2`

Parametersx1 : *LinearSpaceVector*

The dividend

x2 : *LinearSpaceVector*

The divisor

out : *LinearSpaceVector*, optional

Vector to write the ratio to

Returnsout : *LinearSpaceVector*

Ratio of the vectors. If `out` was provided, the returned object is a reference to it.

Fn.element

`Fn.`**`element`**(*inp=None*, *data_ptr=None*)

Create a new element.

Parametersinp : *array-like*, optional

Input to initialize the new element.

If `inp` is `None`, an empty element is created with no guarantee of its state (memory allocation only).

If `inp` is a `numpy.ndarray` of shape `(size,)` and the same data type as this space, the array is wrapped, not copied. Other array-like objects are copied.

Returnselement : *NtuplesVector*

The new element created (from `inp`).

Notes

This method preserves "array views" of correct size and type, see the examples below.

Examples

```
>>> strings3 = Ntuples(3, dtype='U1')  # 1-char strings
>>> x = strings3.element(['w', 'b', 'w'])
>>> print(x)
[w, b, w]
>>> x.space
Ntuples(3, '<U1')
```

Construction from data pointer:

```
>>> int3 = Ntuples(3, dtype='int')
>>> x = int3.element([1, 2, 3])
>>> y = int3.element(data_ptr=x.data_ptr)
>>> print(y)
[1, 2, 3]
>>> y[0] = 5
>>> print(x)
[5, 2, 3]
```

Fn.inner

`Fn.`**`inner`**(*x1*, *x2*)

Calculate the inner product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Factors in the inner product

Returnsout : *LinearSpace.field* element

Product of the vectors. If `out` was provided, the returned object is a reference to it.

Fn.lincomb

`Fn.`**`lincomb`**(*a*, *x1*, *b=None*, *x2=None*, *out=None*)

Linear combination of vectors.

Calculates

```
out = a * x1
```

or, if b and y are given,

```
out = a*x1 + b*x2
```

with error checking of types.

Parametersa : Scalar in the field of this space

Scalar to multiply `x1` with.

x1 : *LinearSpaceVector*

The first of the summands

b : Scalar, optional

Scalar to multiply `x2` with.

x2 : *LinearSpaceVector*, optional

The second of the summands

out : *LinearSpaceVector*, optional

The Vector that the result should be written to.

Returnsout : *LinearSpaceVector*

Result of the linear combination. If `out` was provided, the returned object is a reference to it.

Notes

The vectors `out`, `x1` and `x2` may be aligned, thus a call

```
space.lincomb(x, 2, x, 3.14, out=x)
```

is (mathematically) equivalent to

```
x = x * (1 + 2 + 3.14)
```

Fn.multiply

`Fn.`**`multiply`**(*x1*, *x2*, *out=None*)

Calculate the pointwise product of `x1` and `x2`.

Parametersx1, x2 : *LinearSpaceVector*

Multiplicands in the product

out : *LinearSpaceVector*, optional

Vector to write the product to

Returnsout : *LinearSpaceVector*

Product of the vectors. If `out` was provided, the returned object is a reference to it.

Fn.norm

`Fn.`**`norm`**`(`*x*`)`

Calculate the norm of a vector.

Parametersx : *LinearSpaceVector*

The vector

Returnsout : `float`

Norm of the vector

Fn.one

`Fn.`**`one`**`()`

Create a vector of ones.

Examples

```
>>> c3 = Cn(3)
>>> x = c3.one()
>>> x
Cn(3).element([(1+0j), (1+0j), (1+0j)])
```

Fn.zero

`Fn.`**`zero`**`()`

Create a vector of zeros.

Examples

```
>>> c3 = Cn(3)
>>> x = c3.zero()
>>> x
Cn(3).element([0j, 0j, 0j])
```

`__init__`(*size*, *dtype*, ***kwargs*)

Initialize a new instance.

Parameterssize : positive `int`

The number of dimensions of the space

dtype : `object`

The data type of the storage array. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as `numpy.dtype` or as `string`.

Only scalar data types are allowed.

weight : optional

Use weighted inner product, norm, and dist. The following types are supported as `weight`:

FnWeightingBase: Use this weighting as-is. Compatibility with this space's elements is not checked during init.

float: Weighting by a constant

array-like: Weighting by a matrix (2-dim. array) or a vector (1-dim. array, corresponds to a diagonal matrix). A matrix can also be given as a sparse matrix (`scipy.sparse.spmatrix`).

Default: no weighting

This option cannot be combined with `dist`, `norm` or `inner`.

exponent : positive `float`, optional

Exponent of the norm. For values other than 2.0, no inner product is defined. If `weight` is a sparse matrix, only 1.0, 2.0 and `inf` are allowed.

This option is ignored if `dist`, `norm` or `inner` is given.

Default: 2.0

dist : `callable`, optional

The distance function defining a metric on $\mathbb{F}^n$. It must accept two *FnVector* arguments and fulfill the following mathematical conditions for any three vectors x, y, z:

- $d(x, y) = d(y, x)$
- $d(x, y) \geq 0$
- $d(x, y) = 0 \Leftrightarrow x = y$
- $d(x, y) \geq d(x, z) + d(z, y)$

By default, `dist(x, y)` is calculated as `norm(x - y)`. This creates an intermediate array `x-y`, which can be avoided by choosing `dist_using_inner=True`.

This option cannot be combined with `weight`, `norm` or `inner`.

norm : `callable`, optional

The norm implementation. It must accept an *FnVector* argument, return a `float` and satisfy the following conditions for all vectors x, y and scalars s:

- $\|x\| \geq 0$
- $\|x\| = 0 \Leftrightarrow x = 0$
- $\|sx\| = |s|\|x\|$
- $\|x + y\| \leq \|x\| + \|y\|$.

By default, `norm(x)` is calculated as `inner(x, x)`.

This option cannot be combined with `weight`, `dist` or `inner`.

inner : `callable`, optional

The inner product implementation. It must accept two *FnVector* arguments, return a element from the field of the space (real or complex number) and satisfy the following conditions for all vectors x, y, z and scalars s:

- $\langle x, y \rangle = \overline{\langle y, x \rangle}$
- $\langle sx, y \rangle = s\langle x, y \rangle$
- $\langle x + z, y \rangle = \langle x, y \rangle + \langle z, y \rangle$
- $\langle x, x \rangle = 0 \Leftrightarrow x = 0$

This option cannot be combined with `weight`, `dist` or `norm`.

dist_using_inner : `bool`, optional

Calculate `dist` using the formula

$\|x - y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y \rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

This option can only be used if `exponent` is 2.0.

Default: `False`.

FnConstWeighting

class `odl.space.ntuples.`**`FnConstWeighting`**(*constant*, *exponent=2.0*, *dist_using_inner=False*)

Bases: *odl.space.base_ntuples.FnWeightingBase*

Weighting of *Fn* by a constant.

For exponent 2.0, a new weighted inner product with constant c is defined as

$\langle a, b \rangle_c := c\, b^H a$

with b^H standing for transposed complex conjugate.

For other exponents, only norm and dist are defined. In the case of exponent `inf`, the weighted norm is defined as

$\|a\|_{c,\infty} := c\|a\|_\infty$,

otherwise it is

$\|a\|_{c,p} := c^{1/p}\|a\|_p$.

Not that this definition does **not** fulfill the limit property in p, i.e.

$\lim_{p\to\infty}\|a\|_{c,p} = \|a\|_\infty \neq \|a\|_{c,\infty}$

unless $c = 1$.

The constant c must be positive.

Attributes

const	Weighting constant of this inner product.
exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

FnConstWeighting.const

`FnConstWeighting.`**`const`**
Weighting constant of this inner product.

FnConstWeighting.exponent

`FnConstWeighting.`**`exponent`**
Exponent of this weighting.

FnConstWeighting.impl

`FnConstWeighting.`**`impl`**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the constant-weighted distance between two vectors.
equiv(other)	Test if other is an equivalent weighting.
inner(x1, x2)	Calculate the constant-weighted inner product of two vectors.
norm(x)	Calculate the constant-weighted norm of a vector.

FnConstWeighting.__eq__

`FnConstWeighting.`**`__eq__`**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if other is an *FnConstWeighting* instance with the same constant, `False` otherwise.

FnConstWeighting.dist

`FnConstWeighting.`**`dist`**(*x1*, *x2*)
Calculate the constant-weighted distance between two vectors.

Parametersx1, x2 : *FnVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

FnConstWeighting.equiv

`FnConstWeighting.`**`equiv`**(*other*)
Test if other is an equivalent weighting.

Returnsequivalent : bool

True if other is an *FnWeightingBase* instance with the same *FnWeightingBase.impl*, which yields the same result as this inner product for any input, False otherwise. This is the same as equality if other is an *FnConstWeighting* instance, otherwise the *equiv* method of other is called.

FnConstWeighting.inner

FnConstWeighting.**inner**(*x1*, *x2*)

Calculate the constant-weighted inner product of two vectors.

Parametersx1, x2 : *FnVector*

Vectors whose inner product is calculated

Returnsinner : float or complex

The inner product of the two provided vectors

FnConstWeighting.norm

FnConstWeighting.**norm**(*x*)

Calculate the constant-weighted norm of a vector.

Parametersx1 : *FnVector*

Vector whose norm is calculated

Returnsnorm : float

The norm of the vector

__init__(*constant*, *exponent=2.0*, *dist_using_inner=False*)

Initialize a new instance.

Parametersconstant : positive float

Weighting constant of the inner product.

exponent : positive float

Exponent of the norm. For values other than 2.0, the inner product is not defined.

dist_using_inner : bool, optional

Calculate dist using the formula

$\|x - y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y\rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

Can only be used if exponent is 2.0.

FnCustomDist

class odl.space.ntuples.**FnCustomDist**(*dist*)

Bases: *odl.space.base_ntuples.FnWeightingBase*

Custom distance on *Fn*, removes norm and inner.

Attributes

dist	Custom distance of this instance..
exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

FnCustomDist.dist

FnCustomDist.**dist**
Custom distance of this instance..

FnCustomDist.exponent

FnCustomDist.**exponent**
Exponent of this weighting.

FnCustomDist.impl

FnCustomDist.**impl**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
equiv(other)	Test if `other` is an equivalent inner product.
inner(x1, x2)	Inner product is not defined for custom distance.
norm(x)	Norm is not defined for custom distance.

FnCustomDist.__eq__

FnCustomDist.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if other is an *FnCustomDist* instance with the same norm, `False` otherwise.

FnCustomDist.equiv

FnCustomDist.**equiv**(*other*)
Test if `other` is an equivalent inner product.

Should be overwritten, default tests for equality.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise.

FnCustomDist.inner

FnCustomDist.**inner**(*x1*, *x2*)
Inner product is not defined for custom distance.

FnCustomDist.norm

FnCustomDist.**norm**(*x*)
Norm is not defined for custom distance.

__init__(*dist*)
Initialize a new instance.

Parametersdist : callable

The distance function defining a metric on $\mathbb{F}^n$. It must accept two *FnVector* arguments and fulfill the following mathematical conditions for any three vectors x, y, z:

- $d(x, y) = d(y, x)$
- $d(x, y) \geq 0$
- $d(x, y) = 0 \Leftrightarrow x = y$
- $d(x, y) \geq d(x, z) + d(z, y)$

FnCustomInnerProduct

class odl.space.ntuples.**FnCustomInnerProduct**(*inner*, *dist_using_inner=False*)
Bases: *odl.space.base_ntuples.FnWeightingBase*

Custom inner product on *Fn*.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.
inner	Custom inner product of this instance..

FnCustomInnerProduct.exponent

FnCustomInnerProduct.**exponent**
Exponent of this weighting.

FnCustomInnerProduct.impl

FnCustomInnerProduct.**impl**
Implementation backend of this weighting.

FnCustomInnerProduct.inner

FnCustomInnerProduct.**inner**
Custom inner product of this instance..

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the distance between two vectors.
equiv(other)	Test if `other` is an equivalent inner product.
norm(x)	Calculate the norm of a vector.

FnCustomInnerProduct.__eq__

FnCustomInnerProduct.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if other is an *FnCustomInnerProduct* instance with the same inner product, `False` otherwise.

FnCustomInnerProduct.dist

FnCustomInnerProduct.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

This is the standard implementation using *norm*. Subclasses should override it for optimization purposes.

Parametersx1, x2 : *FnBaseVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

FnCustomInnerProduct.equiv

FnCustomInnerProduct.**equiv**(*other*)
Test if `other` is an equivalent inner product.

Should be overwritten, default tests for equality.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise.

FnCustomInnerProduct.norm

FnCustomInnerProduct.**norm**(*x*)
Calculate the norm of a vector.

This is the standard implementation using *inner*. Subclasses should override it for optimization purposes.

Parametersx1 : *FnBaseVector*

Vector whose norm is calculated

Returnsnorm : float

The norm of the vector

__init__(*inner*, *dist_using_inner=False*)
Initialize a new instance.

Parametersinner : callable

The inner product implementation. It must accept two *FnVector* arguments, return a element from the field of the space (real or complex number) and satisfy the following conditions for all vectors x, y, z and scalars s:

- $\langle x, y \rangle = \overline{\langle y, x \rangle}$
- $\langle sx, y \rangle = s\langle x, y \rangle$
- $\langle x + z, y \rangle = \langle x, y \rangle + \langle z, y \rangle$
- $\langle x, x \rangle = 0 \Leftrightarrow x = 0$

dist_using_inner : bool, optional

Calculate dist using the formula

$\|x - y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y \rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

FnCustomNorm

class odl.space.ntuples.**FnCustomNorm**(*norm*)
Bases: *odl.space.base_ntuples.FnWeightingBase*

Custom norm on *Fn*, removes inner.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.
norm	Custom norm of this instance..

FnCustomNorm.exponent

FnCustomNorm.**exponent**
Exponent of this weighting.

FnCustomNorm.impl

FnCustomNorm.**impl**
Implementation backend of this weighting.

FnCustomNorm.norm

FnCustomNorm.**norm**
Custom norm of this instance..

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the distance between two vectors.
equiv(other)	Test if `other` is an equivalent inner product.
inner(x1, x2)	Inner product is not defined for custom distance.

FnCustomNorm.__eq__

FnCustomNorm.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if other is an *FnCustomNorm* instance with the same norm, `False` otherwise.

FnCustomNorm.dist

FnCustomNorm.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

This is the standard implementation using *norm*. Subclasses should override it for optimization purposes.

Parametersx1, x2 : *FnBaseVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

FnCustomNorm.equiv

FnCustomNorm.**equiv**(*other*)
Test if `other` is an equivalent inner product.

Should be overwritten, default tests for equality.

Returnsequivalent : `bool`

`True` if `other` is a *FnWeightingBase* instance which yields the same result as this inner product for any input, `False` otherwise.

FnCustomNorm.inner

FnCustomNorm.**inner**(*x1*, *x2*)
Inner product is not defined for custom distance.

__init__ (*norm*)
Initialize a new instance.

Parametersnorm : callable

The norm implementation. It must accept an *FnVector* argument, return a float and satisfy the following conditions for all vectors x, y and scalars s:

- $\|x\| \geq 0$
- $\|x\| = 0 \Leftrightarrow x = 0$
- $\|sx\| = |s|\|x\|$
- $\|x + y\| \leq \|x\| + \|y\|$.

FnMatrixWeighting

class odl.space.ntuples.**FnMatrixWeighting**(*matrix*, *exponent=2.0*, *dist_using_inner=False*, ***kwargs*)

Bases: *odl.space.base_ntuples.FnWeightingBase*

Matrix weighting for *Fn*.

For exponent 2.0, a new weighted inner product with matrix W is defined as

$\langle a, b\rangle_W := b^H W a$

with b^H standing for transposed complex conjugate.

For other exponents, only norm and dist are defined. In the case of exponent inf, the weighted norm is

$\|a\|_{W,\infty} := \|Wa\|_\infty$,

otherwise it is

$\|a\|_{W,p} := \|W^{1/p} a\|_p$.

Not that this definition does **not** fulfill the limit property in p, i.e.

$\lim_{p\to\infty} \|a\|_{W,p} = \|a\|_\infty \neq \|a\|_{W,\infty}$

unless W is the identity matrix.

The matrix must be Hermitian and posivive definite, otherwise it does not define an inner product or norm, respectively. This is not checked during initialization.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.
matrix	Weighting matrix of this inner product.
matrix_issparse	Whether the representing matrix is sparse or not.

FnMatrixWeighting.exponent

FnMatrixWeighting.**exponent**
Exponent of this weighting.

FnMatrixWeighting.impl

FnMatrixWeighting.**impl**
Implementation backend of this weighting.

FnMatrixWeighting.matrix

FnMatrixWeighting.**matrix**
Weighting matrix of this inner product.

FnMatrixWeighting.matrix_issparse

FnMatrixWeighting.**matrix_issparse**
Whether the representing matrix is sparse or not.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the distance between two vectors.
equiv(other)	Test if other is an equivalent weighting.
inner(x1, x2)	Calculate the matrix-weighted inner product of two vectors.
matrix_isvalid()	Test if the matrix is positive definite Hermitian.
norm(x)	Calculate the matrix-weighted norm of a vector.

FnMatrixWeighting.__eq__

FnMatrixWeighting.**__eq__**(*other*)
Return `self == other`.

Returnsequals : `bool`

`True` if other is an *FnMatrixWeighting* instance with **identical** matrix, `False` otherwise.

See also:

equivtest for equivalent inner products

FnMatrixWeighting.dist

FnMatrixWeighting.**dist**(*x1*, *x2*)
Calculate the distance between two vectors.

This is the standard implementation using *norm*. Subclasses should override it for optimization purposes.

Parametersx1, x2 : *FnBaseVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

FnMatrixWeighting.equiv

FnMatrixWeighting.**equiv**(*other*)
Test if other is an equivalent weighting.

Returnsequivalent : bool

True if other is an *FnWeightingBase* instance with the same *FnWeightingBase.impl*, which yields the same result as this inner product for any input, False otherwise. This is checked by entry-wise comparison of this inner product's matrix with the matrix or constant of other.

FnMatrixWeighting.inner

FnMatrixWeighting.**inner**(*x1*, *x2*)
Calculate the matrix-weighted inner product of two vectors.

Parametersx1, x2 : *FnVector*

Vectors whose inner product is calculated

Returnsinner : float or complex

The inner product of the vectors

FnMatrixWeighting.matrix_isvalid

FnMatrixWeighting.**matrix_isvalid**()
Test if the matrix is positive definite Hermitian.

This test tries to calculate a Cholesky decomposition and can be very time-consuming for large matrices. Sparse matrices are not supported.

FnMatrixWeighting.norm

FnMatrixWeighting.**norm**(*x*)
Calculate the matrix-weighted norm of a vector.

Parametersx : *FnVector*

Vector whose norm is calculated

Returnsnorm : float

The norm of the vector

__init__(*matrix*, *exponent=2.0*, *dist_using_inner=False*, ***kwargs*)
Initialize a new instance.

Parametersmatrix : scipy.sparse.spmatrix or *array-like*, 2-dim.

Square weighting matrix of the inner product

exponent : positive float

Exponent of the norm. For values other than 2.0, the inner product is not defined. If matrix is a sparse matrix, only 1.0, 2.0 and inf are allowed.

dist_using_inner : bool, optional

Calculate `dist` using the formula

$\|x - y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y\rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

Can only be used if `exponent` is 2.0.

precomp_mat_pow : `bool`

If `True`, precompute the matrix power $W^{1/p}$ during initialization. This has no effect if `exponent` is 1.0, 2.0 or `inf`.

Default: `False`

cache_mat_pow : `bool`

If `True`, cache the matrix power $W^{1/p}$ during the first call to `norm` or `dist`. This has no effect if `exponent` is 1.0, 2.0 or `inf`.

Default: `False`

FnNoWeighting

class `odl.space.ntuples.`**`FnNoWeighting`**(*exponent=2.0*, *dist_using_inner=False*)

Bases: *odl.space.ntuples.FnConstWeighting*

Weighting of *Fn* with constant 1.

For exponent 2.0, the unweighted inner product is defined as

$\langle a, b\rangle := b^H a$

with b^H standing for transposed complex conjugate.

For other exponents, only norm and dist are defined.

Attributes

const	Weighting constant of this inner product.
exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.

FnNoWeighting.const

`FnNoWeighting.`**`const`**

Weighting constant of this inner product.

FnNoWeighting.exponent

`FnNoWeighting.`**`exponent`**

Exponent of this weighting.

FnNoWeighting.impl

FnNoWeighting.**impl**
Implementation backend of this weighting.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the constant-weighted distance between two vectors.
equiv(other)	Test if other is an equivalent weighting.
inner(x1, x2)	Calculate the constant-weighted inner product of two vectors.
norm(x)	Calculate the constant-weighted norm of a vector.

FnNoWeighting.__eq__

FnNoWeighting.**__eq__**(*other*)
Return `self == other`.

Returnsequal : `bool`

`True` if other is an *FnConstWeighting* instance with the same constant, `False` otherwise.

FnNoWeighting.dist

FnNoWeighting.**dist**(*x1*, *x2*)
Calculate the constant-weighted distance between two vectors.

Parametersx1, x2 : *FnVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

FnNoWeighting.equiv

FnNoWeighting.**equiv**(*other*)
Test if other is an equivalent weighting.

Returnsequivalent : `bool`

`True` if other is an *FnWeightingBase* instance with the same *FnWeightingBase.impl*, which yields the same result as this inner product for any input, `False` otherwise. This is the same as equality if `other` is an *FnConstWeighting* instance, otherwise the *equiv* method of `other` is called.

FnNoWeighting.inner

FnNoWeighting.**inner**(*x1*, *x2*)
Calculate the constant-weighted inner product of two vectors.

Parametersx1, x2 : *FnVector*

Vectors whose inner product is calculated

Returnsinner : `float` or `complex`

The inner product of the two provided vectors

FnNoWeighting.norm

`FnNoWeighting.`**`norm`**(*x*)

Calculate the constant-weighted norm of a vector.

Parametersx1 : *FnVector*

Vector whose norm is calculated

Returnsnorm : `float`

The norm of the vector

`__init__`(*exponent=2.0*, *dist_using_inner=False*)

Initialize a new instance.

Parametersexponent : positive `float`

Exponent of the norm. For values other than 2.0, the inner product is not defined.

dist_using_inner : `bool`, optional

Calculate `dist` using the formula

$\|x-y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y\rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

Can only be used if `exponent` is 2.0.

FnVector

class `odl.space.ntuples.`**`FnVector`**(*space*, *data*)

Bases: *odl.space.base_ntuples.FnBaseVector*, *odl.space.ntuples.NtuplesVector*

Representation of an *Fn* element.

Attributes

T	The transpose of a vector, the functional given by (.
data	The raw `numpy.ndarray` representing the data.
data_ptr	A raw pointer to the data container.
dtype	Length of this vector, equal to space size.
imag	The imaginary part of this vector.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions, always 1.
real	The real part of this vector.

Continued on next page

Table 8.213 – continued from previous page

shape	Number of entries per axis, equals (size,) for linear storage.
size	Length of this vector, equal to space size.
space	Space to which this vector.
ufunc	*NtuplesUFuncs*, access to numpy style ufuncs.

FnVector.T

FnVector.**T**

The transpose of a vector, the functional given by (. , self)

Returnstranspose : *InnerProductOperator*

Notes

This function is only defined in inner product spaces.

In a complex space, this takes the conjugate transpose of the vector.

Examples

```
>>> from odl import Rn
>>> import numpy as np
>>> rn = Rn(3)
>>> x = rn.element([1, 2, 3])
>>> y = rn.element([2, 1, 3])
>>> x.T(y)
13.0
```

FnVector.data

FnVector.**data**

The raw numpy.ndarray representing the data.

FnVector.data_ptr

FnVector.**data_ptr**

A raw pointer to the data container.

Examples

```
>>> import ctypes
>>> vec = Ntuples(3, 'int32').element([1, 2, 3])
>>> arr_type = ctypes.c_int32 * 3
>>> buffer = arr_type.from_address(vec.data_ptr)
>>> arr = np.frombuffer(buffer, dtype='int32')
>>> print(arr)
[1 2 3]
```

In-place modification via pointer:

```
>>> arr[0] = 5
>>> print(vec)
[5, 2, 3]
```

FnVector.dtype

FnVector.**dtype**
Length of this vector, equal to space size.

FnVector.imag

FnVector.**imag**
The imaginary part of this vector.

Returnsimag : *FnVector*

The imaginary part this vector as a vector in *Rn*

Examples

```
>>> c3 = Cn(3)
>>> x = c3.element([5+1j, 3, 2-2j])
>>> x.imag
Rn(3).element([1.0, 0.0, -2.0])
```

The *Rn* vector is really a view, so changes affect the original array:

```
>>> x.imag *= 2
>>> x
Cn(3).element([(5+2j), (3+0j), (2-4j)])
```

FnVector.itemsize

FnVector.**itemsize**
The size in bytes on one element of this type.

FnVector.nbytes

FnVector.**nbytes**
The number of bytes this vector uses in memory.

FnVector.ndim

FnVector.**ndim**
Number of dimensions, always 1.

FnVector.real

FnVector.**real**
The real part of this vector.

Returnsreal : *FnVector* view with dtype

The real part this vector as a vector in *Rn*

Examples

```
>>> c3 = Cn(3)
>>> x = c3.element([5+1j, 3, 2-2j])
>>> x.real
Rn(3).element([5.0, 3.0, 2.0])
```

The *Rn* vector is really a view, so changes affect the original array:

```
>>> x.real *= 2
>>> x
Cn(3).element([(10+1j), (6+0j), (4-2j)])
```

FnVector.shape

FnVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

FnVector.size

FnVector.**size**
Length of this vector, equal to space size.

FnVector.space

FnVector.**space**
Space to which this vector.

FnVector.ufunc

FnVector.**ufunc**
NtuplesUFuncs, access to numpy style ufuncs.

Notes

These are optimized for use with ntuples and incur no overhead.

Examples

```
>>> r2 = Rn(2)
>>> x = r2.element([1, -2])
>>> x.ufunc.absolute()
Rn(2).element([1.0, 2.0])
```

These functions can also be used with broadcasting

```
>>> x.ufunc.add(3)
Rn(2).element([4.0, 1.0])
```

and non-space elements

```
>>> x.ufunc.subtract([3, 3])
Rn(2).element([-2.0, -5.0])
```

There is also support for various reductions (sum, prod, min, max)

```
>>> x.ufunc.sum()
-1.0
```

They also support an out parameter

```
>>> y = r2.element([3, 4])
>>> out = r2.element()
>>> result = x.ufunc.add(y, out=out)
>>> result
Rn(2).element([4.0, 2.0])
>>> result is out
True
```

Methods

__eq__(other)	
__getitem__(indices)	Access values of this vector.
__setitem__(indices, values)	Set values of this vector.
asarray([start, stop, step, out])	Extract the data of this array as a numpy array.
assign(other)	Assign the values of `other` to self.
conj([out])	The complex conjugate of this vector.
copy()	
dist(other)	Distance to `other`.
divide(x, y)	Divide by `other` inplace.
inner(other)	Inner product with `other`.
lincomb(a, x1[, b, x2])	Assign a linear combination to this vector.
multiply(x, y)	Multiply by `other` inplace.
norm()	Norm of vector
set_zero()	Set this vector to zero.
show([title, method, show, fig])	Display the function graphically.

FnVector.__eq__

FnVector.**__eq__**(*other*)

FnVector.__getitem__

FnVector.**__getitem__**(*indices*)

Access values of this vector.

Parameters
indices : int or slice

The position(s) that should be accessed

Returns
values : scalar or *NtuplesVector*

The value(s) at the index (indices)

Examples

```
>>> str_3 = Ntuples(3, dtype='U6')  # 6-char unicode
>>> x = str_3.element(['a', 'Hello!', '0'])
>>> print(x[0])
a
>>> print(x[1:3])
[Hello!, 0]
>>> x[1:3].space
Ntuples(2, '<U6')
```

FnVector.__setitem__

FnVector.**__setitem__**(*indices*, *values*)

Set values of this vector.

Parameters
indices : int or slice

The position(s) that should be set

values : scalar, *array-like* or *NtuplesVector*

The value(s) that are to be assigned.

If indices is an integer, value must be scalar.

If indices is a slice, value must be broadcastable to the size of the slice (same size, shape (1,) or single value).

Returns
None

Examples

```
>>> int_3 = Ntuples(3, 'int')
>>> x = int_3.element([1, 2, 3])
>>> x[0] = 5
>>> x
Ntuples(3, 'int').element([5, 2, 3])
```

Assignment from array-like structures or another vector:

```
>>> y = Ntuples(2, 'short').element([-1, 2])
>>> x[:2] = y
>>> x
```

```
Ntuples(3, 'int').element([-1, 2, 3])
>>> x[1:3] = [7, 8]
>>> x
Ntuples(3, 'int').element([-1, 7, 8])
>>> x[:] = np.array([0, 0, 0])
>>> x
Ntuples(3, 'int').element([0, 0, 0])
```

Broadcasting is also supported:

```
>>> x[1:3] = -2.
>>> x
Ntuples(3, 'int').element([0, -2, -2])
```

Array views are preserved:

```
>>> y = x[::2]  # view into x
>>> y[:] = -9
>>> print(y)
[-9, -9]
>>> print(x)
[-9, -2, -9]
```

Be aware of unsafe casts and over-/underflows, there will be warnings at maximum.

```
>>> x = Ntuples(2, 'int8').element([0, 0])
>>> maxval = 255  # maximum signed 8-bit unsigned int
>>> x[0] = maxval + 1
>>> x
Ntuples(2, 'int8').element([0, 0])
```

FnVector.asarray

FnVector.**asarray**(*start=None*, *stop=None*, *step=None*, *out=None*)

Extract the data of this array as a numpy array.

Parametersstart : int, optional

Start position. None means the first element.

start : int, optional

One element past the last element to be extracted. None means the last element.

start : int, optional

Step length. None means 1.

out : numpy.ndarray, optional

Array in which the result should be written in-place. Has to be contiguous and of the correct dtype.

Returnsasarray : numpy.ndarray

Numpy array of the same type as the space.

Examples

```
>>> import ctypes
>>> vec = Ntuples(3, 'float').element([1, 2, 3])
>>> vec.asarray()
array([ 1.,  2.,  3.])
>>> vec.asarray(start=1, stop=3)
array([ 2.,  3.])
```

Using the out parameter

```
>>> out = np.empty((3,), dtype='float')
>>> result = vec.asarray(out=out)
>>> out
array([ 1.,  2.,  3.])
>>> result is out
True
```

FnVector.assign

`FnVector.`**`assign`**(*other*)

Assign the values of `other` to self.

FnVector.conj

`FnVector.`**`conj`**(*out=None*)

The complex conjugate of this vector.

Parametersout : *FnVector*, optional

Vector to which the complex conjugate is written. Must be an element of this vector's space.

Returnsout : *FnVector*

The complex conjugate vector. If `out` was provided, the returned object is a reference to it.

Examples

```
>>> x = Cn(3).element([5+1j, 3, 2-2j])
>>> y = x.conj(); print(y)
[(5-1j), (3-0j), (2+2j)]
```

The out parameter allows you to avoid a copy

```
>>> z = Cn(3).element()
>>> z_out = x.conj(out=z); print(z)
[(5-1j), (3-0j), (2+2j)]
>>> z_out is z
True
```

It can also be used for in-place conj

```
>>> x_out = x.conj(out=x); print(x)
[(5-1j), (3-0j), (2+2j)]
>>> x_out is x
True
```

FnVector.copy

FnVector.**copy**()

FnVector.dist

FnVector.**dist**(*other*)

Distance to other.

LinearSpace.dist

FnVector.divide

FnVector.**divide**(*x*, *y*)

Divide by other inplace.

LinearSpace.divide

FnVector.inner

FnVector.**inner**(*other*)

Inner product with other.

LinearSpace.inner

FnVector.lincomb

FnVector.**lincomb**(*a*, *x1*, *b=None*, *x2=None*)

Assign a linear combination to this vector.

Implemented as space.lincomb(a, x1, b, x2, out=self).

LinearSpace.lincomb

FnVector.multiply

FnVector.**multiply**(*x*, *y*)

Multiply by other inplace.

LinearSpace.multiply

FnVector.norm

FnVector.**norm**()
Norm of vector

LinearSpace.norm

FnVector.set_zero

FnVector.**set_zero**()
Set this vector to zero.

LinearSpace.zero

FnVector.show

FnVector.**show**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)
Display the function graphically.

Parameterstitle : str, optional

Set the title of the figure

method : str, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : bool, optional

If the plot should be showed now or deferred until later.

fig : matplotlib.figure.Figure

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that fig is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : matplotlib.figure.Figure

The resulting figure. It is also shown to the user.

See also:

odl.util.graphics.show_discrete_dataUnderlying implementation

__init__(*space*, *data*)
Initialize a new instance.

FnVectorWeighting

class odl.space.ntuples.**FnVectorWeighting**(*vector*, *exponent=2.0*, *dist_using_inner=False*)
Bases: *odl.space.base_ntuples.FnWeightingBase*

Vector weighting for *Fn*.

For exponent 2.0, a new weighted inner product with vector w is defined as

$\langle a, b\rangle_w := b^H(w \odot a)$

with b^H standing for transposed complex conjugate and $w \odot a$ for element-wise multiplication.

For other exponents, only norm and dist are defined. In the case of exponent `inf`, the weighted norm is

$\|a\|_{w,\infty} := \|w \odot a\|_\infty$,

otherwise it is

$\|a\|_{w,p} := \|w^{1/p} \odot a\|_p$.

Not that this definition does **not** fulfill the limit property in p, i.e.

$\lim_{p\to\infty}\|a\|_{w,p} = \|a\|_\infty \neq \|a\|_{w,\infty}$

unless $w = (1, \ldots, 1)$.

The vector may only have positive entries, otherwise it does not define an inner product or norm, respectively. This is not checked during initialization.

Attributes

exponent	Exponent of this weighting.
impl	Implementation backend of this weighting.
vector	Weighting vector of this inner product.

FnVectorWeighting.exponent

FnVectorWeighting.**exponent**
Exponent of this weighting.

FnVectorWeighting.impl

FnVectorWeighting.**impl**
Implementation backend of this weighting.

FnVectorWeighting.vector

FnVectorWeighting.**vector**
Weighting vector of this inner product.

Methods

__eq__(other)	Return `self == other`.
dist(x1, x2)	Calculate the distance between two vectors.
equiv(other)	Test if other is an equivalent weighting.
inner(x1, x2)	Calculate the vector weighted inner product of two vectors.
norm(x)	Calculate the vector-weighted norm of a vector.
vector_is_valid()	Test if the vector is a valid weight, i.e.

FnVectorWeighting.__eq__

`FnVectorWeighting.`**`__eq__`**(*other*)

Return `self == other`.

Returnsequals : `bool`

`True` if other is an *FnVectorWeighting* instance with **identical** vector, `False` otherwise.

See also:

equivtest for equivalent inner products

FnVectorWeighting.dist

`FnVectorWeighting.`**`dist`**(*x1*, *x2*)

Calculate the distance between two vectors.

This is the standard implementation using *norm*. Subclasses should override it for optimization purposes.

Parametersx1, x2 : *FnBaseVector*

Vectors whose mutual distance is calculated

Returnsdist : `float`

The distance between the vectors

FnVectorWeighting.equiv

`FnVectorWeighting.`**`equiv`**(*other*)

Test if other is an equivalent weighting.

Returnsequivalent : `bool`

`True` if `other` is an *FnWeightingBase* instance with the same *FnWeightingBase.impl*, which yields the same result as this inner product for any input, `False` otherwise. This is checked by entry-wise comparison of matrices/vectors/constant of this inner product and `other`.

FnVectorWeighting.inner

`FnVectorWeighting.`**`inner`**(*x1*, *x2*)

Calculate the vector weighted inner product of two vectors.

Parametersx1, x2 : *FnVector*

Vectors whose inner product is calculated

Returnsinner : `float` or `complex`

The inner product of the two provided vectors

FnVectorWeighting.norm

`FnVectorWeighting.`**`norm`**`(`*x*`)`

Calculate the vector-weighted norm of a vector.

Parametersx : *FnVector*

Vector whose norm is calculated

Returnsnorm : `float`

The norm of the provided vector

FnVectorWeighting.vector_is_valid

`FnVectorWeighting.`**`vector_is_valid`**`()`

Test if the vector is a valid weight, i.e. positive.

`__init__``(`*vector*, *exponent=2.0*, *dist_using_inner=False*`)`

Initialize a new instance.

Parametersvector : *array-like*, one-dim.

Weighting vector of the inner product

exponent : positive `float`

Exponent of the norm. For values other than 2.0, the inner product is not defined. If `matrix` is a sparse matrix, only 1.0, 2.0 and `inf` are allowed.

dist_using_inner : `bool`, optional

Calculate `dist` using the formula

$\|x-y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y\rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

Can only be used if `exponent` is 2.0.

MatVecOperator

class `odl.space.ntuples.`**`MatVecOperator`**`(`*matrix*, *dom=None*, *ran=None*`)`

Bases: *odl.operator.operator.Operator*

Matrix multiply operator $\mathbb{F}^n -> \mathbb{F}^m$.

Attributes

adjoint	Adjoint operator represented by the adjoint matrix.

Continued on next page

Table 8.217 – continued from previous page

domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
matrix	Matrix representing this operator.
matrix_issparse	Whether the representing matrix is sparse or not.
range	Set in which the result of an evaluation of this operator lies.

MatVecOperator.adjoint

`MatVecOperator.`**`adjoint`**
Adjoint operator represented by the adjoint matrix.

MatVecOperator.domain

`MatVecOperator.`**`domain`**
Set of objects on which this operator can be evaluated.

MatVecOperator.inverse

`MatVecOperator.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

MatVecOperator.is_functional

`MatVecOperator.`**`is_functional`**
`True` if the this operator's range is a *Field*.

MatVecOperator.is_linear

`MatVecOperator.`**`is_linear`**
`True` if this operator is linear.

MatVecOperator.matrix

`MatVecOperator.`**`matrix`**
Matrix representing this operator.

MatVecOperator.matrix_issparse

`MatVecOperator.`**`matrix_issparse`**
Whether the representing matrix is sparse or not.

MatVecOperator.range

MatVecOperator.**range**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Raw apply method on input, writing to given output.
derivative(point)	Return the operator derivative at `point`.

MatVecOperator.__call__

MatVecOperator.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
        >>> y = rn.element()
        >>> op(x, out=y)
        Rn(3).element([2.0, 4.0, 6.0])
        >>> y
        Rn(3).element([2.0, 4.0, 6.0])
```

MatVecOperator._call

MatVecOperator.**_call**(*x*, *out=None*)
Raw apply method on input, writing to given output.

MatVecOperator.derivative

MatVecOperator.**derivative**(*point*)
Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*matrix*, *dom=None*, *ran=None*)
Initialize a new instance.

Parametersmatrix : *array-like* or `scipy.sparse.spmatrix`

Matrix representing the linear operator. Its shape must be `(m, n)`, where `n` is the size of `dom` and `m` the size of `ran`. Its dtype must be castable to the range `dtype`.

dom : *Fn*, optional

Space on whose elements the matrix acts. If not provided, the domain is inferred from the matrix `dtype` and `shape`. If provided, its dtype must be castable to the range dtype.

ran : *Fn*, optional

Space to which the matrix maps. If not provided, the domain is inferred from the matrix `dtype` and `shape`.

Ntuples

class odl.space.ntuples.**Ntuples**(*size*, *dtype*)
Bases: *odl.space.base_ntuples.NtuplesBase*

The set of n-tuples of arbitrary type.

Attributes

dtype	The data type of each entry.
element_type	*NtuplesVector*
shape	The shape of this space.
size	The number of entries per tuple.

Ntuples.dtype

Ntuples.**dtype**
The data type of each entry.

Ntuples.element_type

Ntuples.**element_type**
NtuplesVector

Ntuples.shape

Ntuples.**shape**
The shape of this space.

Ntuples.size

Ntuples.**size**
The number of entries per tuple.

Methods

__contains__(other)	Return `other in self`.
__eq__(other)	Return `self == other`.
contains_all(other)	Test if all points in `other` are contained in this set.
contains_set(other)	Test if `other` is a subset of this set.
element([inp, data_ptr])	Create a new element.
one()	Create a vector of ones.
zero()	Create a vector of zeros.

Ntuples.__contains__

Ntuples.**__contains__**(*other*)
Return `other in self`.

Returnscontains : `bool`

`True` if `other` is an *NtuplesBaseVector* instance and `other.space` is equal to this space, `False` otherwise.

Examples

```
>>> from odl import Ntuples
>>> long_3 = Ntuples(3, dtype='int64')
>>> long_3.element() in long_3
True
>>> long_3.element() in Ntuples(3, dtype='int32')
False
```

```
>>> long_3.element() in Ntuples(3, dtype='float64')
False
```

Ntuples.__eq__

Ntuples.**__eq__**(*other*)

Return `self == other`.

Returnsequals : `bool`

`True` if `other` is an instance of this space's type with the same *`size`* and *`dtype`*, otherwise `False`.

Examples

```
>>> from odl import Ntuples
>>> int_3 = Ntuples(3, dtype=int)
>>> int_3 == int_3
True
```

Equality is not identity:

```
>>> int_3a, int_3b = Ntuples(3, int), Ntuples(3, int)
>>> int_3a == int_3b
True
>>> int_3a is int_3b
False
```

```
>>> int_3, int_4 = Ntuples(3, int), Ntuples(4, int)
>>> int_3 == int_4
False
>>> int_3, str_3 = Ntuples(3, 'int'), Ntuples(3, 'S2')
>>> int_3 == str_3
False
```

Ntuples.contains_all

Ntuples.**contains_all**(*other*)

Test if all points in `other` are contained in this set.

This is a default implementation and should be overridden by subclasses.

Ntuples.contains_set

Ntuples.**contains_set**(*other*)

Test if `other` is a subset of this set.

Implementing this method is optional. Default it tests for equality.

Ntuples.element

Ntuples.**element**(*inp=None*, *data_ptr=None*)

Create a new element.

Parametersinp : *array-like*, optional

Input to initialize the new element.

If `inp` is `None`, an empty element is created with no guarantee of its state (memory allocation only).

If `inp` is a `numpy.ndarray` of shape `(size,)` and the same data type as this space, the array is wrapped, not copied. Other array-like objects are copied.

Returnselement : *NtuplesVector*

The new element created (from `inp`).

Notes

This method preserves "array views" of correct size and type, see the examples below.

Examples

```
>>> strings3 = Ntuples(3, dtype='U1')  # 1-char strings
>>> x = strings3.element(['w', 'b', 'w'])
>>> print(x)
[w, b, w]
>>> x.space
Ntuples(3, '<U1')
```

Construction from data pointer:

```
>>> int3 = Ntuples(3, dtype='int')
>>> x = int3.element([1, 2, 3])
>>> y = int3.element(data_ptr=x.data_ptr)
>>> print(y)
[1, 2, 3]
>>> y[0] = 5
>>> print(x)
[5, 2, 3]
```

Ntuples.one

`Ntuples.one()`
Create a vector of ones.

Examples

```
>>> c3 = Cn(3)
>>> x = c3.one()
>>> x
Cn(3).element([(1+0j), (1+0j), (1+0j)])
```

Ntuples.zero

Ntuples.**zero**()
Create a vector of zeros.

Examples

```
>>> c3 = Cn(3)
>>> x = c3.zero()
>>> x
Cn(3).element([0j, 0j, 0j])
```

__init__(*size*, *dtype*)
Initialize a new instance.

Parameterssize : non-negative int

The number of entries per tuple

dtype :

The data type for each tuple entry. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string.

NtuplesVector

class odl.space.ntuples.**NtuplesVector**(*space*, *data*)
Bases: *odl.space.base_ntuples.NtuplesBaseVector*

Representation of an *Ntuples* element.

Attributes

data	The raw `numpy.ndarray` representing the data.
data_ptr	A raw pointer to the data container.
dtype	Length of this vector, equal to space size.
itemsize	The size in bytes on one element of this type.
nbytes	The number of bytes this vector uses in memory.
ndim	Number of dimensions, always 1.
shape	Number of entries per axis, equals (size,) for linear storage.
size	Length of this vector, equal to space size.
space	Space to which this vector.
ufunc	*NtuplesUFuncs*, access to numpy style ufuncs.

NtuplesVector.data

NtuplesVector.**data**
The raw `numpy.ndarray` representing the data.

NtuplesVector.data_ptr

NtuplesVector.**data_ptr**
A raw pointer to the data container.

Examples

```
>>> import ctypes
>>> vec = Ntuples(3, 'int32').element([1, 2, 3])
>>> arr_type = ctypes.c_int32 * 3
>>> buffer = arr_type.from_address(vec.data_ptr)
>>> arr = np.frombuffer(buffer, dtype='int32')
>>> print(arr)
[1 2 3]
```

In-place modification via pointer:

```
>>> arr[0] = 5
>>> print(vec)
[5, 2, 3]
```

NtuplesVector.dtype

NtuplesVector.**dtype**
Length of this vector, equal to space size.

NtuplesVector.itemsize

NtuplesVector.**itemsize**
The size in bytes on one element of this type.

NtuplesVector.nbytes

NtuplesVector.**nbytes**
The number of bytes this vector uses in memory.

NtuplesVector.ndim

NtuplesVector.**ndim**
Number of dimensions, always 1.

NtuplesVector.shape

NtuplesVector.**shape**
Number of entries per axis, equals (size,) for linear storage.

NtuplesVector.size

NtuplesVector.**size**
Length of this vector, equal to space size.

NtuplesVector.space

NtuplesVector.**space**
Space to which this vector.

NtuplesVector.ufunc

NtuplesVector.**ufunc**
NtuplesUFuncs, access to numpy style ufuncs.

Notes

These are optimized for use with ntuples and incur no overhead.

Examples

```
>>> r2 = Rn(2)
>>> x = r2.element([1, -2])
>>> x.ufunc.absolute()
Rn(2).element([1.0, 2.0])
```

These functions can also be used with broadcasting

```
>>> x.ufunc.add(3)
Rn(2).element([4.0, 1.0])
```

and non-space elements

```
>>> x.ufunc.subtract([3, 3])
Rn(2).element([-2.0, -5.0])
```

There is also support for various reductions (sum, prod, min, max)

```
>>> x.ufunc.sum()
-1.0
```

They also support an out parameter

```
>>> y = r2.element([3, 4])
>>> out = r2.element()
>>> result = x.ufunc.add(y, out=out)
>>> result
Rn(2).element([4.0, 2.0])
>>> result is out
True
```

Methods

__eq__(other)	Return `self == other`.
__getitem__(indices)	Access values of this vector.
__setitem__(indices, values)	Set values of this vector.
asarray([start, stop, step, out])	Extract the data of this array as a numpy array.
copy()	Create an identical (deep) copy of this vector.
show([title, method, show, fig])	Display the function graphically.

NtuplesVector.__eq__

NtuplesVector.**__eq__**(*other*)

Return `self == other`.

Returnsequals : `bool`

`True` if all entries of other are equal to this vector's entries, `False` otherwise.

Notes

Space membership is not checked, hence vectors from different spaces can be equal.

Examples

```
>>> vec1 = Ntuples(3, int).element([1, 2, 3])
>>> vec2 = Ntuples(3, int).element([-1, 2, 0])
>>> vec1 == vec2
False
>>> vec2 = Ntuples(3, int).element([1, 2, 3])
>>> vec1 == vec2
True
```

Space membership matters:

```
>>> vec2 = Ntuples(3, float).element([1, 2, 3])
>>> vec1 == vec2 or vec2 == vec1
False
```

NtuplesVector.__getitem__

NtuplesVector.**__getitem__**(*indices*)

Access values of this vector.

Parametersindices : `int` or `slice`

The position(s) that should be accessed

Returnsvalues : scalar or *NtuplesVector*

The value(s) at the index (indices)

Examples

```
>>> str_3 = Ntuples(3, dtype='U6')  # 6-char unicode
>>> x = str_3.element(['a', 'Hello!', '0'])
>>> print(x[0])
a
>>> print(x[1:3])
[Hello!, 0]
>>> x[1:3].space
Ntuples(2, '<U6')
```

NtuplesVector.__setitem__

NtuplesVector.**__setitem__**(*indices*, *values*)

Set values of this vector.

Parameters

indices : `int` or `slice`

The position(s) that should be set

values : scalar, *array-like* or *NtuplesVector*

The value(s) that are to be assigned.

If `indices` is an integer, `value` must be scalar.

If `indices` is a slice, `value` must be broadcastable to the size of the slice (same size, shape `(1,)` or single value).

Returns

`None`

Examples

```
>>> int_3 = Ntuples(3, 'int')
>>> x = int_3.element([1, 2, 3])
>>> x[0] = 5
>>> x
Ntuples(3, 'int').element([5, 2, 3])
```

Assignment from array-like structures or another vector:

```
>>> y = Ntuples(2, 'short').element([-1, 2])
>>> x[:2] = y
>>> x
Ntuples(3, 'int').element([-1, 2, 3])
>>> x[1:3] = [7, 8]
>>> x
Ntuples(3, 'int').element([-1, 7, 8])
>>> x[:] = np.array([0, 0, 0])
>>> x
Ntuples(3, 'int').element([0, 0, 0])
```

Broadcasting is also supported:

```
>>> x[1:3] = -2.
>>> x
Ntuples(3, 'int').element([0, -2, -2])
```

Array views are preserved:

```
>>> y = x[::2]  # view into x
>>> y[:] = -9
>>> print(y)
[-9, -9]
>>> print(x)
[-9, -2, -9]
```

Be aware of unsafe casts and over-/underflows, there will be warnings at maximum.

```
>>> x = Ntuples(2, 'int8').element([0, 0])
>>> maxval = 255  # maximum signed 8-bit unsigned int
>>> x[0] = maxval + 1
>>> x
Ntuples(2, 'int8').element([0, 0])
```

NtuplesVector.asarray

`NtuplesVector.`**`asarray`**(*start=None*, *stop=None*, *step=None*, *out=None*)

Extract the data of this array as a numpy array.

Parametersstart : `int`, optional

Start position. None means the first element.

start : `int`, optional

One element past the last element to be extracted. None means the last element.

start : `int`, optional

Step length. None means 1.

out : `numpy.ndarray`, optional

Array in which the result should be written in-place. Has to be contiguous and of the correct dtype.

Returnsasarray : `numpy.ndarray`

Numpy array of the same type as the space.

Examples

```
>>> import ctypes
>>> vec = Ntuples(3, 'float').element([1, 2, 3])
>>> vec.asarray()
array([ 1.,  2.,  3.])
>>> vec.asarray(start=1, stop=3)
array([ 2.,  3.])
```

Using the out parameter

```
>>> out = np.empty((3,), dtype='float')
>>> result = vec.asarray(out=out)
>>> out
array([ 1.,  2.,  3.])
>>> result is out
True
```

NtuplesVector.copy

NtuplesVector.**copy**()

Create an identical (deep) copy of this vector.

ParametersNone

Returnscopy : *NtuplesVector*

The deep copy

Examples

```
>>> vec1 = Ntuples(3, 'int').element([1, 2, 3])
>>> vec2 = vec1.copy()
>>> vec2
Ntuples(3, 'int').element([1, 2, 3])
>>> vec1 == vec2
True
>>> vec1 is vec2
False
```

NtuplesVector.show

NtuplesVector.**show**(*title=None*, *method='scatter'*, *show=False*, *fig=None*, ***kwargs*)

Display the function graphically.

Parameterstitle : str, optional

Set the title of the figure

method : str, optional

1d methods:

'plot' : graph plot

'scatter' : point plot

show : bool, optional

If the plot should be showed now or deferred until later.

fig : matplotlib.figure.Figure

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common use case is that fig is the return value from an earlier call to this function.

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : matplotlib.figure.Figure

The resulting figure. It is also shown to the user.

See also:

*odl.util.graphics.show_discrete_data*Underlying implementation

__init__ (*space*, *data*)
Initialize a new instance.

Functions

Cn(size[, dtype])	The complex vector space C^n with vector multiplication.
Rn(size[, dtype])	The real vector space R^n with vector multiplication.
weighted_dist(weight[, exponent, use_inner])	Weighted distance on *Fn* spaces as free function.
weighted_inner(weight)	Weighted inner product on *Fn* spaces as free function.
weighted_norm(weight[, exponent])	Weighted norm on *Fn* spaces as free function.

Cn

odl.space.ntuples.**Cn** (*size*, *dtype='complex128'*, ***kwargs*)
The complex vector space C^n with vector multiplication.

Parameters

size : positive `int`

The number of dimensions of the space

dtype : `object`

The data type of the storage array. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string.

Only complex floating-point data types are allowed.

kwargs : {'weight', 'dist', 'norm', 'inner', 'dist_using_inner'}

See *Fn*

See also:

Fn n-tuples over a field $\mathbb{F}$ with arbitrary scalar data type

Rn

odl.space.ntuples.**Rn** (*size*, *dtype='float64'*, ***kwargs*)
The real vector space R^n with vector multiplication.

Parameters

size : positive `int`

The number of dimensions of the space

dtype : `object`

The data type of the storage array. Can be provided in any way the `numpy.dtype` function understands, most notably as built-in type, as one of NumPy's internal datatype objects or as string.

Only real floating-point data types are allowed.

kwargs : {'weight', 'dist', 'norm', 'inner', 'dist_using_inner'}

See *Fn*

See also:

*Fn*n-tuples over a field $\mathbb{F}$ with arbitrary scalar data type

weighted_dist

odl.space.ntuples.**weighted_dist**(*weight*, *exponent=2.0*, *use_inner=False*)
Weighted distance on *Fn* spaces as free function.

Parametersweight : scalar or *array-like*

Weight of the distance. A scalar is interpreted as a constant weight, a 1-dim. array as a weighting vector and a 2-dimensional array as a weighting matrix.

exponent : positive `float`

Exponent of the norm. If `weight` is a sparse matrix, only 1.0, 2.0 and `inf` are allowed.

use_inner : `bool`, optional

Calculate `dist` using the formula

$\|x - y\|^2 = \|x\|^2 + \|y\|^2 - 2\Re\langle x, y\rangle$.

This avoids the creation of new arrays and is thus faster for large arrays. On the downside, it will not evaluate to exactly zero for equal (but not identical) x and y.

Can only be used if `exponent` is 2.0.

Returnsdist : `callable`

Distance function with given weight. Constant weightings are applicable to spaces of any size, for arrays the sizes of the weighting and the space must match.

See also:

FnConstWeighting, *FnVectorWeighting*, *FnMatrixWeighting*

weighted_inner

odl.space.ntuples.**weighted_inner**(*weight*)
Weighted inner product on *Fn* spaces as free function.

Parametersweight : scalar or *array-like*

Weight of the inner product. A scalar is interpreted as a constant weight, a 1-dim. array as a weighting vector and a 2-dimensional array as a weighting matrix.

Returnsinner : `callable`

Inner product function with given weight. Constant weightings are applicable to spaces of any size, for arrays the sizes of the weighting and the space must match.

See also:

FnConstWeighting, *FnVectorWeighting*, *FnMatrixWeighting*

weighted_norm

odl.space.ntuples.**weighted_norm**(*weight*, *exponent=2.0*)
Weighted norm on *Fn* spaces as free function.

Parametersweight : scalar or *array-like*

Weight of the norm. A scalar is interpreted as a constant weight, a 1-dim. array as a weighting vector and a 2-dimensional array as a weighting matrix.

exponent : positive `float`

Exponent of the norm. If `weight` is a sparse matrix, only 1.0, 2.0 and `inf` are allowed.

Returnsnorm : `callable`

Norm function with given weight. Constant weightings are applicable to spaces of any size, for arrays the sizes of the weighting and the space must match.

See also:

FnConstWeighting, *FnVectorWeighting*, *FnMatrixWeighting*

8.6.5 space_utils

Utility functions for space implementations.

Functions

vector(array[, dtype, impl])	Create an n-tuples type vector from an array.

vector

odl.space.space_utils.**vector**(*array*, *dtype=None*, *impl='numpy'*)

Create an n-tuples type vector from an array.

Parametersarray : *array-like*

Array from which to create the vector. Scalars become one-dimensional vectors.

dtype : `object`, optional

Set the data type of the vector manually with this option. By default, the space type is inferred from the input data.

impl : {'numpy', 'cuda'}

Implementation backend for the vector

Returnsvec : *NtuplesBaseVector*

Vector created from the input array. Its concrete type depends on the provided arguments.

Notes

This is a convenience function and not intended for use in speed-critical algorithms. It creates a NumPy array first, hence especially CUDA vectors as input result in a large speed penalty.

Examples

```
>>> vector([1, 2, 3])  # No automatic cast to float
Fn(3, 'int').element([1, 2, 3])
>>> vector([1, 2, 3], dtype=float)
Rn(3).element([1.0, 2.0, 3.0])
>>> vector([1 + 1j, 2, 3 - 2j])
Cn(3).element([(1+1j), (2+0j), (3-2j)])
```

Non-scalar types are also supported:

```
>>> vector([True, False])
Ntuples(2, 'bool').element([True, False])
```

Scalars become a one-element vector:

```
>>> vector(0.0)
Rn(1).element([0.0])
```

8.7 tomo

Tomography related operators and geometries.

Modules

8.7.1 backends

Back-ends for other libraries.

Modules

astra_cpu

Backend for ASTRA using CPU.

Functions

astra_cpu_back_projector(proj_data, ...[, out])	Run an ASTRA backward projection on the given data using the CPU.
astra_cpu_forward_projector(vol_data, ...[, out])	Run an ASTRA forward projection on the given data using the CPU.

astra_cpu_back_projector

odl.tomo.backends.astra_cpu.**astra_cpu_back_projector**(*proj_data*, *geometry*, *reco_space*, *out=None*)

Run an ASTRA backward projection on the given data using the CPU.

Parameters

proj_data : *DiscreteLpVector*

Projection data to which the backward projector is applied

geometry : *Geometry*

Geometry defining the tomographic setup

reco_space : *DiscreteLp*

Space to which the calling operator maps

out : *DiscreteLpVector* or `None`, optional

Vector in the reconstruction space to which the result is written. If `None` creates an element in the reconstruction space `reco_space`

Returnsout : `reco_space` element

Reconstruction data resulting from the application of the backward projector

astra_cpu_forward_projector

`odl.tomo.backends.astra_cpu.`**`astra_cpu_forward_projector`**(*vol_data*, *geometry*, *proj_space*, *out=None*)

Run an ASTRA forward projection on the given data using the CPU.

Parametersvol_data : *DiscreteLpVector*

Volume data to which the forward projector is applied

geometry : *Geometry*

Geometry defining the tomographic setup

proj_space : *DiscreteLp*

Space to which the calling operator maps

out : *DiscreteLpVector*, optional

Vector in the projection space to which the result is written. If `None` creates an element in the projection space `proj_space`

Returnsout : `proj_space` *element*

Projection data resulting from the application of the projector

astra_cuda

Backend for ASTRA using CUDA.

Functions

astra_cuda_back_projector(proj_data, ...[, out])	Run an ASTRA backward projection on the given data using the GPU.
astra_cuda_forward_projector(vol_data, ...)	Run an ASTRA forward projection on the given data using the GPU.

astra_cuda_back_projector

`odl.tomo.backends.astra_cuda.`**`astra_cuda_back_projector`**(*proj_data*, *geometry*, *reco_space*, *out=None*)

Run an ASTRA backward projection on the given data using the GPU.

Parametersproj_data : *DiscreteLp* element

Projection data to which the backward projector is applied

geometry : *Geometry*

Geometry defining the tomographic setup

reco_space : *DiscreteLp*

Space to which the calling operator maps

out : *DiscreteLpVector*, optional

Vector in the reconstruction space to which the result is written. If `None` creates an element in the reconstruction space `reco_space`

Returnsout : `reco_space` element

Reconstruction data resulting from the application of the backward projector

astra_cuda_forward_projector

odl.tomo.backends.astra_cuda.**astra_cuda_forward_projector**(*vol_data*, *geometry*, *proj_space*, *out=None*)

Run an ASTRA forward projection on the given data using the GPU.

Parametersvol_data : *DiscreteLpVector*

Volume data to which the projector is applied

geometry : *Geometry*

Geometry defining the tomographic setup

proj_space : *DiscreteLp*

Space to which the calling operator maps

out : *DiscreteLpVector*, optional

Vector in the projection space to which the result is written. If `None` creates an element in the projection space `proj_space`

Returnsout : `proj_space` element

Projection data resulting from the application of the projector

astra_setup

Helper functions to prepare ASTRA algorithms.

This module contains utility functions to convert data structures from the ODL geometry representation to ASTRA's data structures, including:

- volume geometries
- projection geometries
- create vectors from geometries
- data arrays
- projectors
- algorithm configuration dictionaries

ASTRA documentation on Sourceforge.

ASTRA on GitHub.

Functions

astra_algorithm(direction, ndim, vol_id, ...)	Create an ASTRA algorithm object to run the projector.
astra_conebeam_2d_geom_to_vec(geometry)	Create vectors for ASTRA projection geometries from ODL geometry.
astra_conebeam_3d_geom_to_vec(geometry)	Create vectors for ASTRA projection geometries from ODL geometry.
astra_data(astra_geom, datatype[, data, ndim])	Create an ASTRA data structure.
astra_parallel_3d_geom_to_vec(geometry)	Create vectors for ASTRA projection geometries from ODL geometry.
astra_projection_geometry(geometry)	Create an ASTRA projection geometry from an ODL geometry object.
astra_projector(vol_interp, astra_vol_geom, ...)	Create an ASTRA projector configuration dictionary.
astra_volume_geometry(discr_reco)	Create an ASTRA volume geometry from the discretized domain.

astra_algorithm

odl.tomo.backends.astra_setup.**astra_algorithm**(*direction*, *ndim*, *vol_id*, *sino_id*, *proj_id*, *impl*)

Create an ASTRA algorithm object to run the projector.

Parametersdirection : {'forward', 'backward'}

Apply the forward projection if 'forward', otherwise the back projection

ndim : {2, 3}

Number of dimensions of the projector

vol_id : `int`

ASTRA ID of the volume data object

sino_id : `int`

ASTRA ID of the projection data object

proj_id : `int`

ASTRA ID of the projector

impl : {'cpu', 'cuda'}

Implementation of the projector

Returnsid : `int`

ASTRA internal ID for the new algorithm structure

astra_conebeam_2d_geom_to_vec

odl.tomo.backends.astra_setup.**astra_conebeam_2d_geom_to_vec**(*geometry*)

Create vectors for ASTRA projection geometries from ODL geometry.

The 2D vectors are used to create an ASTRA projection geometry for cone beam geometries ('flat_vec') with helical acquisition curves.

Output vectors:

Each row of vectors corresponds to a single projection, and consists of:(srcX, srcY, dX, dY, uX, uY) src : the ray source d : the center of the detector u : the vector between the centers of detector pixels 0 and 1

Parametersgeometry : *Geometry*

The ODL geometry instance used to create the ASTRA geometry

Returnsvectors : `numpy.ndarray`

Numpy array of shape `(number of angles, 6)`

astra_conebeam_3d_geom_to_vec

`odl.tomo.backends.astra_setup.`**`astra_conebeam_3d_geom_to_vec`**(*geometry*)
Create vectors for ASTRA projection geometries from ODL geometry.

The 3D vectors are used to create an ASTRA projection geometry for cone beam geometries ('cone_vec') with helical acquisition curves.

Output vectors:

Each row of vectors corresponds to a single projection, and consists of:(srcX, srcY, srcZ, dX, dY, dZ, uX, uY, uZ, vX, vY, vZ): src : the ray source d : the center of the detector u : the vector from detector pixel (0,0) to (0,1) v : the vector from detector pixel (0,0) to (1,0)

Parametersgeometry : *Geometry*

The ODL geometry instance used to create the ASTRA geometry

Returnsvectors : `numpy.ndarray`

Numpy array of shape `(number of angles, 12)`

astra_data

`odl.tomo.backends.astra_setup.`**`astra_data`**(*astra_geom*, *datatype*, *data=None*, *ndim=2*)
Create an ASTRA data structure.

Parametersastra_geom : `dict`

ASTRA geometry object for the data creator, must correspond to the given data type

datatype : {'volume', 'projection'}

Type of the data container

data : *DiscreteLpVector*, optional

Data for the initialization of the data structure. If `None` creates an ASTRA data object filled with zeros

ndim : {2, 3}, optional

Dimension of the data. If `data` is not `None`, this parameter has no effect.

Returnsid : `int`

ASTRA internal ID for the new data structure

astra_parallel_3d_geom_to_vec

`odl.tomo.backends.astra_setup.`**`astra_parallel_3d_geom_to_vec`**(*geometry*)
Create vectors for ASTRA projection geometries from ODL geometry.

The 3D vectors are used to create an ASTRA projection geometry for parallel beam geometries ('parallel3d_vec').

Output vectors:

Each row of vectors corresponds to a single projection, and consists of:(rayX, rayY, rayZ, dX, dY, dZ, uX, uY, uZ, vX, vY, vZ) ray : the ray direction d : the center of the detector u : the vector from detector pixel (0,0) to (0,1) v : the vector from detector pixel (0,0) to (1,0)

Parametersgeometry : *Geometry*

The ODL geometry instance used to create the ASTRA geometry

Returnsvectors : `numpy.ndarray`

Numpy array of shape `(number of angles, 12)`

astra_projection_geometry

`odl.tomo.backends.astra_setup.`**`astra_projection_geometry`**(*geometry*)

Create an ASTRA projection geometry from an ODL geometry object.

As of ASTRA version 1.7, the length values are not required any more to be rescaled for 3D geometries and non-unit (but isotropic) voxel sizes.

Parametersgeometry : instance of `Geometry`

The ODL geometry instance used to create the projection geometry

Returnsproj_geom : `dict`

Dictionary defining the ASTRA projection geometry

astra_projector

`odl.tomo.backends.astra_setup.`**`astra_projector`**(*vol_interp*, *astra_vol_geom*, *astra_proj_geom*, *ndim*, *impl*)

Create an ASTRA projector configuration dictionary.

Parametersvol_interp : {'nearest', 'linear'}

Interpolation type of the volume discretization

astra_vol_geom : `dict`

ASTRA volume geometry dictionary

astra_proj_geom : `dict`

ASTRA projection geometry dictionary

ndim : {2, 3}

Number of dimensions of the projector

impl : {'cpu', 'cuda'}

Implementation of the projector

Returnsproj_id : `int`

ASTRA reference ID to the ASTRA dict with initialized 'type' key

astra_volume_geometry

odl.tomo.backends.astra_setup.**astra_volume_geometry**(*discr_reco*)

Create an ASTRA volume geometry from the discretized domain.

From the ASTRA documentation:

In all 3D geometries, the coordinate system is defined around the reconstruction volume. The center of the reconstruction volume is the origin, and the sides of the voxels in the volume have length 1.

All dimensions in the projection geometries are relative to this unit length.

Parametersdiscr_reco : *DiscreteLp*

Discretization of an L2 space on the reconstruction domain. It must be 2- or 3-dimensional and sampled by a regular grid.

Returnsastra_geom : dict

The ASTRA volume geometry

RaisesNotImplementedError

if the cell sizes are not the same in each dimension

stir_bindings

Back-end for STIR: Software for Tomographic Reconstruction.

Back and forward projectors for PET.

ForwardProjectorByBinWrapper and *BackProjectorByBinWrapper* are general objects of STIR projectors and back-projectors, these can be used to wrap a given projector.

stir_projector_from_file allows users a easy way to create a *ForwardProjectorByBinWrapper* by giving file paths to the required templates.

References

See the STIR webpage for more information and the STIR doc for info on the STIR classes used here.

Classes

BackProjectorByBinWrapper(dom, ran, volume, ...)	A back projector using STIR.
ForwardProjectorByBinWrapper(dom, ran, ...)	A forward projector using STIR.
StirVerbosity(verbosity)	Context manager setting STIR verbosity to a fixed level.

BackProjectorByBinWrapper

class odl.tomo.backends.stir_bindings.**BackProjectorByBinWrapper**(*dom*, *ran*, *volume*, *proj_data*, *back_projector=None*, *adjoint=None*)

Bases: *odl.operator.operator.Operator*

A back projector using STIR.

Attributes

adjoint	The operator adjoint (abstract).
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

BackProjectorByBinWrapper.adjoint
`BackProjectorByBinWrapper.`**`adjoint`**
The operator adjoint (abstract).

RaisesOpNotImplementedError

Since the adjoint cannot be default implemented.

BackProjectorByBinWrapper.domain
`BackProjectorByBinWrapper.`**`domain`**
Set of objects on which this operator can be evaluated.

BackProjectorByBinWrapper.inverse
`BackProjectorByBinWrapper.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

BackProjectorByBinWrapper.is_functional
`BackProjectorByBinWrapper.`**`is_functional`**
`True` if the this operator's range is a *Field*.

BackProjectorByBinWrapper.is_linear
`BackProjectorByBinWrapper.`**`is_linear`**
`True` if this operator is linear.

BackProjectorByBinWrapper.range
`BackProjectorByBinWrapper.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(projections, out)	Back project.
derivative(point)	Return the operator derivative at `point`.

BackProjectorByBinWrapper.__call__

BackProjectorByBinWrapper.__call__(*x*, *out=None*, ***kwargs*)
Return self(x[, out, **kwargs]).

Implementation of the call pattern op(x) with the private _call() method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the self.domain.element method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If out was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

BackProjectorByBinWrapper._call
BackProjectorByBinWrapper._call(*projections*, *out*)
Back project.

BackProjectorByBinWrapper.derivative
BackProjectorByBinWrapper.derivative(*point*)
Return the operator derivative at point.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*dom*, *ran*, *volume*, *proj_data*, *back_projector=None*, *adjoint=None*)

Initialize a new instance.

Parametersdom : *DiscreteLp*

Projection space. Needs to have the same shape as `proj_data.to_array().shape()`.

ran : *DiscreteLp*

Volume of the projection. Needs to have the same shape as `volume.shape()`.

volume : `stir.FloatVoxelsOnCartesianGrid`

The stir volume to use in the forward projection

proj_data : `stir.ProjData`

The stir description of the projection.

back_projector : `stir.BackProjectorByBin`, optional

A pre-initialized back-projector.

adjoint : *ForwardProjectorByBinWrapper*, optional

A pre-initialized adjoint.

Notes

See STIR doc for info on the STIR classes.

References

ForwardProjectorByBinWrapper

class `odl.tomo.backends.stir_bindings.`**ForwardProjectorByBinWrapper**(*dom*, *ran*, *volume*, *proj_data*, *projector=None*, *adjoint=None*)

Bases: *odl.operator.operator.Operator*

A forward projector using STIR.

Uses "ForwardProjectorByBinUsingProjMatrixByBin" as a projector.

Attributes

adjoint	The back-projector associated with this operator.
domain	Set of objects on which this operator can be evaluated.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

ForwardProjectorByBinWrapper.adjoint
`ForwardProjectorByBinWrapper.`**`adjoint`**
The back-projector associated with this operator.

ForwardProjectorByBinWrapper.domain
`ForwardProjectorByBinWrapper.`**`domain`**
Set of objects on which this operator can be evaluated.

ForwardProjectorByBinWrapper.inverse
`ForwardProjectorByBinWrapper.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

ForwardProjectorByBinWrapper.is_functional
`ForwardProjectorByBinWrapper.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

ForwardProjectorByBinWrapper.is_linear
`ForwardProjectorByBinWrapper.`**`is_linear`**
`True` if this operator is linear.

ForwardProjectorByBinWrapper.range
`ForwardProjectorByBinWrapper.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

`__call__`(x[, out])	Return `self(x[, out, **kwargs])`.
`__eq__`	Return self==value.
`_call`(volume, out)	Forward project a volume.
`derivative`(point)	Return the operator derivative at `point`.

ForwardProjectorByBinWrapper.__call__
`ForwardProjectorByBinWrapper.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *`Operator.domain element-like`*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *`Operator.range element`*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_call Implementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

ForwardProjectorByBinWrapper._call

`ForwardProjectorByBinWrapper.`**`_call`**(*volume*, *out*)

Forward project a volume.

ForwardProjectorByBinWrapper.derivative

`ForwardProjectorByBinWrapper.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*dom*, *ran*, *volume*, *proj_data*, *projector=None*, *adjoint=None*)

Initialize a new instance.

Parametersdom : *DiscreteLp*

Volume of the projection. Needs to have the same shape as `volume.shape()`.

ran : *DiscreteLp*

Projection space. Needs to have the same shape as `proj_data.to_array().shape()`.

volume : `stir.FloatVoxelsOnCartesianGrid`

The stir volume to use in the forward projection

proj_data : `stir.ProjData`

The stir description of the projection.

projector : `stir.ForwardProjectorByBin`, optional

A pre-initialized projector.

adjoint : *BackProjectorByBinWrapper*, optional

A pre-initialized adjoint.

StirVerbosity

class `odl.tomo.backends.stir_bindings.`**`StirVerbosity`**(*verbosity*)

Bases: `object`

Context manager setting STIR verbosity to a fixed level.

Methods

`__eq__`	Return self==value.

`__init__`(*verbosity*)

Functions

stir_projector_from_file(volume_file, ...)	Create a STIR projector from given template files.

stir_projector_from_file

`odl.tomo.backends.stir_bindings.`**`stir_projector_from_file`**(*volume_file*, *projection_file*)

Create a STIR projector from given template files.

Parametersvolume_file : `str`

Full file path to the STIR input file containing information on the volume. This is usually a '.hv' file. For STIR reasons, a '.v' file is also needed.

projection_file : `str`

Full file path to the STIR input file with information on the projection data. This is usually a '.hs' file. For STIR reasons, a '.s' file is also needed.

Returnsprojector : *ForwardProjectorByBinWrapper*

A STIR forward projector.

8.7.2 geometry

Modules

conebeam

Cone beam geometries in 3 dimensions.

Classes

CircularConeFlatGeometry(apart, dpart, ...)	Cone beam geometry with circular source curve and flat detector.
HelicalConeFlatGeometry(apart, dpart, ...[, ...])	Cone beam geometry with helical source curve and flat detector.

CircularConeFlatGeometry

class odl.tomo.geometry.conebeam.**CircularConeFlatGeometry**(*apart, dpart, src_radius, det_radius, axis=[0, 0, 1], **kwargs*)

Bases: *odl.tomo.geometry.conebeam.HelicalConeFlatGeometry*

Cone beam geometry with circular source curve and flat detector.

The source moves along a circle with radius `src_radius` in the plane perpendicular to a fixed `axis`. The detector reference point is opposite to the source, i.e. in the same plane on a circle with radius `det_rad` at maximum distance to the source. This implies that it lies on the line through the source point and the intersection of the `axis` with the azimuthal plane.

The motion parameter is the 1d rotation angle parameterizing source and detector positions simultaneously.

In the standard configuration, the rotation axis is `(0, 0, 1)`, the initial source-to-detector vector is `(1, 0, 0)`, and the initial detector axes are `[(0, 1, 0), (0, 0, 1)]`.

See also:

HelicalConeFlatGeometry General case with motion in z direction

Attributes

axis	The normalized axis of rotation, a 3-element vector.
det_grid	Sampling grid of *det_params*.
det_init_axes	Initial axes defining the detector orientation.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
det_radius	Detector circle radius of this geometry.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.
pitch	Constant vertical distance traversed in a full rotation.
pitch_offset	Vertical offset at `angle=0`
src_radius	Source circle radius of this geometry.
src_to_det_init	Initial state of the vector pointing from source to detector reference point.

CircularConeFlatGeometry.axis
CircularConeFlatGeometry.**axis**

The normalized axis of rotation, a 3-element vector.

CircularConeFlatGeometry.det_grid
`CircularConeFlatGeometry.det_grid`
Sampling grid of *det_params*.

CircularConeFlatGeometry.det_init_axes
`CircularConeFlatGeometry.det_init_axes`
Initial axes defining the detector orientation.

CircularConeFlatGeometry.det_params
`CircularConeFlatGeometry.det_params`
Continuous detector parameter range, an *IntervalProd*.

CircularConeFlatGeometry.det_partition
`CircularConeFlatGeometry.det_partition`
Partition of the detector parameter set into subsets.

CircularConeFlatGeometry.det_radius
`CircularConeFlatGeometry.det_radius`
Detector circle radius of this geometry.

CircularConeFlatGeometry.detector
`CircularConeFlatGeometry.detector`
Detector representation of this geometry.

CircularConeFlatGeometry.grid
`CircularConeFlatGeometry.grid`
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

CircularConeFlatGeometry.implementation_cache
`CircularConeFlatGeometry.implementation_cache`
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : `dict`

CircularConeFlatGeometry.motion_grid
`CircularConeFlatGeometry.motion_grid`
Sampling grid of *motion_params*.

CircularConeFlatGeometry.motion_params
`CircularConeFlatGeometry.motion_params`
Continuous motion parameter range, an *IntervalProd*.

CircularConeFlatGeometry.motion_partition
`CircularConeFlatGeometry.`**`motion_partition`**
Partition of the motion parameter set into subsets.

CircularConeFlatGeometry.ndim
`CircularConeFlatGeometry.`**`ndim`**
The number of dimensions of the geometry.

CircularConeFlatGeometry.params
`CircularConeFlatGeometry.`**`params`**
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

CircularConeFlatGeometry.partition
`CircularConeFlatGeometry.`**`partition`**
Joined parameter set partition for motion and detector.

Returns a *`RectPartition`* with the detector partition inserted after the motion partition.

CircularConeFlatGeometry.pitch
`CircularConeFlatGeometry.`**`pitch`**
Constant vertical distance traversed in a full rotation.

CircularConeFlatGeometry.pitch_offset
`CircularConeFlatGeometry.`**`pitch_offset`**
Vertical offset at `angle=0`

CircularConeFlatGeometry.src_radius
`CircularConeFlatGeometry.`**`src_radius`**
Source circle radius of this geometry.

CircularConeFlatGeometry.src_to_det_init
`CircularConeFlatGeometry.`**`src_to_det_init`**
Initial state of the vector pointing from source to detector reference point.

Methods

`__eq__`	Return self==value.
`det_point_position`(mpar, dpar)	The detector point position function.
`det_refpoint`(angle)	Return the detector reference point position at `angle`.
`det_to_src`(mpar, dpar[, normalized])	Vector pointing from a detector location to the source.
`rotation_matrix`(angle)	The detector rotation function.
`src_position`(angle)	Return the source position at `angle`.

CircularConeFlatGeometry.det_point_position
`CircularConeFlatGeometry.`**`det_point_position`**(*mpar*, *dpar*)
The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : numpy.ndarray, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

CircularConeFlatGeometry.det_refpoint

CircularConeFlatGeometry.**det_refpoint**(*angle*)

Return the detector reference point position at angle.

For an angle phi, the detector position is given by:

```
ref(phi) = det_rad * rot_matrix(phi) * src_to_det_init +
           (pitch_offset + pitch * phi) * axis
```

where src_to_det_init is the initial unit vector pointing from source to detector.

Parametersangle : float

Rotation angle given in radians, must be contained in this geometry's *motion_params*

Returnspoint : numpy.ndarray, shape (3,)

Detector reference point corresponding to the given angle

See also:

rotation_matrix

CircularConeFlatGeometry.det_to_src

CircularConeFlatGeometry.**det_to_src**(*mpar*, *dpar*, *normalized=True*)

Vector pointing from a detector location to the source.

A function of the motion and detector parameters.

The default implementation uses the *det_point_position* and *src_position* functions. Implementations can override this, for example if no source position is given.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

normalized : bool, optional

If True, return a normalized (unit) vector.

Returnsvec : numpy.ndarray, shape (*ndim*,)

(Unit) vector pointing from the detector to the source

CircularConeFlatGeometry.rotation_matrix

`CircularConeFlatGeometry.`**`rotation_matrix`**`(`*`angle`*`)`

The detector rotation function.

Returns the matrix for rotating a vector in 3d by an angle `angle` about the rotation axis given by the property *`axis`* according to the right hand rule.

The matrix is computed according to Rodrigues' rotation formula.

Parametersangle : `float`

The motion parameter given in radian. It must be contained in this geometry's *`motion_params`*.

Returnsrot_mat : `numpy.ndarray`, shape `(3, 3)`

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

CircularConeFlatGeometry.src_position

`CircularConeFlatGeometry.`**`src_position`**`(`*`angle`*`)`

Return the source position at `angle`.

For an angle `phi`, the source position is given by:

```
src(phi) = -src_rad * rot_matrix(phi) * src_to_det_init +
           (pitch_offset + pitch * phi) * axis
```

where `src_to_det_init` is the initial unit vector pointing from source to detector.

Parametersangle : `float`

Rotation angle given in radians, must be contained in this geometry's *`motion_params`*

Returnspoint : `numpy.ndarray`, shape (3,)

Detector reference point corresponding to the given angle

See also:

`rotation_matrix`

`__init__``(`*`apart, dpart, src_radius, det_radius, axis=[0, 0, 1], **kwargs`*`)`

Initialize a new instance.

Parametersapart : 1-dim. *`RectPartition`*

Partition of the angle interval

dpart : 2-dim. *`RectPartition`*

Partition of the detector parameter rectangle

src_radius : nonnegative `float`

Radius of the source circle

det_radius : nonnegative `float`

Radius of the detector circle

axis : *`array-like`*, shape `(3,)`, optional

Fixed rotation axis, the symmetry axis of the helix

src_to_det_init : *array-like*, shape `(2,)`, optional

Initial state of the vector pointing from source to detector reference point. The zero vector is not allowed. By default, a *perpendicular_vector* to `axis` is used.

det_init_axes : 2-tuple of *array-like* (shape `(2,)`), optional

Initial axes defining the detector orientation. By default, the normalized cross product of `axis` and `src_to_det_init` is used as first axis and `axis` as second.

HelicalConeFlatGeometry

class `odl.tomo.geometry.conebeam.`**`HelicalConeFlatGeometry`**(*apart, dpart, src_radius, det_radius, pitch, axis=[0, 0, 1], **kwargs*)

Bases: *odl.tomo.geometry.geometry.DivergentBeamGeometry*, *odl.tomo.geometry.geometry.AxisOrientedGeometry*

Cone beam geometry with helical source curve and flat detector.

The source moves along a spiral oriented along a fixed `axis`, with radius `src_radius` in the azimuthal plane and a given `pitch`. The detector reference point is opposite to the source, i.e. in the point at distance `src_rad + det_rad` on the line in the azimuthal plane through the source point and `axis`.

The motion parameter is the 1d rotation angle parameterizing source and detector positions simultaneously.

In the standard configuration, the rotation axis is `(0, 0, 1)`, the initial source-to-detector vector is `(1, 0, 0)`, and the initial detector axes are `[(0, 1, 0), (0, 0, 1)]`.

See also:

CircularConeFlatGeometry Case with zero pitch

Attributes

axis	The normalized axis of rotation, a 3-element vector.
det_grid	Sampling grid of *det_params*.
det_init_axes	Initial axes defining the detector orientation.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
det_radius	Detector circle radius of this geometry.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.
pitch	Constant vertical distance traversed in a full rotation.
pitch_offset	Vertical offset at `angle=0`
src_radius	Source circle radius of this geometry.
src_to_det_init	Initial state of the vector pointing from source to detector reference point.

HelicalConeFlatGeometry.axis
`HelicalConeFlatGeometry.`**`axis`**
The normalized axis of rotation, a 3-element vector.

HelicalConeFlatGeometry.det_grid
`HelicalConeFlatGeometry.`**`det_grid`**
Sampling grid of *det_params*.

HelicalConeFlatGeometry.det_init_axes
`HelicalConeFlatGeometry.`**`det_init_axes`**
Initial axes defining the detector orientation.

HelicalConeFlatGeometry.det_params
`HelicalConeFlatGeometry.`**`det_params`**
Continuous detector parameter range, an *IntervalProd*.

HelicalConeFlatGeometry.det_partition
`HelicalConeFlatGeometry.`**`det_partition`**
Partition of the detector parameter set into subsets.

HelicalConeFlatGeometry.det_radius
`HelicalConeFlatGeometry.`**`det_radius`**
Detector circle radius of this geometry.

HelicalConeFlatGeometry.detector
`HelicalConeFlatGeometry.`**`detector`**
Detector representation of this geometry.

HelicalConeFlatGeometry.grid
`HelicalConeFlatGeometry.`**`grid`**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

HelicalConeFlatGeometry.implementation_cache
`HelicalConeFlatGeometry.`**`implementation_cache`**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : `dict`

HelicalConeFlatGeometry.motion_grid
`HelicalConeFlatGeometry.`**`motion_grid`**
Sampling grid of *motion_params*.

HelicalConeFlatGeometry.motion_params
`HelicalConeFlatGeometry.motion_params`
Continuous motion parameter range, an *IntervalProd*.

HelicalConeFlatGeometry.motion_partition
`HelicalConeFlatGeometry.motion_partition`
Partition of the motion parameter set into subsets.

HelicalConeFlatGeometry.ndim
`HelicalConeFlatGeometry.ndim`
The number of dimensions of the geometry.

HelicalConeFlatGeometry.params
`HelicalConeFlatGeometry.params`
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

HelicalConeFlatGeometry.partition
`HelicalConeFlatGeometry.partition`
Joined parameter set partition for motion and detector.

Returns a *RectPartition* with the detector partition inserted after the motion partition.

HelicalConeFlatGeometry.pitch
`HelicalConeFlatGeometry.pitch`
Constant vertical distance traversed in a full rotation.

HelicalConeFlatGeometry.pitch_offset
`HelicalConeFlatGeometry.pitch_offset`
Vertical offset at `angle=0`

HelicalConeFlatGeometry.src_radius
`HelicalConeFlatGeometry.src_radius`
Source circle radius of this geometry.

HelicalConeFlatGeometry.src_to_det_init
`HelicalConeFlatGeometry.src_to_det_init`
Initial state of the vector pointing from source to detector reference point.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(angle)	Return the detector reference point position at `angle`.
det_to_src(mpar, dpar[, normalized])	Vector pointing from a detector location to the source.
rotation_matrix(angle)	The detector rotation function.
src_position(angle)	Return the source position at `angle`.

HelicalConeFlatGeometry.det_point_position

`HelicalConeFlatGeometry.det_point_position(mpar, dpar)`

The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

HelicalConeFlatGeometry.det_refpoint

`HelicalConeFlatGeometry.det_refpoint(angle)`

Return the detector reference point position at `angle`.

For an angle `phi`, the detector position is given by:

```
ref(phi) = det_rad * rot_matrix(phi) * src_to_det_init +
           (pitch_offset + pitch * phi) * axis
```

where `src_to_det_init` is the initial unit vector pointing from source to detector.

Parametersangle : `float`

Rotation angle given in radians, must be contained in this geometry's *motion_params*

Returnspoint : `numpy.ndarray`, shape (3,)

Detector reference point corresponding to the given angle

See also:

rotation_matrix

HelicalConeFlatGeometry.det_to_src

`HelicalConeFlatGeometry.det_to_src(mpar, dpar, normalized=True)`

Vector pointing from a detector location to the source.

A function of the motion and detector parameters.

The default implementation uses the *det_point_position* and *src_position* functions. Implementations can override this, for example if no source position is given.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

normalized : `bool`, optional

If `True`, return a normalized (unit) vector.

Returnsvec : `numpy.ndarray`, shape (*ndim*,)

(Unit) vector pointing from the detector to the source

HelicalConeFlatGeometry.rotation_matrix

`HelicalConeFlatGeometry.`**`rotation_matrix`**(*angle*)

The detector rotation function.

Returns the matrix for rotating a vector in 3d by an angle `angle` about the rotation axis given by the property *`axis`* according to the right hand rule.

The matrix is computed according to Rodrigues' rotation formula.

Parametersangle : `float`

The motion parameter given in radian. It must be contained in this geometry's *`motion_params`*.

Returnsrot_mat : `numpy.ndarray`, shape `(3, 3)`

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

HelicalConeFlatGeometry.src_position

`HelicalConeFlatGeometry.`**`src_position`**(*angle*)

Return the source position at `angle`.

For an angle `phi`, the source position is given by:

```
src(phi) = -src_rad * rot_matrix(phi) * src_to_det_init +
           (pitch_offset + pitch * phi) * axis
```

where `src_to_det_init` is the initial unit vector pointing from source to detector.

Parametersangle : `float`

Rotation angle given in radians, must be contained in this geometry's *`motion_params`*

Returnspoint : `numpy.ndarray`, shape (3,)

Detector reference point corresponding to the given angle

See also:

`rotation_matrix`

`__init__`(*apart, dpart, src_radius, det_radius, pitch, axis=[0, 0, 1], **kwargs*)

Initialize a new instance.

Parametersapart : 1-dim. *`RectPartition`*

Partition of the angle interval

dpart : 2-dim. *`RectPartition`*

Partition of the detector parameter rectangle

src_radius : nonnegative `float`

Radius of the source circle

det_radius : nonnegative `float`

Radius of the detector circle

pitch : `float`

Constant vertical distance that a point on the helix traverses when increasing the angle parameter by `2 * pi`

axis : *array-like*, shape `(3,)`, optional

Fixed rotation axis, the symmetry axis of the helix

Other Parameterssrc_to_det_init : *array-like*, shape `(2,)`, optional

Initial state of the vector pointing from source to detector reference point. The zero vector is not allowed. By default, a *perpendicular_vector* to `axis` is used.

det_init_axes : 2-tuple of *array-like* (shape `(2,)`), optional

Initial axes defining the detector orientation. By default, the normalized cross product of `axis` and `src_to_det_init` is used as first axis and `axis` as second.

pitch_offset : `float`, optional

Offset along the `axis` at `angle=0`

detector

Detectors for tomographic imaging.

Classes

CircleSectionDetector(part, circ_rad)	A 1d detector given by a section of a circle.
Detector(part)	Abstract detector class.
Flat1dDetector(part, axis)	A 1d line detector aligned with `axis`.
Flat2dDetector(part, axes)	A 2d flat panel detector aligned with `axes`.
FlatDetector(part)	Abstract class for flat detectors in 2 and 3 dimensions.

CircleSectionDetector

class `odl.tomo.geometry.detector.`**`CircleSectionDetector`**(*part*, *circ_rad*)

Bases: *odl.tomo.geometry.detector.Detector*

A 1d detector given by a section of a circle.

The reference circular section is part of a circle with radius `r`, which is shifted by the vector `(-r, 0)` such that the parameter value 0 results in the detector reference point `(0, 0)`.

Attributes

circ_rad	Circle radius of this detector.
grid	Sampling grid of the parameters.
ndim	Number of dimensions of this detector (0, 1 or 2).
params	Surface parameter set of this detector.
partition	Partition of the detector parameter set into subsets.
shape	Number of subsets (pixels) of the detector per axis.
size	Total number of pixels.

CircleSectionDetector.circ_rad
`CircleSectionDetector.`**`circ_rad`**
Circle radius of this detector.

CircleSectionDetector.grid
`CircleSectionDetector.`**`grid`**
Sampling grid of the parameters.

CircleSectionDetector.ndim
`CircleSectionDetector.`**`ndim`**
Number of dimensions of this detector (0, 1 or 2).

CircleSectionDetector.params
`CircleSectionDetector.`**`params`**
Surface parameter set of this detector.

CircleSectionDetector.partition
`CircleSectionDetector.`**`partition`**
Partition of the detector parameter set into subsets.

CircleSectionDetector.shape
`CircleSectionDetector.`**`shape`**
Number of subsets (pixels) of the detector per axis.

CircleSectionDetector.size
`CircleSectionDetector.`**`size`**
Total number of pixels.

Methods

`__eq__`	Return self==value.
surface(param)	The parametrization of the detector reference surface.
surface_deriv(param)	The partial derivative(s) of the surface parametrization.
surface_measure(param)	The constant density function of the surface measure.

CircleSectionDetector.surface
`CircleSectionDetector.`**`surface`**(*param*)
The parametrization of the detector reference surface.

Parameters **param** : element of *params*

The parameter value where to evaluate the function

CircleSectionDetector.surface_deriv
`CircleSectionDetector.`**`surface_deriv`**(*param*)
The partial derivative(s) of the surface parametrization.

Parameters **param** : element of *params*

The parameter value where to evaluate the function

CircleSectionDetector.surface_measure
`CircleSectionDetector.`**`surface_measure`**(*param*)
The constant density function of the surface measure.

Parametersparam : element of *params*

The parameter value where to evaluate the function

Returnsmeasure : `float`

The constant density `r`, equal to the length of the tangent to the detector circle at any point

`__init__`(*part*, *circ_rad*)
Initialize a new instance.

Parameterspart : 1-dim. *RectPartition*

Partition of the parameter interval, corresponding to the angle sections along the line

circ_rad : positive `float`

Radius of the circle along which the detector is curved

Detector

class `odl.tomo.geometry.detector.`**`Detector`**(*part*)
Bases: `object`

Abstract detector class.

A detector is described by

- a set of parameters for surface parametrization (including sampling),
- a function mapping a surface parameter to the location of a detector point relative to its reference point,
- optionally a surface measure function.

Attributes

grid	Sampling grid of the parameters.
ndim	Number of dimensions of this detector (0, 1 or 2).
params	Surface parameter set of this detector.
partition	Partition of the detector parameter set into subsets.
shape	Number of subsets (pixels) of the detector per axis.
size	Total number of pixels.

Detector.grid
`Detector.`**`grid`**
Sampling grid of the parameters.

Detector.ndim
`Detector.`**`ndim`**
Number of dimensions of this detector (0, 1 or 2).

Detector.params
`Detector.`**`params`**
Surface parameter set of this detector.

Detector.partition
`Detector.`**`partition`**
Partition of the detector parameter set into subsets.

Detector.shape
`Detector.`**`shape`**
Number of subsets (pixels) of the detector per axis.

Detector.size
`Detector.`**`size`**
Total number of pixels.

Methods

`__eq__`	Return self==value.
`surface`(param)	Parametrization of the detector reference surface.
`surface_deriv`(param)	Partial derivative(s) of the surface parametrization.
`surface_measure`(param)	Density function of the surface measure.

Detector.surface
`Detector.`**`surface`**(*param*)
Parametrization of the detector reference surface.

Parametersparam : element of *`params`*

Parameter value where to evaluate the function

Returnspoint :

Spatial location of the detector point corresponding to `param`

Detector.surface_deriv
`Detector.`**`surface_deriv`**(*param*)
Partial derivative(s) of the surface parametrization.

Parametersparam : element of *`params`*

The parameter value where to evaluate the function

Returnsderiv :

Vector (`ndim=1`) or sequence of vectors corresponding to the partial derivatives at `param`

Detector.surface_measure
`Detector.`**`surface_measure`**(*param*)
Density function of the surface measure.

This is the default implementation relying on the *surface_deriv* method. For `ndim == 1`, the density is given by the *Arc length*, for `ndim == 2`, it is the length of the cross product of the partial derivatives of the parametrization, see Wikipedia's *Surface area* article.

Parametersparam : element of *params*

The parameter value where to evaluate the function

Returnsmeasure : `float`

The density value at the given parameter

https://en.wikipedia.org/wiki/Curve#Lengths_of_curves

https://en.wikipedia.org/wiki/Surface_area

__init__(*part*)

Initialize a new instance.

Parameterspart : *RectPartition*

Partition of the detector parameter set (pixelization). It determines dimension, parameter range and discretization.

Flat1dDetector

class odl.tomo.geometry.detector.**Flat1dDetector**(*part*, *axis*)

Bases: *odl.tomo.geometry.detector.FlatDetector*

A 1d line detector aligned with `axis`.

Attributes

axis	Normalized principal axis of the detector.
grid	Sampling grid of the parameters.
ndim	Number of dimensions of this detector (0, 1 or 2).
normal	Unit vector perpendicular to the detector.
params	Surface parameter set of this detector.
partition	Partition of the detector parameter set into subsets.
shape	Number of subsets (pixels) of the detector per axis.
size	Total number of pixels.

Flat1dDetector.axis

Flat1dDetector.**axis**

Normalized principal axis of the detector.

Flat1dDetector.grid

Flat1dDetector.**grid**

Sampling grid of the parameters.

Flat1dDetector.ndim

Flat1dDetector.**ndim**

Number of dimensions of this detector (0, 1 or 2).

Flat1dDetector.normal
`Flat1dDetector.`**`normal`**
Unit vector perpendicular to the detector.

Its orientation is chosen such that the system `axis, normal` is right-handed.

Flat1dDetector.params
`Flat1dDetector.`**`params`**
Surface parameter set of this detector.

Flat1dDetector.partition
`Flat1dDetector.`**`partition`**
Partition of the detector parameter set into subsets.

Flat1dDetector.shape
`Flat1dDetector.`**`shape`**
Number of subsets (pixels) of the detector per axis.

Flat1dDetector.size
`Flat1dDetector.`**`size`**
Total number of pixels.

Methods

`__eq__`	Return self==value.
`surface`(param)	The parametrization of the (1d) detector reference surface.
`surface_deriv`([param])	The derivative of the surface parametrization.
`surface_measure`([param])	The constant density function of the surface measure.

Flat1dDetector.surface
`Flat1dDetector.`**`surface`**(*param*)
The parametrization of the (1d) detector reference surface.

The reference line segment is chosen to be aligned with the second coordinate axis, such that the parameter value 0 results in the reference point (0, 0).

Parametersparam : element of *`params`*

The parameter value where to evaluate the function

Returnspoint : `numpy.ndarray`, shape (2,)

The point on the detector surface corresponding to the given parameters

Flat1dDetector.surface_deriv
`Flat1dDetector.`**`surface_deriv`**(*param=None*)
The derivative of the surface parametrization.

Parametersparam : element of *`params`*, optional

The parameter value where to evaluate the function

Returnsderivative : `numpy.ndarray`, shape (2,)

The constant derivative

Flat1dDetector.surface_measure
`Flat1dDetector.surface_measure(param=None)`
The constant density function of the surface measure.

Parametersparam : element of *params*, optional

The parameter value where to evaluate the function

Returnsmeasure : `float`

The constant density 1.0

__init__(*part*, *axis*)
Initialize a new instance.

Parameterspart : 1-dim. *RectPartition*

Partition of the parameter interval, corresponding to the line elements

axis : *array-like*, shape `(2,)`

Principal axis of the detector

Flat2dDetector

class `odl.tomo.geometry.detector.Flat2dDetector`(*part*, *axes*)
Bases: *odl.tomo.geometry.detector.FlatDetector*

A 2d flat panel detector aligned with `axes`.

Attributes

axes	Normalized principal axes of this detector as a 2-tuple.
grid	Sampling grid of the parameters.
ndim	Number of dimensions of this detector (0, 1 or 2).
normal	Unit vector perpendicular to this detector.
params	Surface parameter set of this detector.
partition	Partition of the detector parameter set into subsets.
shape	Number of subsets (pixels) of the detector per axis.
size	Total number of pixels.

Flat2dDetector.axes
`Flat2dDetector.axes`
Normalized principal axes of this detector as a 2-tuple.

Flat2dDetector.grid
`Flat2dDetector.grid`
Sampling grid of the parameters.

Flat2dDetector.ndim
`Flat2dDetector.ndim`
Number of dimensions of this detector (0, 1 or 2).

Flat2dDetector.normal
`Flat2dDetector.`**`normal`**
Unit vector perpendicular to this detector.

The orientation is chosen such that the triple `axes[0], axes[1], normal` form a right-hand system.

Flat2dDetector.params
`Flat2dDetector.`**`params`**
Surface parameter set of this detector.

Flat2dDetector.partition
`Flat2dDetector.`**`partition`**
Partition of the detector parameter set into subsets.

Flat2dDetector.shape
`Flat2dDetector.`**`shape`**
Number of subsets (pixels) of the detector per axis.

Flat2dDetector.size
`Flat2dDetector.`**`size`**
Total number of pixels.

Methods

`__eq__`	Return self==value.
`surface`(param)	Parametrization of the 2d detector reference surface.
`surface_deriv`([param])	The derivative of the surface parametrization.
`surface_measure`([param])	The constant density function of the surface measure.

Flat2dDetector.surface
`Flat2dDetector.`**`surface`**(*param*)
Parametrization of the 2d detector reference surface.

The reference plane segment is chosen to be aligned with the second and third coordinate axes, in this order, such that the parameter value (0, 0) results in the reference (0, 0, 0).

Parametersparam : element of *`params`*

The parameter value where to evaluate the function

Returnspoint : `numpy.ndarray`, shape (3,)

The point on the detector surface corresponding to the given parameters

Flat2dDetector.surface_deriv
`Flat2dDetector.`**`surface_deriv`**(*param=None*)
The derivative of the surface parametrization.

Parametersparam : element of *`params`*, optional

The parameter value where to evaluate the function

Returnsderivatives : 2-tuple of `numpy.ndarray` (shape `(3,)`)

The constant partial derivatives given by the detector axes

Flat2dDetector.surface_measure
`Flat2dDetector.surface_measure(param=None)`
The constant density function of the surface measure.

Parametersparam : element of *params*, optional

The parameter value where to evaluate the function

Returnsmeasure : `float`

The constant density 1.0

__init__ (*part*, *axes*)
Initialize a new instance.

Parameterspart : 1-dim. *RectPartition*

Partition of the parameter interval, corresponding to the pixels

axes : 2-tuple of *array-like* (shape `(3,)`)

Principal axes of the detector, e.g. `[(0, 1, 0), (0, 0, 1)]`

FlatDetector

class `odl.tomo.geometry.detector.FlatDetector(part)`
Bases: *odl.tomo.geometry.detector.Detector*

Abstract class for flat detectors in 2 and 3 dimensions.

Attributes

grid	Sampling grid of the parameters.
ndim	Number of dimensions of this detector (0, 1 or 2).
params	Surface parameter set of this detector.
partition	Partition of the detector parameter set into subsets.
shape	Number of subsets (pixels) of the detector per axis.
size	Total number of pixels.

FlatDetector.grid
`FlatDetector.grid`
Sampling grid of the parameters.

FlatDetector.ndim
`FlatDetector.ndim`
Number of dimensions of this detector (0, 1 or 2).

FlatDetector.params
`FlatDetector.params`
Surface parameter set of this detector.

FlatDetector.partition

FlatDetector.**partition**
Partition of the detector parameter set into subsets.

FlatDetector.shape
FlatDetector.**shape**
Number of subsets (pixels) of the detector per axis.

FlatDetector.size
FlatDetector.**size**
Total number of pixels.

Methods

__eq__	Return self==value.
surface(param)	Parametrization of the detector reference surface.
surface_deriv(param)	Partial derivative(s) of the surface parametrization.
surface_measure([param])	The constant density function of the surface measure.

FlatDetector.surface
FlatDetector.**surface**(*param*)
Parametrization of the detector reference surface.

Parametersparam : element of *params*

Parameter value where to evaluate the function

Returnspoint :

Spatial location of the detector point corresponding to `param`

FlatDetector.surface_deriv
FlatDetector.**surface_deriv**(*param*)
Partial derivative(s) of the surface parametrization.

Parametersparam : element of *params*

The parameter value where to evaluate the function

Returnsderiv :

Vector (`ndim=1`) or sequence of vectors corresponding to the partial derivatives at `param`

FlatDetector.surface_measure
FlatDetector.**surface_measure**(*param=None*)
The constant density function of the surface measure.

Parametersparam : element of *params*, optional

The parameter value where to evaluate the function

Returnsmeasure : `float`

The constant density 1.0

__init__ (*part*)
Initialize a new instance.

Parameterspart : *RectPartition*

Partition of the detector parameter set (pixelization). It determines dimension, parameter range and discretization.

fanbeam

Fan beam geometries in 2 dimensions.

Classes

FanFlatGeometry(apart, dpart, src_radius, ...)	Abstract 2d fan beam geometry with flat 1d detector.

FanFlatGeometry

class odl.tomo.geometry.fanbeam.**FanFlatGeometry**(*apart*, *dpart*, *src_radius*, *det_radius*, ***kwargs*)

Bases: *odl.tomo.geometry.geometry.DivergentBeamGeometry*

Abstract 2d fan beam geometry with flat 1d detector.

The source moves on a circle with radius `src_radius`, and the detector reference point is opposite to the source, i.e. at maximum distance, on a circle with radius `det_radius`. One of the two radii can be chosen as 0, which corresponds to a stationary source or detector, respectively.

The motion parameter is the 1d rotation angle parameterizing source and detector positions simultaneously.

In the standard configuration, the source and detector start on the first coodinate axis with vector `(1, 0)` from source to detector, and the initial detector axis is `(0, 1)`.

Attributes

det_grid	Sampling grid of *det_params*.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
det_radius	Detector circle radius of this geometry.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.
src_radius	Source circle radius of this geometry.

FanFlatGeometry.det_grid

FanFlatGeometry.**det_grid**
Sampling grid of *det_params*.

FanFlatGeometry.det_params
FanFlatGeometry.**det_params**
Continuous detector parameter range, an *IntervalProd*.

FanFlatGeometry.det_partition
FanFlatGeometry.**det_partition**
Partition of the detector parameter set into subsets.

FanFlatGeometry.det_radius
FanFlatGeometry.**det_radius**
Detector circle radius of this geometry.

FanFlatGeometry.detector
FanFlatGeometry.**detector**
Detector representation of this geometry.

FanFlatGeometry.grid
FanFlatGeometry.**grid**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

FanFlatGeometry.implementation_cache
FanFlatGeometry.**implementation_cache**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : dict

FanFlatGeometry.motion_grid
FanFlatGeometry.**motion_grid**
Sampling grid of *motion_params*.

FanFlatGeometry.motion_params
FanFlatGeometry.**motion_params**
Continuous motion parameter range, an *IntervalProd*.

FanFlatGeometry.motion_partition
FanFlatGeometry.**motion_partition**
Partition of the motion parameter set into subsets.

FanFlatGeometry.ndim
FanFlatGeometry.**ndim**
The number of dimensions of the geometry.

FanFlatGeometry.params
`FanFlatGeometry.params`
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

FanFlatGeometry.partition
`FanFlatGeometry.partition`
Joined parameter set partition for motion and detector.

Returns a *RectPartition* with the detector partition inserted after the motion partition.

FanFlatGeometry.src_radius
`FanFlatGeometry.src_radius`
Source circle radius of this geometry.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(angle)	Return the detector reference point position at `angle`.
det_to_src(mpar, dpar[, normalized])	Vector pointing from a detector location to the source.
rotation_matrix(angle)	Return the rotation matrix for `angle`.
src_position(angle)	Return the source position at `angle`.

FanFlatGeometry.det_point_position
`FanFlatGeometry.det_point_position`(*mpar*, *dpar*)
The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

FanFlatGeometry.det_refpoint
`FanFlatGeometry.det_refpoint`(*angle*)
Return the detector reference point position at `angle`.

For an angle `phi`, the detector position is given by:

```
ref(phi) = det_rad * rot_matrix(phi) * src_to_det_init
```

where `src_to_det_init` is the initial unit vector pointing from source to detector.

Parametersangle : `float`

Rotation angle given in radians, must be contained in this geometry's *motion_params*

Returnspoint : numpy.ndarray, shape (2,)

Detector reference point corresponding to the given angle

See also:

rotation_matrix

FanFlatGeometry.det_to_src

FanFlatGeometry.**det_to_src**(*mpar*, *dpar*, *normalized=True*)

Vector pointing from a detector location to the source.

A function of the motion and detector parameters.

The default implementation uses the *det_point_position* and *src_position* functions. Implementations can override this, for example if no source position is given.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

normalized : bool, optional

If True, return a normalized (unit) vector.

Returnsvec : numpy.ndarray, shape (*ndim*,)

(Unit) vector pointing from the detector to the source

FanFlatGeometry.rotation_matrix

FanFlatGeometry.**rotation_matrix**(*angle*)

Return the rotation matrix for angle.

For an angle phi, the matrix is given by:

```
rot(phi) = [[cos(phi), -sin(phi)],
            [sin(phi), cos(phi)]]
```

Parametersangle : float

Rotation angle given in radians, must be contained in this geometry's *motion_params*

Returnsrot : numpy.ndarray, shape (2, 2)

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system

FanFlatGeometry.src_position

FanFlatGeometry.**src_position**(*angle*)

Return the source position at angle.

For an angle phi, the source position is given by:

```
src(phi) = -src_rad * rot_matrix(phi) * src_to_det_init
```

where src_to_det_init is the initial unit vector pointing from source to detector.

Parametersangle : `float`

Rotation angle given in radians, must be contained in this geometry's *motion_params*

Returnspoint : `numpy.ndarray`, shape `(2,)`

Source position corresponding to the given angle

__init__(*apart*, *dpart*, *src_radius*, *det_radius*, ***kwargs*)

Initialize a new instance.

Parametersapart : 1-dim. *RectPartition*

Partition of the angle interval

dpart : 1-dim. *RectPartition*

Partition of the detector parameter interval

src_radius : nonnegative `float`

Radius of the source circle

det_radius : nonnegative `float`

Radius of the detector circle

src_to_det_init : *array-like*, shape `(2,)`, optional

Initial state of the vector pointing from source to detector reference point. The zero vector is not allowed. Default: `(1, 0)`.

det_init_axis : *array-like* (shape `(2,)`), optional

Initial axis defining the detector orientation. By default, a normalized *perpendicular_vector* to `src_to_det_init` is used.

geometry

Geometry base and mixin classes.

Classes

AxisOrientedGeometry(axis)	Mixin class for 3d geometries oriented according to an axis.
DivergentBeamGeometry(ndim, motion_part, ...)	Abstract divergent beam geometry class.
Geometry(ndim, motion_part, detector)	Abstract geometry class.

AxisOrientedGeometry

class `odl.tomo.geometry.geometry.`**AxisOrientedGeometry**(*axis*)

Bases: `object`

Mixin class for 3d geometries oriented according to an axis.

Attributes

axis	The normalized axis of rotation, a 3-element vector.

AxisOrientedGeometry.axis

`AxisOrientedGeometry.`**`axis`**

The normalized axis of rotation, a 3-element vector.

Methods

`__eq__`	Return self==value.
rotation_matrix(angle)	The detector rotation function.

AxisOrientedGeometry.rotation_matrix

`AxisOrientedGeometry.`**`rotation_matrix`**(*angle*)

The detector rotation function.

Returns the matrix for rotating a vector in 3d by an angle `angle` about the rotation axis given by the property *axis* according to the right hand rule.

The matrix is computed according to Rodrigues' rotation formula.

Parametersangle : `float`

The motion parameter given in radian. It must be contained in this geometry's *motion_params*.

Returnsrot_mat : `numpy.ndarray`, shape `(3, 3)`

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

`__init__`(*axis*)

Initialize a new instance.

Parametersaxis : 3-element *array-like*

Vector defining the fixed rotation axis after normalization

DivergentBeamGeometry

class `odl.tomo.geometry.geometry.`**`DivergentBeamGeometry`**(*ndim*, *motion_part*, *detector*)

Bases: *odl.tomo.geometry.geometry.Geometry*

Abstract divergent beam geometry class.

A divergent beam geometry is characterized by the presence of a point source.

Special cases include fan beam in 2d and cone beam in 3d.

Attributes

det_grid	Sampling grid of *det_params*.
det_params	Continuous detector parameter range, an *IntervalProd*.

Continued on next page

Table 8.257 – continued from previous page

det_partition	Partition of the detector parameter set into subsets.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.

DivergentBeamGeometry.det_grid
`DivergentBeamGeometry.`**`det_grid`**
Sampling grid of *det_params*.

DivergentBeamGeometry.det_params
`DivergentBeamGeometry.`**`det_params`**
Continuous detector parameter range, an *IntervalProd*.

DivergentBeamGeometry.det_partition
`DivergentBeamGeometry.`**`det_partition`**
Partition of the detector parameter set into subsets.

DivergentBeamGeometry.detector
`DivergentBeamGeometry.`**`detector`**
Detector representation of this geometry.

DivergentBeamGeometry.grid
`DivergentBeamGeometry.`**`grid`**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

DivergentBeamGeometry.implementation_cache
`DivergentBeamGeometry.`**`implementation_cache`**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : `dict`

DivergentBeamGeometry.motion_grid
`DivergentBeamGeometry.`**`motion_grid`**
Sampling grid of *motion_params*.

DivergentBeamGeometry.motion_params
`DivergentBeamGeometry.`**`motion_params`**
Continuous motion parameter range, an *IntervalProd*.

DivergentBeamGeometry.motion_partition
`DivergentBeamGeometry.motion_partition`
Partition of the motion parameter set into subsets.

DivergentBeamGeometry.ndim
`DivergentBeamGeometry.ndim`
The number of dimensions of the geometry.

DivergentBeamGeometry.params
`DivergentBeamGeometry.params`
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

DivergentBeamGeometry.partition
`DivergentBeamGeometry.partition`
Joined parameter set partition for motion and detector.

Returns a *RectPartition* with the detector partition inserted after the motion partition.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(mpar)	The detector reference point function.
det_to_src(mpar, dpar[, normalized])	Vector pointing from a detector location to the source.
rotation_matrix(mpar)	The detector rotation function for calculating the detector reference position.
src_position(mpar)	The source position function.

DivergentBeamGeometry.det_point_position
`DivergentBeamGeometry.det_point_position`(*mpar*, *dpar*)
The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

DivergentBeamGeometry.det_refpoint
`DivergentBeamGeometry.det_refpoint`(*mpar*)
The detector reference point function.

Parametersmpar : element of motion parameters

Motion parameter for which to calculate the detector reference point

Returnspoint : `numpy.ndarray`, shape (*ndim*,)

The reference point, an *ndim*-dimensional vector

DivergentBeamGeometry.det_to_src

`DivergentBeamGeometry.det_to_src(mpar, dpar, normalized=True)`

Vector pointing from a detector location to the source.

A function of the motion and detector parameters.

The default implementation uses the *det_point_position* and *src_position* functions. Implementations can override this, for example if no source position is given.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

normalized : `bool`, optional

If `True`, return a normalized (unit) vector.

Returnsvec : `numpy.ndarray`, shape (*ndim*,)

(Unit) vector pointing from the detector to the source

DivergentBeamGeometry.rotation_matrix

`DivergentBeamGeometry.rotation_matrix(mpar)`

The detector rotation function for calculating the detector reference position.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter for which to calculate the detector reference rotation

Returnsrot : `numpy.ndarray`, shape (*ndim*, *ndim*)

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

DivergentBeamGeometry.src_position

`DivergentBeamGeometry.src_position(mpar)`

The source position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter for which to calculate the source position

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

__init__(*ndim*, *motion_part*, *detector*)

Initialize a new instance.

Parametersndim : positive `int`

Number of dimensions of this geometry, i.e. dimensionality of the physical space in which this geometry is embedded

motion_part : *RectPartition*

Partition for the set of "motion" parameters

detector : *Detector*

The detector of this geometry

Geometry

class odl.tomo.geometry.geometry.**Geometry**(*ndim*, *motion_part*, *detector*)
Bases: object

Abstract geometry class.

A geometry is described by

- a detector,
- a set of detector motion parameters,
- a function mapping motion parameters to the location of a reference point (e.g. the center of the detector surface),
- a rotation applied to the detector surface, depending on the motion parameters,
- a mapping from the motion and surface parameters to the detector pixel direction to the source,
- optionally a mapping from the motion parameters to the source position

Attributes

det_grid	Sampling grid of *det_params*.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.

Geometry.det_grid
Geometry.**det_grid**
Sampling grid of *det_params*.

Geometry.det_params
Geometry.**det_params**
Continuous detector parameter range, an *IntervalProd*.

Geometry.det_partition
Geometry.**det_partition**
Partition of the detector parameter set into subsets.

Geometry.detector
`Geometry.`**`detector`**
Detector representation of this geometry.

Geometry.grid
`Geometry.`**`grid`**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

Geometry.implementation_cache
`Geometry.`**`implementation_cache`**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : `dict`

Geometry.motion_grid
`Geometry.`**`motion_grid`**
Sampling grid of *`motion_params`*.

Geometry.motion_params
`Geometry.`**`motion_params`**
Continuous motion parameter range, an *`IntervalProd`*.

Geometry.motion_partition
`Geometry.`**`motion_partition`**
Partition of the motion parameter set into subsets.

Geometry.ndim
`Geometry.`**`ndim`**
The number of dimensions of the geometry.

Geometry.params
`Geometry.`**`params`**
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

Geometry.partition
`Geometry.`**`partition`**
Joined parameter set partition for motion and detector.

Returns a *`RectPartition`* with the detector partition inserted after the motion partition.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(mpar)	The detector reference point function.
det_to_src(mpar, dpar[, normalized])	Vector pointing from a detector location to the source.
rotation_matrix(mpar)	The detector rotation function for calculating the detector reference position.

Geometry.det_point_position

`Geometry.`**`det_point_position`**(*mpar*, *dpar*)

The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

Geometry.det_refpoint

`Geometry.`**`det_refpoint`**(*mpar*)

The detector reference point function.

Parametersmpar : element of motion parameters

Motion parameter for which to calculate the detector reference point

Returnspoint : `numpy.ndarray`, shape (*ndim*,)

The reference point, an *ndim*-dimensional vector

Geometry.det_to_src

`Geometry.`**`det_to_src`**(*mpar*, *dpar*, *normalized=True*)

Vector pointing from a detector location to the source.

A function of the motion and detector parameters.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

normalized : `bool`, optional

If `True`, return a normalized (unit) vector. Default: `True`

Returnsvec : `numpy.ndarray`, shape (*ndim*,)

(Unit) vector pointing from the detector to the source

Geometry.rotation_matrix
`Geometry.`**`rotation_matrix`**(*mpar*)
The detector rotation function for calculating the detector reference position.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter for which to calculate the detector reference rotation

Returnsrot : `numpy.ndarray`, shape (*ndim*, *ndim*)

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

__init__(*ndim*, *motion_part*, *detector*)
Initialize a new instance.

Parametersndim : positive `int`

Number of dimensions of this geometry, i.e. dimensionality of the physical space in which this geometry is embedded

motion_part : *RectPartition*

Partition for the set of "motion" parameters

detector : *Detector*

The detector of this geometry

parallel

Parallel beam geometries in 2 and 3 dimensions.

Classes

Parallel2dGeometry(apart, dpart, **kwargs)	Parallel beam geometry in 2d.
Parallel3dAxisGeometry(apart, dpart[, axis])	Parallel beam geometry in 3d with single rotation axis.
Parallel3dGeometry(apart, dpart, **kwargs)	Parallel beam geometry in 3d.
ParallelGeometry(ndim, apart, detector, ...)	Abstract parallel beam geometry in 2 or 3 dimensions.

Parallel2dGeometry

class `odl.tomo.geometry.parallel.`**`Parallel2dGeometry`**(*apart*, *dpart*, ***kwargs*)
Bases: *odl.tomo.geometry.parallel.ParallelGeometry*

Parallel beam geometry in 2d.

The motion parameter is the counter-clockwise rotation angle around the origin, and the detector is a line detector perpendicular to the ray direction.

In the standard configuration, the detector reference point starts at `(1, 0)`, and the initial detector axis is `(0, 1)`.

Attributes

det_grid	Sampling grid of *det_params*.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.

Parallel2dGeometry.det_grid
`Parallel2dGeometry.`**`det_grid`**
Sampling grid of *det_params*.

Parallel2dGeometry.det_params
`Parallel2dGeometry.`**`det_params`**
Continuous detector parameter range, an *IntervalProd*.

Parallel2dGeometry.det_partition
`Parallel2dGeometry.`**`det_partition`**
Partition of the detector parameter set into subsets.

Parallel2dGeometry.detector
`Parallel2dGeometry.`**`detector`**
Detector representation of this geometry.

Parallel2dGeometry.grid
`Parallel2dGeometry.`**`grid`**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

Parallel2dGeometry.implementation_cache
`Parallel2dGeometry.`**`implementation_cache`**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : `dict`

Parallel2dGeometry.motion_grid
`Parallel2dGeometry.`**`motion_grid`**
Sampling grid of *motion_params*.

Parallel2dGeometry.motion_params
`Parallel2dGeometry.motion_params`
Continuous motion parameter range, an *IntervalProd*.

Parallel2dGeometry.motion_partition
`Parallel2dGeometry.motion_partition`
Partition of the motion parameter set into subsets.

Parallel2dGeometry.ndim
`Parallel2dGeometry.ndim`
The number of dimensions of the geometry.

Parallel2dGeometry.params
`Parallel2dGeometry.params`
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

Parallel2dGeometry.partition
`Parallel2dGeometry.partition`
Joined parameter set partition for motion and detector.

Returns a *RectPartition* with the detector partition inserted after the motion partition.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(angles)	Return the position of the detector ref.
det_to_src(angles, dpar[, normalized])	Direction from a detector location to the source.
rotation_matrix(angle)	Return the rotation matrix for `angle`.

Parallel2dGeometry.det_point_position
`Parallel2dGeometry.det_point_position`(*mpar*, *dpar*)
The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

Parallel2dGeometry.det_refpoint
`Parallel2dGeometry.det_refpoint`(*angles*)
Return the position of the detector ref. point at `angles`.

The reference point is given by a rotation of the initial position by `angles`.

Parametersangles : `float`

Parameters describing the detector rotation, must be contained in *motion_params*.

Returnspoint : `numpy.ndarray`, shape (*ndim*,)

The reference point for the given parameters

Parallel2dGeometry.det_to_src

`Parallel2dGeometry.det_to_src`(*angles*, *dpar*, *normalized=True*)

Direction from a detector location to the source.

In parallel geometry, this function is independent of the detector parameter.

Since the (virtual) source is infinitely far away, only the normalized version is valid.

Parametersangles : *array-like*

Euler angles given in radians, must be contained in this geometry's *motion_params*

dpar : `float`

Detector parameters, must be contained in this geometry's *det_params*

normalized : `bool`, optional

If `True`, return the normalized version of the vector. For parallel geometry, this is the only sensible option.

Returnsvec : `numpy.ndarray`, shape (*ndim*,)

Unit vector pointing from the detector to the source

RaisesNotImplementedError

if `normalized=False` is given, since this case is not well defined.

Parallel2dGeometry.rotation_matrix

`Parallel2dGeometry.rotation_matrix`(*angle*)

Return the rotation matrix for `angle`.

For an angle `phi`, the matrix is given by:

```
rot(phi) = [[cos(phi), -sin(phi)],
            [sin(phi), cos(phi)]]
```

Parametersangle : `float`

Rotation angle given in radians, must be contained in this geometry's *motion_params*

Returnsrot : `numpy.ndarray`, shape (2, 2)

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system

`__init__`(*apart*, *dpart*, ***kwargs*)

Initialize a new instance.

Parametersapart : 1-dim. *RectPartition*

Partition of the angle interval

dpart : 1-dim. *RectPartition*

Partition of the detector parameter interval

det_init_pos : *array-like*, shape `(2,)`, optional

Initial position of the detector reference point. The zero vector is only allowed if `det_init_axis` is explicitly given. Default: `(1, 0)`.

det_init_axis : *array-like* (shape `(2,)`), optional

Initial axis defining the detector orientation. By default, a normalized *perpendicular_vector* to `det_init_pos` is used, which is only valid if `det_init_axis` is not zero.

Parallel3dAxisGeometry

class `odl.tomo.geometry.parallel.`**`Parallel3dAxisGeometry`**(*apart, dpart, axis=[0, 0, 1], **kwargs*)

Bases: *odl.tomo.geometry.parallel.ParallelGeometry*, *odl.tomo.geometry.geometry.AxisOriente*

Parallel beam geometry in 3d with single rotation axis.

The motion parameter is the rotation angle around the specified axis, and the detector is a flat 2d detector perpendicular to the ray direction.

In the standard configuration, the rotation axis is `(0, 0, 1)`, the detector reference point starts at `(1, 0, 0)`, and the initial detector axes are `[(0, 1, 0), (0, 0, 1)]`.

Attributes

axis	The normalized axis of rotation, a 3-element vector.
det_grid	Sampling grid of *det_params*.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.

Parallel3dAxisGeometry.axis

`Parallel3dAxisGeometry.`**`axis`**

The normalized axis of rotation, a 3-element vector.

Parallel3dAxisGeometry.det_grid

`Parallel3dAxisGeometry.`**`det_grid`**

Sampling grid of *det_params*.

Parallel3dAxisGeometry.det_params
Parallel3dAxisGeometry.**det_params**
Continuous detector parameter range, an *IntervalProd*.

Parallel3dAxisGeometry.det_partition
Parallel3dAxisGeometry.**det_partition**
Partition of the detector parameter set into subsets.

Parallel3dAxisGeometry.detector
Parallel3dAxisGeometry.**detector**
Detector representation of this geometry.

Parallel3dAxisGeometry.grid
Parallel3dAxisGeometry.**grid**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

Parallel3dAxisGeometry.implementation_cache
Parallel3dAxisGeometry.**implementation_cache**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : dict

Parallel3dAxisGeometry.motion_grid
Parallel3dAxisGeometry.**motion_grid**
Sampling grid of *motion_params*.

Parallel3dAxisGeometry.motion_params
Parallel3dAxisGeometry.**motion_params**
Continuous motion parameter range, an *IntervalProd*.

Parallel3dAxisGeometry.motion_partition
Parallel3dAxisGeometry.**motion_partition**
Partition of the motion parameter set into subsets.

Parallel3dAxisGeometry.ndim
Parallel3dAxisGeometry.**ndim**
The number of dimensions of the geometry.

Parallel3dAxisGeometry.params
Parallel3dAxisGeometry.**params**
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

Parallel3dAxisGeometry.partition
`Parallel3dAxisGeometry.`**`partition`**
Joined parameter set partition for motion and detector.

Returns a *RectPartition* with the detector partition inserted after the motion partition.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(angles)	Return the position of the detector ref.
det_to_src(angles, dpar[, normalized])	Direction from a detector location to the source.
rotation_matrix(angle)	The detector rotation function.

Parallel3dAxisGeometry.det_point_position
`Parallel3dAxisGeometry.`**`det_point_position`**(*mpar*, *dpar*)
The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

Parallel3dAxisGeometry.det_refpoint
`Parallel3dAxisGeometry.`**`det_refpoint`**(*angles*)
Return the position of the detector ref. point at `angles`.

The reference point is given by a rotation of the initial position by `angles`.

Parametersangles : `float`

Parameters describing the detector rotation, must be contained in *motion_params*.

Returnspoint : `numpy.ndarray`, shape (*ndim*,)

The reference point for the given parameters

Parallel3dAxisGeometry.det_to_src
`Parallel3dAxisGeometry.`**`det_to_src`**(*angles*, *dpar*, *normalized=True*)
Direction from a detector location to the source.

In parallel geometry, this function is independent of the detector parameter.

Since the (virtual) source is infinitely far away, only the normalized version is valid.

Parametersangles : *array-like*

Euler angles given in radians, must be contained in this geometry's *motion_params*

dpar : `float`

Detector parameters, must be contained in this geometry's *det_params*

normalized : `bool`, optional

If `True`, return the normalized version of the vector. For parallel geometry, this is the only sensible option.

Returnsvec : `numpy.ndarray`, shape (*ndim*,)

Unit vector pointing from the detector to the source

RaisesNotImplementedError

if `normalized=False` is given, since this case is not well defined.

Parallel3dAxisGeometry.rotation_matrix

`Parallel3dAxisGeometry.`**`rotation_matrix`**(*angle*)

The detector rotation function.

Returns the matrix for rotating a vector in 3d by an angle `angle` about the rotation axis given by the property *axis* according to the right hand rule.

The matrix is computed according to Rodrigues' rotation formula.

Parametersangle : `float`

The motion parameter given in radian. It must be contained in this geometry's *motion_params*.

Returnsrot_mat : `numpy.ndarray`, shape `(3, 3)`

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

__init__(*apart, dpart, axis=[0, 0, 1], **kwargs*)

Initialize a new instance.

Parametersapart : 1-dim. *RectPartition*

Partition of the angle interval

dpart : 2-dim. *RectPartition*

Partition of the detector parameter interval

axis : *array-like*, shape `(3,)`, optional

Fixed rotation axis defined by a 3-element vector

det_init_pos : *array-like*, shape `(3,)`, optional

Initial position of the detector reference point. The zero vector is only allowed if `det_init_axes` is explicitly given. By default, a *perpendicular_vector* to `axis` is used.

det_init_axes : 2-tuple of *array-like* (shape `(3,)`), optional

Initial axes defining the detector orientation. By default, the normalized cross product of `axis` and `det_init_pos` is used as first axis and `axis` as second.

Parallel3dGeometry

class `odl.tomo.geometry.parallel.`**`Parallel3dGeometry`**(*apart*, *dpart*, ***kwargs*)

Bases: *odl.tomo.geometry.parallel.ParallelGeometry*

Parallel beam geometry in 3d.

The motion parameters are two or three Euler angles, and the detector is flat and two-dimensional.

In the standard configuration, the detector reference point starts at `(1, 0, 0)`, and the initial detector axes are `[(0, 1, 0), (0, 0, 1)]`.

Attributes

det_grid	Sampling grid of *det_params*.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.

Parallel3dGeometry.det_grid
`Parallel3dGeometry.`**`det_grid`**
Sampling grid of *det_params*.

Parallel3dGeometry.det_params
`Parallel3dGeometry.`**`det_params`**
Continuous detector parameter range, an *IntervalProd*.

Parallel3dGeometry.det_partition
`Parallel3dGeometry.`**`det_partition`**
Partition of the detector parameter set into subsets.

Parallel3dGeometry.detector
`Parallel3dGeometry.`**`detector`**
Detector representation of this geometry.

Parallel3dGeometry.grid
`Parallel3dGeometry.`**`grid`**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

Parallel3dGeometry.implementation_cache
`Parallel3dGeometry.`**`implementation_cache`**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : `dict`

Parallel3dGeometry.motion_grid
`Parallel3dGeometry.motion_grid`
Sampling grid of *motion_params*.

Parallel3dGeometry.motion_params
`Parallel3dGeometry.motion_params`
Continuous motion parameter range, an *IntervalProd*.

Parallel3dGeometry.motion_partition
`Parallel3dGeometry.motion_partition`
Partition of the motion parameter set into subsets.

Parallel3dGeometry.ndim
`Parallel3dGeometry.ndim`
The number of dimensions of the geometry.

Parallel3dGeometry.params
`Parallel3dGeometry.params`
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

Parallel3dGeometry.partition
`Parallel3dGeometry.partition`
Joined parameter set partition for motion and detector.

Returns a *RectPartition* with the detector partition inserted after the motion partition.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(angles)	Return the position of the detector ref.
det_to_src(angles, dpar[, normalized])	Direction from a detector location to the source.
rotation_matrix(angles)	Matrix defining the detector rotation at `angles`.

Parallel3dGeometry.det_point_position
`Parallel3dGeometry.det_point_position`(*mpar*, *dpar*)
The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

Parallel3dGeometry.det_refpoint

`Parallel3dGeometry.`**`det_refpoint`**(*angles*)

Return the position of the detector ref. point at `angles`.

The reference point is given by a rotation of the initial position by `angles`.

Parametersangles : `float`

Parameters describing the detector rotation, must be contained in *motion_params*.

Returnspoint : `numpy.ndarray`, shape (*ndim*,)

The reference point for the given parameters

Parallel3dGeometry.det_to_src

`Parallel3dGeometry.`**`det_to_src`**(*angles*, *dpar*, *normalized=True*)

Direction from a detector location to the source.

In parallel geometry, this function is independent of the detector parameter.

Since the (virtual) source is infinitely far away, only the normalized version is valid.

Parametersangles : *array-like*

Euler angles given in radians, must be contained in this geometry's *motion_params*

dpar : `float`

Detector parameters, must be contained in this geometry's *det_params*

normalized : `bool`, optional

If `True`, return the normalized version of the vector. For parallel geometry, this is the only sensible option.

Returnsvec : `numpy.ndarray`, shape (*ndim*,)

Unit vector pointing from the detector to the source

RaisesNotImplementedError

if `normalized=False` is given, since this case is not well defined.

Parallel3dGeometry.rotation_matrix

`Parallel3dGeometry.`**`rotation_matrix`**(*angles*)

Matrix defining the detector rotation at `angles`.

Parametersangles : *array-like*

Angles in radians defining the rotation, must be contained in this geometry's `motion_params`

Returnsrot : `numpy.ndarray`, shape `(3, 3)`

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

`__init__`(*apart*, *dpart*, ***kwargs*)

Initialize a new instance.

Parametersapart : 2- or 3-dim. *RectPartition*

Partition of the angle parameter set

dpart : 2-dim. *RectPartition*

Partition of the detector parameter interval

det_init_pos : *array-like*, shape `(3,)`, optional

Initial position of the detector reference point. The zero vector is only allowed if `det_init_axes` is explicitly given. Default: `(1, 0, 0)`

det_init_axes : 2-tuple of *array-like* (shape `(3,)`), optional

Initial axes defining the detector orientation. By default, a normalized *perpendicular_vector* to `det_init_pos` is taken as first axis, and the normalized cross product of these two as second.

ParallelGeometry

class `odl.tomo.geometry.parallel.`**`ParallelGeometry`**(*ndim*, *apart*, *detector*, *det_init_pos*)
Bases: *odl.tomo.geometry.geometry.Geometry*

Abstract parallel beam geometry in 2 or 3 dimensions.

Parallel geometries are characterized by a virtual source at infinity, such that a unit vector from a detector point towards the source (*det_to_src*) is independent of the location on the detector.

Attributes

det_grid	Sampling grid of *det_params*.
det_params	Continuous detector parameter range, an *IntervalProd*.
det_partition	Partition of the detector parameter set into subsets.
detector	Detector representation of this geometry.
grid	Joined sampling grid for motion and detector.
implementation_cache	Dictionary acting as a cache for this geometry.
motion_grid	Sampling grid of *motion_params*.
motion_params	Continuous motion parameter range, an *IntervalProd*.
motion_partition	Partition of the motion parameter set into subsets.
ndim	The number of dimensions of the geometry.
params	Joined parameter set for motion and detector.
partition	Joined parameter set partition for motion and detector.

ParallelGeometry.det_grid
`ParallelGeometry.`**`det_grid`**
Sampling grid of *det_params*.

ParallelGeometry.det_params
`ParallelGeometry.`**`det_params`**
Continuous detector parameter range, an *IntervalProd*.

ParallelGeometry.det_partition
`ParallelGeometry.`**`det_partition`**
Partition of the detector parameter set into subsets.

ParallelGeometry.detector
`ParallelGeometry.`**`detector`**
Detector representation of this geometry.

ParallelGeometry.grid
`ParallelGeometry.`**`grid`**
Joined sampling grid for motion and detector.

By convention, the motion grid comes before the detector grid.

ParallelGeometry.implementation_cache
`ParallelGeometry.`**`implementation_cache`**
Dictionary acting as a cache for this geometry.

Intended for reuse of computations. Implementations that use this storage should take care of unique naming.

Returnsimplementations : `dict`

ParallelGeometry.motion_grid
`ParallelGeometry.`**`motion_grid`**
Sampling grid of *motion_params*.

ParallelGeometry.motion_params
`ParallelGeometry.`**`motion_params`**
Continuous motion parameter range, an *IntervalProd*.

ParallelGeometry.motion_partition
`ParallelGeometry.`**`motion_partition`**
Partition of the motion parameter set into subsets.

ParallelGeometry.ndim
`ParallelGeometry.`**`ndim`**
The number of dimensions of the geometry.

ParallelGeometry.params
`ParallelGeometry.`**`params`**
Joined parameter set for motion and detector.

By convention, the motion parameters come before the detector parameters.

ParallelGeometry.partition
`ParallelGeometry.`**`partition`**
Joined parameter set partition for motion and detector.

Returns a *RectPartition* with the detector partition inserted after the motion partition.

Methods

`__eq__`	Return self==value.
det_point_position(mpar, dpar)	The detector point position function.
det_refpoint(angles)	Return the position of the detector ref.
det_to_src(angles, dpar[, normalized])	Direction from a detector location to the source.
rotation_matrix(mpar)	The detector rotation function for calculating the detector reference position.

ParallelGeometry.det_point_position

`ParallelGeometry.`**`det_point_position`**(*mpar*, *dpar*)

The detector point position function.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter at which to evaluate

dpar : element of detector parameters *det_params*

Detector parameter at which to evaluate

Returnspos : `numpy.ndarray`, shape (*ndim*,)

The source position, a *ndim*-dimensional vector

ParallelGeometry.det_refpoint

`ParallelGeometry.`**`det_refpoint`**(*angles*)

Return the position of the detector ref. point at `angles`.

The reference point is given by a rotation of the initial position by `angles`.

Parametersangles : `float`

Parameters describing the detector rotation, must be contained in *motion_params*.

Returnspoint : `numpy.ndarray`, shape (*ndim*,)

The reference point for the given parameters

ParallelGeometry.det_to_src

`ParallelGeometry.`**`det_to_src`**(*angles*, *dpar*, *normalized=True*)

Direction from a detector location to the source.

In parallel geometry, this function is independent of the detector parameter.

Since the (virtual) source is infinitely far away, only the normalized version is valid.

Parametersangles : *array-like*

Euler angles given in radians, must be contained in this geometry's *motion_params*

dpar : `float`

Detector parameters, must be contained in this geometry's *det_params*

normalized : `bool`, optional

If `True`, return the normalized version of the vector. For parallel geometry, this is the only sensible option.

Returnsvec : `numpy.ndarray`, shape (*ndim*,)

Unit vector pointing from the detector to the source

RaisesNotImplementedError

if `normalized=False` is given, since this case is not well defined.

ParallelGeometry.rotation_matrix

`ParallelGeometry.`**`rotation_matrix`**(*mpar*)

The detector rotation function for calculating the detector reference position.

Parametersmpar : element of motion parameters *motion_params*

Motion parameter for which to calculate the detector reference rotation

Returnsrot : `numpy.ndarray`, shape (*ndim*, *ndim*)

The rotation matrix mapping the standard basis vectors in the fixed ("lab") coordinate system to the basis vectors of the local coordinate system of the detector reference point, expressed in the fixed system.

`__init__`(*ndim*, *apart*, *detector*, *det_init_pos*)

Initialize a new instance.

Parametersndim : {2, 3}

Number of dimensions of this geometry, i.e. dimensionality of the physical space in which this geometry is embedded

apart : *RectPartition*

Partition of the angle set

detector : *Detector*

The detector to use in this geometry

det_init_pos : *array-like*

Initial position of the detector reference point. The zero vector is not allowed.

8.7.3 operators

Modules

ray_trafo

Ray transforms.

Classes

RayBackProjection(discr_range, geometry[, impl])	The adjoint of the discrete Ray transform between L^p spaces.
RayTransform(discr_domain, geometry[, impl])	The discrete Ray transform between L^p spaces.

RayBackProjection

class `odl.tomo.operators.ray_trafo.`**`RayBackProjection`**(*discr_range*, *geometry*, *impl='astra_cpu'*, ***kwargs*)

Bases: *odl.operator.operator.Operator*

The adjoint of the discrete Ray transform between L^p spaces.

Attributes

adjoint	Return the adjoint operator.
domain	Set of objects on which this operator can be evaluated.
geometry	Geometry of this operator.
impl	Implementation back-end for evaluation of this operator.
inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

RayBackProjection.adjoint
`RayBackProjection.`**`adjoint`**
Return the adjoint operator.

RayBackProjection.domain
`RayBackProjection.`**`domain`**
Set of objects on which this operator can be evaluated.

RayBackProjection.geometry
`RayBackProjection.`**`geometry`**
Geometry of this operator.

RayBackProjection.impl
`RayBackProjection.`**`impl`**
Implementation back-end for evaluation of this operator.

RayBackProjection.inverse
`RayBackProjection.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

RayBackProjection.is_functional
`RayBackProjection.`**`is_functional`**
`True` if the this operator's range is a *Field*.

RayBackProjection.is_linear
`RayBackProjection.`**`is_linear`**
`True` if this operator is linear.

RayBackProjection.range
`RayBackProjection.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x[, out])	Apply the operator to `x` and store the result in `out`.
derivative(point)	Return the operator derivative at `point`.

RayBackProjection.__call__

`RayBackProjection.__call__`(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

RayBackProjection._call
RayBackProjection.**_call**(*x*, *out=None*)
Apply the operator to x and store the result in out.

Parametersx : *DiscreteLpVector*

Element in the domain of the operator which is back-projected

out : *DiscreteLpVector*, optional

Element in the reconstruction space to which the result is written. If None an element in the range of the operator is created.

Returnsout : *DiscreteLpVector*

Returns an element in the projection space

RayBackProjection.derivative
RayBackProjection.**derivative**(*point*)
Return the operator derivative at point.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__(*discr_range*, *geometry*, *impl='astra_cpu'*, ***kwargs*)
Initialize a new instance.

Parametersdiscr_range : *DiscreteLp*

Reconstruction space, the range of the back-projector

geometry : *Geometry*

The geometry of the transform, contains information about the operator domain

impl : {'astra_cpu', 'astra_cuda'}, optional

Implementation back-end for the transform. Supported back-ends: 'astra_cpu': ASTRA toolbox using CPU, only 2D 'astra_cuda': ASTRA toolbox, using CUDA, 2D or 3D

interp : {'nearest', 'linear'}

Interpolation type for the discretization of the operator range. Default: 'nearest'

RayTransform

class odl.tomo.operators.ray_trafo.**RayTransform**(*discr_domain*, *geometry*, *impl='astra_cpu'*, ***kwargs*)
Bases: *odl.operator.operator.Operator*

The discrete Ray transform between L^p spaces.

Attributes

adjoint	Return the adjoint operator.
domain	Set of objects on which this operator can be evaluated.
geometry	Geometry of this operator.
impl	Implementation back-end for evaluation of this operator.

Continued on next page

Table 8.273 – continued from previous page

inverse	Return the operator inverse.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.

RayTransform.adjoint
`RayTransform.`**`adjoint`**
Return the adjoint operator.

RayTransform.domain
`RayTransform.`**`domain`**
Set of objects on which this operator can be evaluated.

RayTransform.geometry
`RayTransform.`**`geometry`**
Geometry of this operator.

RayTransform.impl
`RayTransform.`**`impl`**
Implementation back-end for evaluation of this operator.

RayTransform.inverse
`RayTransform.`**`inverse`**
Return the operator inverse.

RaisesOpNotImplementedError

Since the inverse cannot be default implemented.

RayTransform.is_functional
`RayTransform.`**`is_functional`**
`True` if the this operator's range is a *Field*.

RayTransform.is_linear
`RayTransform.`**`is_linear`**
`True` if this operator is linear.

RayTransform.range
`RayTransform.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
`__eq__`	Return self==value.
_call(x[, out])	Apply the operator to `x` and store the result in `out`.
derivative(point)	Return the operator derivative at `point`.

RayTransform.__call__

`RayTransform.__call__(x, out=None, **kwargs)`

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_call Implementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

RayTransform._call

`RayTransform._call(x, out=None)`

Apply the operator to `x` and store the result in `out`.

Parametersx : *DiscreteLpVector*

Element in the domain of the operator to be forward projected

out : *DiscreteLpVector*, optional

Vector in the projection space to which the result is written. If `None` creates an element in the range of the operator.

Returnsout : *DiscreteLpVector*

Returns an element in the projection space

RayTransform.derivative

`RayTransform.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*discr_domain*, *geometry*, *impl='astra_cpu'*, ***kwargs*)

Initialize a new instance.

Parametersdiscr_domain : *DiscreteLp*

Discretized space, the domain of the forward projector

geometry : *Geometry*

Geometry of the transform, containing information about the operator range

impl : {'astra_cpu', 'astra_cuda'}, optional

Implementation back-end for the transform. Supported back-ends: 'astra_cpu': ASTRA toolbox using CPU, only 2D 'astra_cuda': ASTRA toolbox, using CUDA, 2D or 3D

interp : {'nearest', 'linear'}

Interpolation type for the discretization of the operator range. Default: 'nearest'

8.7.4 util

Modules

utility

Functions

angles_from_matrix(rot_matrix)	
axis_rotation(axis, angle, vectors)	Rotate a vector or an array of vectors around an axis in 3d.
axis_rotation_matrix(axis, angle)	Matrix of the rotation around an axis in 3d.
euler_matrix(*angles)	Rotation matrix in 2 and 3 dimensions.
is_rotation_matrix(mat[, show_diff])	
perpendicular_vector(vec)	Return a vector perpendicular to `vec`.
to_lab_sys(vec_in_local_coords, local_sys)	
to_local_sys(vec_in_lab_coords, local_sys)	

angles_from_matrix

odl.tomo.util.utility.**`angles_from_matrix`**(*rot_matrix*)

axis_rotation

odl.tomo.util.utility.**axis_rotation**(*axis*, *angle*, *vectors*)
Rotate a vector or an array of vectors around an axis in 3d.

The rotation is computed by *Rodriguez' rotation formula*.

Parametersaxis : array-like, shape (3,)

The rotation axis, assumed to be a unit vector

angle : `float`

The rotation angle

vectors : array-like, shape `(3,)` or `(N, 3)`

The vector(s) to be rotated

Returnsrot_vec : `numpy.ndarray`

The rotated vector(s)

https://en.wikipedia.org/wiki/Rodrigues'_rotation_formula

axis_rotation_matrix

odl.tomo.util.utility.**axis_rotation_matrix**(*axis*, *angle*)
Matrix of the rotation around an axis in 3d.

The matrix is computed according to *Rodriguez' rotation formula*.

Parametersaxis : array-like, shape `(3,)`

The rotation axis, assumed to be a unit vector

angle : `float`

The rotation angle

Returnsmat : `numpy.ndarray`, shape `(3, 3)`

The axis rotation matrix

https://en.wikipedia.org/wiki/Rodrigues'_rotation_formula

euler_matrix

odl.tomo.util.utility.**euler_matrix**(**angles*)
Rotation matrix in 2 and 3 dimensions.

Compute the Euler rotation matrix from angles given in radians. Its rows represent the canonical unit vectors as seen from the rotated system while the columns are the rotated unit vectors as seen from the canonical system.

Parametersangle1,...,angleN : `float`

One angle results in a (2x2) matrix representing a counter-clockwise rotation. Two or three angles result in a (3x3) matrix and are interpreted as Euler angles of a 3d rotation according to the 'ZXZ' rotation order, see the Wikipedia article *Euler angles*.

Returnsmat : `numpy.ndarray`, shape `(2, 2)` or `(3, 3)`

The rotation matrix

https://en.wikipedia.org/wiki/Euler_angles#Rotation_matrix

is_rotation_matrix

odl.tomo.util.utility.**is_rotation_matrix**(*mat*, *show_diff=False*)

perpendicular_vector

odl.tomo.util.utility.**perpendicular_vector**(*vec*)

Return a vector perpendicular to `vec`.

Parametersvec : *array-like*

Vector of arbitrary length

Returnsperp_vec : `numpy.ndarray`

Array of same size such that `<vec, perp_vec> == 0`

Examples

Works in 2d:

```
>>> perpendicular_vector([1, 0])
array([ 0.,  1.])
>>> perpendicular_vector([0, 1])
array([-1.,  0.])
```

And in 3d:

```
>>> perpendicular_vector([1, 0, 0])
array([ 0.,  1.,  0.])
>>> perpendicular_vector([0, 1, 0])
array([-1.,  0.,  0.])
>>> perpendicular_vector([0, 0, 1])
array([ 1.,  0.,  0.])
```

to_lab_sys

odl.tomo.util.utility.**to_lab_sys**(*vec_in_local_coords*, *local_sys*)

to_local_sys

odl.tomo.util.utility.**to_local_sys**(*vec_in_lab_coords*, *local_sys*)

8.8 trafos

Function transformations based on ODL.

Modules

8.8.1 fourier

Discretized Fourier transform on L^p spaces.

Classes

DiscreteFourierTransform(dom[, ran, axes, ...])	Plain forward DFT, only evaluating the trigonometric sum.
DiscreteFourierTransformInverse(ran[, dom, ...])	Plain backward DFT, only evaluating the trigonometric sum.
FourierTransform(dom[, ran, impl])	Discretized Fourier transform between discrete L^p spaces.
FourierTransformInverse(ran[, dom, impl])	Inverse of the discretized Fourier transform between L^p spaces.

DiscreteFourierTransform

class odl.trafos.fourier.**DiscreteFourierTransform**(*dom*, *ran=None*, *axes=None*, *sign='-'*, *halfcomplex=False*, *impl='numpy'*)

Bases: *odl.operator.operator.Operator*

Plain forward DFT, only evaluating the trigonometric sum.

This operator calculates the forward DFT:

```
f_hat[k] = sum_j( f[j] * exp(-+ 1j*2*pi * j*k/N) )
```

without any further shifting or scaling compensation. See the Numpy FFT documentation, the pyfftw API documentation or What FFTW really computes for further information.

See also:

numpy.fft.fftn n-dimensional FFT routine

numpy.fft.rfftn n-dimensional half-complex FFT

pyfftw_call apply an FFTW transform

References

Attributes

adjoint	Adjoint transform, equal to the inverse.
axes	Axes along the FT is calculated by this operator.
domain	Set of objects on which this operator can be evaluated.
halfcomplex	Return `True` if the last transform axis is halved.
impl	Backend for the FFT implementation.
inverse	Inverse Fourier transform.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.
sign	Sign of the complex exponent in the transform.

DiscreteFourierTransform.adjoint

DiscreteFourierTransform.**adjoint**
Adjoint transform, equal to the inverse.

DiscreteFourierTransform.axes

DiscreteFourierTransform.**axes**
Axes along the FT is calculated by this operator.

DiscreteFourierTransform.domain

DiscreteFourierTransform.**domain**
Set of objects on which this operator can be evaluated.

DiscreteFourierTransform.halfcomplex

DiscreteFourierTransform.**halfcomplex**
Return `True` if the last transform axis is halved.

DiscreteFourierTransform.impl

DiscreteFourierTransform.**impl**
Backend for the FFT implementation.

DiscreteFourierTransform.inverse

DiscreteFourierTransform.**inverse**
Inverse Fourier transform.

DiscreteFourierTransform.is_functional

DiscreteFourierTransform.**is_functional**
`True` if the this operator's range is a *Field*.

DiscreteFourierTransform.is_linear

DiscreteFourierTransform.**is_linear**
`True` if this operator is linear.

DiscreteFourierTransform.range

DiscreteFourierTransform.**range**
Set in which the result of an evaluation of this operator lies.

DiscreteFourierTransform.sign

DiscreteFourierTransform.**sign**
Sign of the complex exponent in the transform.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x, out, **kwargs)	Implement `self(x, out[, **kwargs])`.
clear_fftw_plan()	Delete the FFTW plan of this transform.
derivative(point)	Return the operator derivative at `point`.
init_fftw_plan([planning_effort])	Initialize the FFTW plan for this transform for later use.

DiscreteFourierTransform.__call__

DiscreteFourierTransform.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

DiscreteFourierTransform._call

DiscreteFourierTransform.**_call**(*x*, *out*, ***kwargs*)

Implement `self(x, out[, **kwargs])`.

Parametersx : domain *element*

Discretized function to be transformed

out : range *element*

Element to which the output is written

See also:

pyfftw_callCall pyfftw backend directly

Notes

See the *pyfftw_call* function for `**kwargs` options. The parameters `axes` and `halfcomplex` cannot be overridden.

DiscreteFourierTransform.clear_fftw_plan

DiscreteFourierTransform.**clear_fftw_plan**()

Delete the FFTW plan of this transform.

DiscreteFourierTransform.derivative

DiscreteFourierTransform.**derivative**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

DiscreteFourierTransform.init_fftw_plan

DiscreteFourierTransform.**init_fftw_plan**(*planning_effort='measure'*, ***kwargs*)

Initialize the FFTW plan for this transform for later use.

If the implementation of this operator is not 'pyfftw', this method has no effect.

Parametersplanning_effort : {'estimate', 'measure', 'patient', 'exhaustive'}

Flag for the amount of effort put into finding an optimal FFTW plan. See the FFTW doc on planner flags.

planning_timelimit : `float`, optional

Limit planning time to roughly this amount of seconds. Default: `None` (no limit)

threads : `int`, optional

Number of threads to use. Default: 1

__init__ (*dom*, *ran=None*, *axes=None*, *sign='-'*, *halfcomplex=False*, *impl='numpy'*)

Initialize a new instance.

Parametersdom : *DiscreteLp*

Domain of the Fourier transform. If its *DiscreteLp.exponent* is equal to 2.0, this operator has an adjoint which is equal to the inverse.

ran : *DiscreteLp*, optional

Range of the Fourier transform. If not given, the range is determined from `dom` and the other parameters as a *discr_sequence_space* with exponent `p / (p - 1)` (read as 'inf' for p=1 and 1 for p='inf').

axes : sequence of `int`, optional

Dimensions in which a transform is to be calculated. `None` means all axes.

sign : {'-', '+'}, optional

Sign of the complex exponent. Default: '-'

halfcomplex : `bool`, optional

If `True`, calculate only the negative frequency part along the last axis in `axes` for real input. This reduces the size of the range to `floor(N[i]/2) + 1` in this axis `i`, where `N` is the shape of the input arrays. Otherwise, calculate the full complex FFT. If `dom_dtype` is a complex type, this option has no effect.

impl : {'numpy', 'pyfftw'}

Backend for the FFT implementation. The 'pyfftw' backend is faster but requires the `pyfftw` package.

Examples

Complex-to-complex (default) transforms have the same grids in domain and range:

```
>>> domain = discr_sequence_space((2, 4))
>>> fft = DiscreteFourierTransform(domain)
>>> fft.domain.shape
(2, 4)
>>> fft.range.shape
(2, 4)
```

Real-to-complex transforms have a range grid with shape `n // 2 + 1` in the last tranform axis:

```
>>> domain = discr_sequence_space((2, 3, 4), dtype='float')
>>> axes = (0, 1)
>>> fft = DiscreteFourierTransform(
...     domain, halfcomplex=True, axes=axes)
>>> fft.range.shape   # shortened in the second axis
(2, 2, 4)
>>> fft.domain.shape
(2, 3, 4)
```

DiscreteFourierTransformInverse

class odl.trafos.fourier.**DiscreteFourierTransformInverse**(*ran*, *dom=None*, *axes=None*, *sign='+'*, *halfcomplex=False*, *impl='numpy'*)

Bases: *odl.trafos.fourier.DiscreteFourierTransform*

Plain backward DFT, only evaluating the trigonometric sum.

This operator calculates the inverse DFT:

```
f[k] = 1/prod(N) * sum_j( f_hat[j] * exp(+- 1j*2*pi * j*k/N) )
```

without any further shifting or scaling compensation. See the Numpy FFT documentation, the pyfftw API documentation or What FFTW really computes for further information.

See also:

numpy.fft.ifftn n-dimensional inverse FFT routine

numpy.fft.irfftn n-dimensional half-complex inverse FFT

pyfftw_call apply an FFTW transform

References

Attributes

adjoint	Adjoint transform, equal to the inverse.
axes	Axes along the FT is calculated by this operator.
domain	Set of objects on which this operator can be evaluated.
halfcomplex	Return `True` if the last transform axis is halved.
impl	Backend for the FFT implementation.
inverse	Inverse Fourier transform.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.
sign	Sign of the complex exponent in the transform.

DiscreteFourierTransformInverse.adjoint

DiscreteFourierTransformInverse.**adjoint**
Adjoint transform, equal to the inverse.

DiscreteFourierTransformInverse.axes

DiscreteFourierTransformInverse.**axes**
Axes along the FT is calculated by this operator.

DiscreteFourierTransformInverse.domain

DiscreteFourierTransformInverse.**domain**
Set of objects on which this operator can be evaluated.

DiscreteFourierTransformInverse.halfcomplex

`DiscreteFourierTransformInverse.`**`halfcomplex`**
Return `True` if the last transform axis is halved.

DiscreteFourierTransformInverse.impl

`DiscreteFourierTransformInverse.`**`impl`**
Backend for the FFT implementation.

DiscreteFourierTransformInverse.inverse

`DiscreteFourierTransformInverse.`**`inverse`**
Inverse Fourier transform.

DiscreteFourierTransformInverse.is_functional

`DiscreteFourierTransformInverse.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

DiscreteFourierTransformInverse.is_linear

`DiscreteFourierTransformInverse.`**`is_linear`**
`True` if this operator is linear.

DiscreteFourierTransformInverse.range

`DiscreteFourierTransformInverse.`**`range`**
Set in which the result of an evaluation of this operator lies.

DiscreteFourierTransformInverse.sign

`DiscreteFourierTransformInverse.`**`sign`**
Sign of the complex exponent in the transform.

Methods

`__call__`(x[, out])	Return `self(x[, out, **kwargs])`.
`__eq__`	Return self==value.
`_call`(x, out, **kwargs)	Implement `self(x, out[, **kwargs])`.
`clear_fftw_plan`()	Delete the FFTW plan of this transform.
`derivative`(point)	Return the operator derivative at `point`.
`init_fftw_plan`([planning_effort])	Initialize the FFTW plan for this transform for later use.

DiscreteFourierTransformInverse.__call__

DiscreteFourierTransformInverse.**__call__**(*x*, *out=None*, ***kwargs*)

Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

DiscreteFourierTransformInverse._call

DiscreteFourierTransformInverse.**_call**(*x*, *out*, ***kwargs*)

Implement `self(x, out[, **kwargs])`.

Parametersx : domain *element*

Discretized function to be transformed

out : range *element*

Element to which the output is written

See also:

pyfftw_callCall pyfftw backend directly

Notes

See the *pyfftw_call* function for `**kwargs` options. The parameters `axes` and `halfcomplex` cannot be overridden.

DiscreteFourierTransformInverse.clear_fftw_plan

`DiscreteFourierTransformInverse.`**`clear_fftw_plan`**`()`
Delete the FFTW plan of this transform.

DiscreteFourierTransformInverse.derivative

`DiscreteFourierTransformInverse.`**`derivative`**(*point*)
Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

DiscreteFourierTransformInverse.init_fftw_plan

`DiscreteFourierTransformInverse.`**`init_fftw_plan`**(*planning_effort='measure'*, ***kwargs*)
Initialize the FFTW plan for this transform for later use.

If the implementation of this operator is not 'pyfftw', this method has no effect.

Parametersplanning_effort : {'estimate', 'measure', 'patient', 'exhaustive'}

Flag for the amount of effort put into finding an optimal FFTW plan. See the FFTW doc on planner flags.

planning_timelimit : `float`, optional

Limit planning time to roughly this amount of seconds. Default: `None` (no limit)

threads : `int`, optional

Number of threads to use. Default: 1

`__init__`(*ran*, *dom=None*, *axes=None*, *sign='+'*, *halfcomplex=False*, *impl='numpy'*)
Initialize a new instance.

Parametersran : *DiscreteLp*

Range of the inverse Fourier transform. If its *DiscreteLp.exponent* is equal to 2.0, this operator has an adjoint which is equal to the inverse.

dom : *DiscreteLp*, optional

Domain of the inverse Fourier transform. If not given, the domain is determined from `ran` and the other parameters as a *discr_sequence_space* with exponent `p / (p - 1)` (read as 'inf' for p=1 and 1 for p='inf').

axes : sequence of `int`, optional

Dimensions in which a transform is to be calculated. `None` means all axes.

sign : {'-', '+'}, optional

Sign of the complex exponent. Default: '-'

halfcomplex : `bool`, optional

If `True`, interpret the last axis in `axes` as the negative frequency part of the transform of a real signal and calculate a "half-complex-to-real" inverse FFT. In this case, the domain has by default the shape `floor(N[i]/2) + 1` in this axis `i`. Otherwise, domain and range have the same shape. If `ran` is a complex space, this option has no effect.

impl : {'numpy', 'pyfftw'}

Backend for the FFT implementation. The 'pyfftw' backend is faster but requires the `pyfftw` package.

Examples

Complex-to-complex (default) transforms have the same grids in domain and range:

```
>>> range_ = discr_sequence_space((2, 4))
>>> ifft = DiscreteFourierTransformInverse(range_)
>>> ifft.domain.shape
(2, 4)
>>> ifft.range.shape
(2, 4)
```

Complex-to-real transforms have a domain grid with shape `n // 2 + 1` in the last tranform axis:

```
>>> range_ = discr_sequence_space((2, 3, 4), dtype='float')
>>> axes = (0, 1)
>>> ifft = DiscreteFourierTransformInverse(
...     range_, halfcomplex=True, axes=axes)
>>> ifft.domain.shape   # shortened in the second axis
(2, 2, 4)
>>> ifft.range.shape
(2, 3, 4)
```

FourierTransform

class `odl.trafos.fourier.`**FourierTransform**(*dom*, *ran=None*, *impl='numpy'*, ***kwargs*)

Bases: *odl.operator.operator.Operator*

Discretized Fourier transform between discrete L^p spaces.

This operator is the discretized variant of the continuous Fourier Transform between Lebesgue L^p spaces. It applies a three-step procedure consisting of a pre-processing step of the data, an FFT evaluation and a post-processing step. Pre- and post-processing account for the shift and scaling of the real-space and Fourier-space grids.

The sign convention ('-' vs. '+') can be changed with the `sign` parameter.

See also:

dft_preprocess_data, *pyfftw_call*, *dft_postprocess_data*

Attributes

adjoint	The adjoint Fourier transform.
axes	Axes along the FT is calculated by this operator.
domain	Set of objects on which this operator can be evaluated.
halfcomplex	Return `True` if the last transform axis is halved.
impl	Backend for the FFT implementation.
inverse	The inverse Fourier transform.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.
shifts	Return the boolean list indicating shifting per axis.
sign	Sign of the complex exponent in the transform.

FourierTransform.adjoint

`FourierTransform.`**`adjoint`**
The adjoint Fourier transform.

FourierTransform.axes

`FourierTransform.`**`axes`**
Axes along the FT is calculated by this operator.

FourierTransform.domain

`FourierTransform.`**`domain`**
Set of objects on which this operator can be evaluated.

FourierTransform.halfcomplex

`FourierTransform.`**`halfcomplex`**
Return `True` if the last transform axis is halved.

FourierTransform.impl

`FourierTransform.`**`impl`**
Backend for the FFT implementation.

FourierTransform.inverse

`FourierTransform.`**`inverse`**
The inverse Fourier transform.

FourierTransform.is_functional

FourierTransform.**is_functional**
`True` if the this operator's range is a *Field*.

FourierTransform.is_linear

FourierTransform.**is_linear**
`True` if this operator is linear.

FourierTransform.range

FourierTransform.**range**
Set in which the result of an evaluation of this operator lies.

FourierTransform.shifts

FourierTransform.**shifts**
Return the boolean list indicating shifting per axis.

FourierTransform.sign

FourierTransform.**sign**
Sign of the complex exponent in the transform.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(x, out, **kwargs)	Implement `self(x, out[, **kwargs])`.
clear_fftw_plan()	Delete the FFTW plan of this transform.
clear_temporaries()	Set the temporaries to `None`.
create_temporaries([r, f])	Allocate and store reusable temporaries.
derivative(point)	Return the operator derivative at `point`.
init_fftw_plan([planning_effort])	Initialize the FFTW plan for this transform for later use.

FourierTransform.__call__

FourierTransform.**__call__**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

FourierTransform._call

`FourierTransform.`**`_call`**(*x*, *out*, ***kwargs*)

Implement `self(x, out[, **kwargs])`.

Parametersx : domain *element*

Discretized function to be transformed

out : range *element*

Element to which the output is written

See also:

pyfftw_callCall pyfftw backend directly

Notes

See the *pyfftw_call* function for `**kwargs` options. The parameters `axes` and `halfcomplex` cannot be overridden.

FourierTransform.clear_fftw_plan

FourierTransform.**clear_fftw_plan**()
Delete the FFTW plan of this transform.

FourierTransform.clear_temporaries

FourierTransform.**clear_temporaries**()
Set the temporaries to None.

FourierTransform.create_temporaries

FourierTransform.**create_temporaries**(*r=True*, *f=True*)
Allocate and store reusable temporaries.

Existing temporaries are overwritten.

Parametersr : bool, optional

Create temporary for the real space

f : bool, optional

Create temporary for the frequency space

See also:

clear_temporaries

clear_fftw_plancan also hold references to the temporaries

Notes

To save memory, clear the temporaries when the transform is no longer used.

FourierTransform.derivative

FourierTransform.**derivative**(*point*)
Return the operator derivative at point.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

FourierTransform.init_fftw_plan

FourierTransform.**init_fftw_plan**(*planning_effort='measure'*, ***kwargs*)
Initialize the FFTW plan for this transform for later use.

If the implementation of this operator is not 'pyfftw', this method has no effect.

Parametersplanning_effort : {'estimate', 'measure', 'patient', 'exhaustive'}

Flag for the amount of effort put into finding an optimal FFTW plan. See the FFTW doc on planner flags.

planning_timelimit : `float`, optional

Limit planning time to roughly this amount of seconds. Default: `None` (no limit)

threads : `int`, optional

Number of threads to use. Default: 1

See also:

clear_fftw_plan

Notes

To save memory, clear the plan when the transform is no longer used (the plan stores 2 arrays).

__init__(*dom*, *ran=None*, *impl='numpy'*, ***kwargs*)

Initialize a new instance.

Parametersdom : *DiscreteLp*

Domain of the Fourier transform. If the *DiscreteLp.exponent* of `dom` and `ran` are equal to 2.0, this operator has an adjoint which is equal to its inverse.

ran : *DiscreteLp*, optional

Range of the Fourier transform. If not given, the range is determined from `dom` and the other parameters. The exponent is chosen to be the conjugate `p / (p - 1)`, which reads as 'inf' for p=1 and 1 for p='inf'.

impl : {'numpy', 'pyfftw'}

Backend for the FFT implementation. The 'pyfftw' backend is faster but requires the `pyfftw` package.

axes : sequence of `int`, optional

Dimensions along which to take the transform. Default: all axes

sign : {'-', '+'}, optional

Sign of the complex exponent. Default: '-'

halfcomplex : `bool`, optional

If `True`, calculate only the negative frequency part along the last axis for real input. If `False`, calculate the full complex FFT. For complex `dom`, it has no effect. Default: `True`

shift : `bool` or sequence of `bool`, optional

If `True`, the reciprocal grid is shifted by half a stride in the negative direction. With a boolean sequence, this option is applied separately to each axis. If a sequence is provided, it must have the same length as `axes` if supplied. Note that this must be set to `True` in the halved axis in half-complex transforms. Default: `True`

Other Parameterstmp_r : *DiscreteLpVector* or `numpy.ndarray`

Temporary for calculations in the real space (domain of this transform). It is shared with the inverse.

Variants using this: R2C, R2HC, C2R (inverse)

tmp_f : *DiscreteLpVector* or `numpy.ndarray`

Temporary for calculations in the frequency (reciprocal) space. It is shared with the inverse.

Variants using this: R2C, C2R (inverse), HC2R (inverse)

Notes

- The transform variants are:
  - **C2C**: complex-to-complex. The default variant, one-to-one and unitary.
  - **R2C**: real-to-complex. This variant has no adjoint, and the inverse may suffer from information loss since the result is cast to real.
  - **R2HC**: real-to-halfcomplex. This variant stores only a half-space of frequencies and is guaranteed to be one-to-one (invertible).
- The *Operator.range* of this operator always has the *ComplexNumbers* as *LinearSpace.field*, i.e. if the field of `dom` is the *RealNumbers*, this operator has no *Operator.adjoint*.

FourierTransformInverse

class `odl.trafos.fourier.`**`FourierTransformInverse`**(*ran*, *dom=None*, *impl='numpy'*, ***kwargs*)

Bases: *odl.trafos.fourier.FourierTransform*

Inverse of the discretized Fourier transform between L^p spaces.

This operator is the exact inverse of the *FourierTransform*, and **not** a discretization of the Fourier integral with "+" sign in the complex exponent. For the latter, use the `sign` parameter of the forward transform.

See also:

FourierTransform

Attributes

adjoint	The adjoint Fourier transform.
axes	Axes along the FT is calculated by this operator.
domain	Set of objects on which this operator can be evaluated.
halfcomplex	Return `True` if the last transform axis is halved.
impl	Backend for the FFT implementation.
inverse	Inverse of the inverse, the forward FT.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
range	Set in which the result of an evaluation of this operator lies.
shifts	Return the boolean list indicating shifting per axis.
sign	Sign of the complex exponent in the transform.

FourierTransformInverse.adjoint

`FourierTransformInverse.`**`adjoint`**

The adjoint Fourier transform.

FourierTransformInverse.axes

FourierTransformInverse.**axes**
Axes along the FT is calculated by this operator.

FourierTransformInverse.domain

FourierTransformInverse.**domain**
Set of objects on which this operator can be evaluated.

FourierTransformInverse.halfcomplex

FourierTransformInverse.**halfcomplex**
Return `True` if the last transform axis is halved.

FourierTransformInverse.impl

FourierTransformInverse.**impl**
Backend for the FFT implementation.

FourierTransformInverse.inverse

FourierTransformInverse.**inverse**
Inverse of the inverse, the forward FT.

FourierTransformInverse.is_functional

FourierTransformInverse.**is_functional**
`True` if the this operator's range is a *Field*.

FourierTransformInverse.is_linear

FourierTransformInverse.**is_linear**
`True` if this operator is linear.

FourierTransformInverse.range

FourierTransformInverse.**range**
Set in which the result of an evaluation of this operator lies.

FourierTransformInverse.shifts

FourierTransformInverse.**shifts**
Return the boolean list indicating shifting per axis.

FourierTransformInverse.sign

FourierTransformInverse.**sign**
Sign of the complex exponent in the transform.

Methods

__call__(x[, out])	Return self(x[, out, **kwargs]).
__eq__	Return self==value.
_call(x, out, **kwargs)	Implement self(x, out[, **kwargs]).
clear_fftw_plan()	Delete the FFTW plan of this transform.
clear_temporaries()	Set the temporaries to None.
create_temporaries([r, f])	Allocate and store reusable temporaries.
derivative(point)	Return the operator derivative at point.
init_fftw_plan([planning_effort])	Initialize the FFTW plan for this transform for later use.

FourierTransformInverse.__call__

FourierTransformInverse.**__call__**(*x*, *out=None*, ***kwargs*)
Return self(x[, out, **kwargs]).

Implementation of the call pattern op(x) with the private _call() method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the self.domain.element method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If out was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

FourierTransformInverse._call

FourierTransformInverse.**_call**(*x*, *out*, ***kwargs*)

Implement `self(x, out[, **kwargs])`.

Parametersx : domain *element*

Discretized function to be transformed

out : range *element*

Element to which the output is written

See also:

pyfftw_callCall pyfftw backend directly

Notes

See the *pyfftw_call* function for `**kwargs` options. The parameters `axes` and `halfcomplex` cannot be overridden.

FourierTransformInverse.clear_fftw_plan

FourierTransformInverse.**clear_fftw_plan**()

Delete the FFTW plan of this transform.

FourierTransformInverse.clear_temporaries

FourierTransformInverse.**clear_temporaries**()

Set the temporaries to `None`.

FourierTransformInverse.create_temporaries

FourierTransformInverse.**create_temporaries**(*r=True*, *f=True*)

Allocate and store reusable temporaries.

Existing temporaries are overwritten.

Parametersr : `bool`, optional

Create temporary for the real space

f : `bool`, optional

Create temporary for the frequency space

See also:

clear_temporaries

clear_fftw_plan can also hold references to the temporaries

Notes

To save memory, clear the temporaries when the transform is no longer used.

FourierTransformInverse.derivative

`FourierTransformInverse.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

FourierTransformInverse.init_fftw_plan

`FourierTransformInverse.`**`init_fftw_plan`**(*planning_effort='measure'*, ***kwargs*)

Initialize the FFTW plan for this transform for later use.

If the implementation of this operator is not 'pyfftw', this method has no effect.

Parametersplanning_effort : {'estimate', 'measure', 'patient', 'exhaustive'}

Flag for the amount of effort put into finding an optimal FFTW plan. See the FFTW doc on planner flags.

planning_timelimit : `float`, optional

Limit planning time to roughly this amount of seconds. Default: `None` (no limit)

threads : `int`, optional

Number of threads to use. Default: 1

See also:

clear_fftw_plan

Notes

To save memory, clear the plan when the transform is no longer used (the plan stores 2 arrays).

`__init__`(*ran*, *dom=None*, *impl='numpy'*, ***kwargs*)

Parametersran : *DiscreteLp*

Range of the inverse Fourier transform. If the *DiscreteLp.exponent* of `dom` and `ran` are equal to 2.0, this operator has an adjoint which is equal to its inverse.

dom : *DiscreteLp*, optional

Domain of the inverse Fourier transform. If not given, the domain is determined from `ran` and the other parameters. The exponent is chosen to be the conjugate `p / (p - 1)`, which reads as 'inf' for p=1 and 1 for p='inf'.

impl : {'numpy', 'pyfftw'}

Backend for the FFT implementation. The 'pyfftw' backend is faster but requires the `pyfftw` package.

axes : sequence of `int`, optional

Dimensions along which to take the transform. Default: all axes

sign : {'-', '+'}, optional

Sign of the complex exponent. Default: '+'

halfcomplex : `bool`, optional

If `True`, calculate only the negative frequency part along the last axis for real input. If `False`, calculate the full complex FFT. For complex `dom`, it has no effect. Default: `True`

shift : `bool` or sequence of `bool`, optional

If `True`, the reciprocal grid is shifted by half a stride in the negative direction. With a boolean sequence, this option is applied separately to each axis. If a sequence is provided, it must have the same length as `axes` if supplied. Note that this must be set to `True` in the halved axis in half-complex transforms. Default: `True`

Other Parameterstmp_r : *DiscreteLpVector* or `numpy.ndarray`

Temporary for calculations in the real space (range of this transform). It is shared with the inverse.

Variants using this: C2R, R2C (forward), R2HC (forward)

tmp_f : *DiscreteLpVector* or `numpy.ndarray`

Temporary for calculations in the frequency (reciprocal) space. It is shared with the inverse.

Variants using this: C2R, HC2R, R2C (forward)

Notes

- The transform variants are:
  - **C2C**: complex-to-complex. The default variant, one-to-one and unitary.
  - **C2R**: complex-to-real. This variant has no adjoint and may suffer from information loss since the result is cast to real.
  - **HC2R**: halfcomplex-to-real. This variant interprets input as a signal on a half-space of frequencies. It is guaranteed to be one-to-one (invertible).
- The *Operator.domain* of this operator always has the *ComplexNumbers* as *LinearSpace.field*, i.e. if the field of `ran` is the *RealNumbers*, this operator has no *Operator.adjoint*.

Functions

dft_postprocess_data(arr, real_grid, ...[, ...])	Post-process the Fourier-space data after DFT.
dft_preprocess_data(arr[, shift, axes, ...])	Pre-process the real-space data before DFT.
inverse_reciprocal(grid, x0[, axes, ...])	Return the inverse reciprocal of the given regular grid.
pyfftw_call(array_in, array_out[, ...])	Calculate the DFT with pyfftw.
reciprocal(grid[, shift, axes, halfcomplex])	Return the reciprocal of the given regular grid.
reciprocal_space(space[, axes, halfcomplex, ...])	Return the range of the Fourier transform on `space`.

dft_postprocess_data

odl.trafos.fourier.**dft_postprocess_data**(*arr*, *real_grid*, *recip_grid*, *shifts*, *axes*, *interp*, *sign='-'*, *op='multiply'*, *out=None*)

Post-process the Fourier-space data after DFT.

This function multiplies the given data with the separable function:

```
q(xi) = exp(+- 1j * dot(x[0], xi)) * s * phi_hat(xi_bar)
```

where `x[0]` and `s` are the minimum point and the stride of the real-space grid, respectively, and `phi_hat(xi_bar)` is the FT of the interpolation kernel. The sign of the exponent depends on the choice of `sign`. Note that for `op='divide'` the multiplication with `s * phi_hat(xi_bar)` is replaced by a division with the same array.

In discretized form on the reciprocal grid, the exponential part of this function becomes an array:

```
q[k] = exp(+- 1j * dot(x[0], xi[k]))
```

and the arguments `xi_bar` to the interpolation kernel are the normalized frequencies:

```
for 'shift=True'  : xi_bar[k] = -pi + pi * (2*k) / N
for 'shift=False' : xi_bar[k] = -pi + pi * (2*k+1) / N
```

See *[Pre+2007]*, Section 13.9 "Computing Fourier Integrals Using the FFT" for a similar approach.

Parametersarr : *array-like*

Array to be pre-processed. An array with real data type is converted to its complex counterpart.

real_grid : *RegularGrid*

Real space grid in the transform

recip_grid : *RegularGrid*

Reciprocal grid in the transform

shifts : sequence of `bool`

If `True`, the grid is shifted by half a stride in the negative direction in the corresponding axes. The sequence must have the same length as `axes`.

axes : sequence of `int`

Dimensions along which to take the transform. The sequence must have the same length as `shifts`.

interp : `str` or `sequence` of `str`

Interpolation scheme used in the real-space

sign : {'-', '+'}, optional

Sign of the complex exponent

op : {'multiply', 'divide'}

Operation to perform with the stride times the interpolation kernel FT

out : `numpy.ndarray`, optional

Array in which the result is stored. If `out is arr`, an in-place modification is performed.

Returnsout : `numpy.ndarray`

Result of the post-processing. If `out` was given, the returned object is a reference to it.

dft_preprocess_data

`odl.trafos.fourier.`**`dft_preprocess_data`**(*arr*, *shift=True*, *axes=None*, *sign='-'*, *out=None*)

Pre-process the real-space data before DFT.

This function multiplies the given data with the separable function:

```
p(x) = exp(+- 1j * dot(x - x[0], xi[0]))
```

where `x[0]` and `xi[0]` are the minimum coodinates of the real-space and reciprocal grids, respectively. The sign of the exponent depends on the choice of `sign`. In discretized form, this function becomes an array:

```
p[k] = exp(+- 1j * k * s * xi[0])
```

If the reciprocal grid is not shifted, i.e. symmetric around 0, it is `xi[0] = pi/s * (-1 + 1/N)`, hence:

```
p[k] = exp(-+ 1j * pi * k * (1 - 1/N))
```

For a shifted grid, we have :math:`xi[0] = -pi/s`, thus the array is given by:

```
p[k] = (-1)**k
```

Parametersarr : *array-like*

Array to be pre-processed. If its data type is a real non-floating type, it is converted to 'float64'.

shift : `bool` or sequence of `bool`, optional

If `True`, the grid is shifted by half a stride in the negative direction. With a sequence, this option is applied separately on each axis.

axes : sequence of `int`, optional

Dimensions in which to calculate the reciprocal. The sequence must have the same length as `shift` if the latter is given as a sequence. `None` means all axes in `dfunc`.

sign : {'-', '+'}, optional

Sign of the complex exponent

out : `numpy.ndarray`, optional

Array in which the result is stored. If `out is arr`, an in-place modification is performed. For real data type, this is only possible for `shift=True` since the factors are complex otherwise.

Returnsout : `numpy.ndarray`

Result of the pre-processing. If `out` was given, the returned object is a reference to it.

Notes

If `out` is not specified, the data type of the returned array is the same as that of `arr` except when `arr` has real data type and `shift` is not `True`. In this case, the return type is the complex counterpart of `arr.dtype`.

inverse_reciprocal

odl.trafos.fourier.**inverse_reciprocal**(*grid*, *x0*, *axes=None*, *halfcomplex=False*, *halfcx_parity='even'*)

Return the inverse reciprocal of the given regular grid.

Given a reciprocal grid:

```
xi[j] = xi[0] + j * sigma,
```

with a multi-index `j = (j[0], ..., j[d-1])` in the range `0 <= j < M`, this function calculates the original grid:

```
x[k] = x[0] + k * s
```

by using a provided `x[0]` and calculating the stride `s`.

If the reciprocal grid is interpreted as coming from a usual complex-to-complex FFT, it is `N == M`, and the stride is:

```
s = 2*pi / (sigma * N)
```

For a reciprocal grid from a real-to-complex (half-complex) FFT, it is `M[i] = floor(N[i]/2) + 1` in the last transform axis `i`. To resolve the ambiguity regarding the parity of `N[i]`, the it must be specified if the output shape should be even or odd, resulting in:

```
odd : N[i] = 2 * M[i] - 1
even: N[i] = 2 * M[i] - 2
```

The output stride is calculated with this `N` as above in this case.

Parametersgrid : *RegularGrid*

Original sampling grid

x0 : array-like

Minimal point of the inverse reciprocal grid

axes : sequence of `int`, optional

Dimensions in which to calculate the reciprocal. The sequence must have the same length as `shift` if the latter is given as a sequence. `None` means all axes in `grid`.

halfcomplex : `bool`, optional

If `True`, interpret the given grid as the reciprocal as used in a half-complex FFT (see above). Otherwise, the grid is regarded as being used in a complex-to-complex transform.

halfcx_parity : {'even', 'odd'}

Use this parity for the shape of the returned grid in the last axis of `axes` in the case `halfcomplex=True`

Returnsirecip : *RegularGrid*

The inverse reciprocal grid

pyfftw_call

odl.trafos.fourier.**pyfftw_call**(*array_in*, *array_out*, *direction='forward'*, *axes=None*, *halfcomplex=False*, ***kwargs*)

Calculate the DFT with pyfftw.

The discrete Fourier (forward) transform calcuates the sum:

```
f_hat[k] = sum_j( f[j] * exp(-2*pi*1j * j*k/N) )
```

where the summation is taken over all indices `j = (j[0], ..., j[d-1])` in the range `0 <= j < N` (component-wise), with `N` being the shape of the input array.

The output indices `k` lie in the same range, except for half-complex transforms, where the last axis `i` in `axes` is shortened to `0 <= k[i] < floor(N[i]/2) + 1`.

In the backward transform, sign of the the exponential argument is flipped.

Parametersarray_in : `numpy.ndarray`

Array to be transformed

array_out : `numpy.ndarray`

Output array storing the transformed values, may be aligned with `array_in`.

direction : {'forward', 'backward'}

Direction of the transform

axes : sequence of `int`, optional

Dimensions along which to take the transform. `None` means using all axis and is equivalent to `np.arange(ndim)`.

halfcomplex : `bool`, optional

If `True`, calculate only the negative frequency part along the last axis. If `False`, calculate the full complex FFT. This option can only be used with real input data.

Returnsfftw_plan : `pyfftw.FFTW`

The plan object created from the input arguments. It can be reused for transforms of the same size with the same data types. Note that reuse only gives a speedup if the initial plan used a planner flag other than `'estimate'`. If `fftw_plan` was specified, the returned object is a reference to it.

Other Parametersfftw_plan : `pyfftw.FFTW`, optional

Use this plan instead of calculating a new one. If specified, the options `planning_effort`, `planning_timelimit` and `threads` have no effect.

planning_effort : {'estimate', 'measure', 'patient', 'exhaustive'}

Flag for the amount of effort put into finding an optimal FFTW plan. See the FFTW doc on planner flags. Default: 'estimate'.

planning_timelimit : `float`, optional

Limit planning time to roughly this amount of seconds. Default: `None` (no limit)

threads : `int`, optional

Number of threads to use. Default: Number of CPUs if the number of data points is larger than 1000, else 1.

normalise_idft : `bool`, optional

If `True`, the backward transform is normalized by `1 / N`, where `N` is the total number of points in `array_in[axes]`. This ensures that the IDFT is the true inverse of the forward DFT. Default: `False`

import_wisdom : filename or file handle, optional

File to load FFTW wisdom from. If the file does not exist, it is ignored.

export_wisdom : filename or file handle, optional

File to append the accumulated FFTW wisdom to

Notes

- The planning and direction flags can also be specified as capitalized and prepended by `'FFTW_'`, i.e. in the original FFTW form.
- For a `halfcomplex` forward transform, the arrays must fulfill `array_out.shape[axes[-1]] == array_in.shape[axes[-1]] // 2 + 1`, and vice versa for backward transforms.
- All planning schemes except `'estimate'` require an internal copy of the input array but are often several times faster after the first call (measuring results are cached). Typically, 'measure' is a good compromise. If you cannot afford the copy, use `'estimate'`.
- If a plan is provided via the `fftw_plan` parameter, no copy is needed internally.

reciprocal

odl.trafos.fourier.**reciprocal**(*grid*, *shift=True*, *axes=None*, *halfcomplex=False*)

Return the reciprocal of the given regular grid.

This function calculates the reciprocal (Fourier/frequency space) grid for a given regular grid defined by the nodes:

```
x[k] = x[0] + k * s,
```

where `k = (k[0], ..., k[d-1])` is a `d`-dimensional index in the range `0 <= k < N` (componentwise). The multi-index `N` is the shape of the input grid. This grid's reciprocal is then given by the nodes:

```
xi[j] = xi[0] + j * sigma,
```

with the reciprocal grid stride `sigma = 2*pi / (s * N)`. The minimum frequency `xi[0]` can in principle be chosen freely, but usually it is chosen in a such a way that the reciprocal grid is centered around zero. For this, there are two possibilities:

1. Make the grid point-symmetric around 0.
2. Make the grid "almost" point-symmetric around zero by shifting it to the left by half a reciprocal stride.

In the first case, the minimum frequency (per axis) is given as:

```
xi_1[0] = -pi/s + pi/(s*n) = -pi/s + sigma/2.
```

For the second case, it is:

```
    xi_1[0] = -pi / s.
```

Note that the zero frequency is contained in case 1 for an odd number of points, while for an even size, the second option guarantees that 0 is contained.

If a real-to-complex (half-complex) transform is to be computed, the reciprocal grid has the shape `M[i] = floor(N[i]/2) + 1` in the last transform axis `i`.

Parametersgrid : *RegularGrid*

Original sampling grid

shift : `bool` or sequence of `bool`, optional

If `True`, the grid is shifted by half a stride in the negative direction. With a sequence, this option is applied separately on each axis.

axes : sequence of `int`, optional

Dimensions in which to calculate the reciprocal. The sequence must have the same length as `shift` if the latter is given as a sequence. `None` means all axes in `grid`.

halfcomplex : `bool`, optional

If `True`, return the half of the grid with last coordinate less than zero. This is related to the fact that for real-valued functions, the other half is the mirrored complex conjugate of the given half and therefore needs not be stored.

Returnsrecip : *RegularGrid*

The reciprocal grid

reciprocal_space

odl.trafos.fourier.**reciprocal_space**(*space*, *axes=None*, *halfcomplex=False*, *shift=True*, ***kwargs*)

Return the range of the Fourier transform on `space`.

Parametersspace : *DiscreteLp*

Real space whose reciprocal is calculated. It must be uniformly discretized.

axes : sequence of `int`, optional

Dimensions along which the Fourier transform is taken. Default: all axes

halfcomplex : `bool`, optional

If `True`, take only the negative frequency part along the last axis for. If `False`, use the full frequency space. This option can only be used if `space` is a space of real-valued functions. Default: `False`

shift : `bool` or sequence of `bool`, optional

If `True`, the reciprocal grid is shifted by half a stride in the negative direction. With a boolean sequence, this option is applied separately to each axis. If a sequence is provided, it must have the same length as `axes` if supplied. Note that this must be set to `True` in the halved axis in half-complex transforms. Default: `True`

exponent : `float`, optional

Create a space with this exponent. By default, the conjugate exponent `q = p / (p - 1)` of the exponent of `space` is used, where `q = inf` for `p = 1` and vice versa.

dtype : optional

Complex data type of the reciprocal space. By default, the complex counterpart of `space.dtype` is used.

Returnsrspace : *DiscreteLp*

Reciprocal of the input `space`. If `halfcomplex=True`, the upper end of the domain (where the half space ends) is chosen to coincide with the grid node.

8.8.2 wavelet

Discrete wavelet transformation on L2 spaces.

Classes

WaveletTransform(dom, nscales, wbasis, mode)	Discrete wavelet trafo between discrete L2 spaces.
WaveletTransformInverse(ran, nscales, ...)	Discrete inverse wavelet trafo between discrete L2 spaces.

WaveletTransform

class odl.trafos.wavelet.**WaveletTransform**(*dom*, *nscales*, *wbasis*, *mode*)

Bases: *odl.operator.operator.Operator*

Discrete wavelet trafo between discrete L2 spaces.

Attributes

adjoint	The adjoint wavelet transform.
domain	Set of objects on which this operator can be evaluated.
inverse	The inverse wavelet transform.
is_biorthogonal	Whether or not the wavelet basis is bi-orthogonal.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
is_orthogonal	Whether or not the wavelet basis is orthogonal.
range	Set in which the result of an evaluation of this operator lies.

WaveletTransform.adjoint

WaveletTransform.**adjoint**

The adjoint wavelet transform.

WaveletTransform.domain

WaveletTransform.**domain**

Set of objects on which this operator can be evaluated.

WaveletTransform.inverse

`WaveletTransform.`**`inverse`**
The inverse wavelet transform.

WaveletTransform.is_biorthogonal

`WaveletTransform.`**`is_biorthogonal`**
Whether or not the wavelet basis is bi-orthogonal.

WaveletTransform.is_functional

`WaveletTransform.`**`is_functional`**
`True` if the this operator's range is a *`Field`*.

WaveletTransform.is_linear

`WaveletTransform.`**`is_linear`**
`True` if this operator is linear.

WaveletTransform.is_orthogonal

`WaveletTransform.`**`is_orthogonal`**
Whether or not the wavelet basis is orthogonal.

WaveletTransform.range

`WaveletTransform.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

`__call__`(x[, out])	Return `self(x[, out, **kwargs])`.
`__eq__`	Return self==value.
`_call`(x)	Compute the discrete wavelet transform.
`derivative`(point)	Return the operator derivative at `point`.

WaveletTransform.__call__

`WaveletTransform.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *`Operator.domain element-like`*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is

treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_call Implementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

WaveletTransform._call

`WaveletTransform.`**`_call`**`(`*x*`)`

Compute the discrete wavelet transform.

Parametersx : *DiscreteLpVector*

Returnsarr : `numpy.ndarray`

Flattened and concatenated coefficient array The length of the array depends on the size of input image to be transformed and on the chosen wavelet basis.

WaveletTransform.derivative

`WaveletTransform.`**`derivative`**`(`*point*`)`

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

__init__ (*dom*, *nscales*, *wbasis*, *mode*)
Initialize a new instance.

Parametersdom : *DiscreteLp*

Domain of the wavelet transform (the "image domain"). The exponent p of the discrete L^p space must be equal to 2.0.

nscales : `int`

Number of scales in the coefficient list. The maximum number of usable scales can be determined by `pywt.dwt_max_level`. For more information see the corresponding documentation of PyWavelets .

wbasis : {`str`, `pywt.Wavelet`}

If a string is given, converts to a `pywt.Wavelet`. Describes properties of a selected wavelet basis. See PyWavelet documentation

Possible wavelet families are:

Haar (`haar`)

Daubechies (`db`)

Symlets (`sym`)

Coiflets (`coif`)

Biorthogonal (`bior`)

Reverse biorthogonal (`rbio`)

Discrete FIR approximation of Meyer wavelet (`dmey`)

mode : `str`

Signal extention modes as defined by `pywt.MODES.modes` http://www.pybytes.com/pywavelets/ref/signal-extension-modes.html

Possible extension modes are:

'zpd': zero-padding – signal is extended by adding zero samples

'cpd': constant padding – border values are replicated

'sym': symmetric padding – signal extension by mirroring samples

'ppd': periodic padding – signal is trated as a periodic one

'sp1': smooth padding – signal is extended according to the first derivatives calculated on the edges (straight line)

'per': periodization – like periodic-padding but gives the smallest possible number of decomposition coefficients.

Examples

```
>>> import odl, pywt
>>> wbasis = pywt.Wavelet('db1')
>>> discr_domain = odl.uniform_discr([0, 0], [1, 1], (16, 16))
>>> op = WaveletTransform(discr_domain, nscales=1,
...                                wbasis=wbasis, mode='per')
```

```
        >>> op.is_biorthogonal
        True
```

WaveletTransformInverse

class odl.trafos.wavelet.**WaveletTransformInverse**(*ran*, *nscales*, *wbasis*, *mode*)
Bases: *odl.operator.operator.Operator*

Discrete inverse wavelet trafo between discrete L2 spaces.

Attributes

adjoint	The adjoint wavelet transform.
domain	Set of objects on which this operator can be evaluated.
inverse	The inverse wavelet transform.
is_biorthogonal	Whether or not the wavelet basis is bi-orthogonal.
is_functional	`True` if the this operator's range is a *Field*.
is_linear	`True` if this operator is linear.
is_orthogonal	Whether or not the wavelet basis is orthogonal.
range	Set in which the result of an evaluation of this operator lies.

WaveletTransformInverse.adjoint

WaveletTransformInverse.**adjoint**
The adjoint wavelet transform.

WaveletTransformInverse.domain

WaveletTransformInverse.**domain**
Set of objects on which this operator can be evaluated.

WaveletTransformInverse.inverse

WaveletTransformInverse.**inverse**
The inverse wavelet transform.

WaveletTransformInverse.is_biorthogonal

WaveletTransformInverse.**is_biorthogonal**
Whether or not the wavelet basis is bi-orthogonal.

WaveletTransformInverse.is_functional

WaveletTransformInverse.**is_functional**
`True` if the this operator's range is a *Field*.

WaveletTransformInverse.is_linear

`WaveletTransformInverse.`**`is_linear`**
`True` if this operator is linear.

WaveletTransformInverse.is_orthogonal

`WaveletTransformInverse.`**`is_orthogonal`**
Whether or not the wavelet basis is orthogonal.

WaveletTransformInverse.range

`WaveletTransformInverse.`**`range`**
Set in which the result of an evaluation of this operator lies.

Methods

__call__(x[, out])	Return `self(x[, out, **kwargs])`.
__eq__	Return self==value.
_call(coeff)	Compute the discrete 1D, 2D or 3D inverse wavelet transform.
derivative(point)	Return the operator derivative at `point`.

WaveletTransformInverse.__call__

`WaveletTransformInverse.`**`__call__`**(*x*, *out=None*, ***kwargs*)
Return `self(x[, out, **kwargs])`.

Implementation of the call pattern `op(x)` with the private `_call()` method and added error checking.

Parametersx : *Operator.domain element-like*

An object which can be converted into an element of this operator's domain with the `self.domain.element` method. The operator is applied to this object, which is treated as immutable, hence it is not modified during evaluation.

out : *Operator.range element*, optional

An object in the operator range to which the result of the operator evaluation is written. The result is independent of the initial state of this object.

kwargs : Further arguments to the function, optional

Passed on to the underlying implementation in *_call*

Returnsout : *Operator.range element*

Result of the operator evaluation. If `out` was provided, the returned object is a reference to it.

See also:

_callImplementation of the method

Examples

```
>>> from odl import Rn, ScalingOperator
>>> rn = Rn(3)
>>> op = ScalingOperator(rn, 2.0)
>>> x = rn.element([1, 2, 3])
```

Out-of-place evaluation:

```
>>> op(x)
Rn(3).element([2.0, 4.0, 6.0])
```

In-place evaluation:

```
>>> y = rn.element()
>>> op(x, out=y)
Rn(3).element([2.0, 4.0, 6.0])
>>> y
Rn(3).element([2.0, 4.0, 6.0])
```

WaveletTransformInverse._call

`WaveletTransformInverse.`**`_call`**(*coeff*)

Compute the discrete 1D, 2D or 3D inverse wavelet transform.

Parameterscoeff : *DiscreteLpVector*

Returnsarr : *DiscreteLpVector*

WaveletTransformInverse.derivative

`WaveletTransformInverse.`**`derivative`**(*point*)

Return the operator derivative at `point`.

RaisesOpNotImplementedError

If the operator is not linear, the derivative cannot be default implemented.

`__init__`(*ran*, *nscales*, *wbasis*, *mode*)

Initialize a new instance.

Parametersdom : *DiscreteLp*

Domain of the wavelet transform (the "image domain"). The exponent p of the discrete L^p space must be equal to 2.0.

nscales : `int`

Number of scales in the coefficient list. The maximum number of usable scales can be determined by `pywt.dwt_max_level`. For more information see the corresponding documentation of PyWavelets .

wbasis : `pywt.Wavelet`

Describes properties of a selected wavelet basis. See PyWavelet documentation

Possible wavelet families are:

Haar (`haar`)

Daubechies (`db`)

Symlets (`sym`)

Coiflets (`coif`)

Biorthogonal (`bior`)

Reverse biorthogonal (`rbio`)

Discrete FIR approximation of Meyer wavelet (`dmey`)

mode : `str`

Signal extention modes as defined by `pywt.MODES.modes` http://www.pybytes.com/pywavelets/ref/signal-extension-modes.html

Possible extension modes are:

'zpd': zero-padding – signal is extended by adding zero samples

'cpd': constant padding – border values are replicated

'sym': symmetric padding – signal extension by mirroring samples

'ppd': periodic padding – signal is trated as a periodic one

'sp1': smooth padding – signal is extended according to the first derivatives calculated on the edges (straight line)

'per': periodization – like periodic-padding but gives the smallest possible number of decomposition coefficients.

Functions

array_to_pywt_coeff(coeff, size_list)	Convert a flat array into a pywt coefficient list.
coeff_size_list(shape, nscales, wbasis, mode)	Construct a size list from given wavelet coefficients.
pywt_coeff_to_array(coeff, size_list)	Convert a Pywavelets coefficient list into a flat array.
wavelet_decomposition3d(x, wbasis, mode, nscales)	Discrete 3D multiresolution wavelet decomposition.
wavelet_reconstruction3d(coeff_list, wbasis, ...)	Discrete 3D multiresolution wavelet reconstruction

array_to_pywt_coeff

odl.trafos.wavelet.**array_to_pywt_coeff**(*coeff*, *size_list*)

Convert a flat array into a pywt coefficient list.

For multilevel 1D, 2D and 3D discrete wavelet transforms.

Parameterscoeff : *DiscreteLpVector*

A flat coefficient vector containing the approximation, and detail coefficients in the following order [aaaN, aadN, adaN, addN, daaN, dadN, ddaN, dddN, ... aad1, ada1, add1, daa1, dad1, dda1, ddd1]

size_list : list

A list of coefficient sizes such that,

`size_list[0]` = size of approximation coefficients at the coarsestlevel,

`size_list[1]` = size of the detailedetails at the coarsest level,

`size_list[N]` = size of the detailed coefficients at the finestlevel,

`size_list[N+1]` = size of original image,

`N` = the number of scaling levels

Returnscoeff : ordered `list`

Coefficient are organized in the list in the following way:

In 1D:

```
[aN, (dN), ...  (d1)]
```

The abbreviations refer to

`a` = approximation,

`d` = detail,

In 2D:

```
[aaN, (adN, daN, ddN), ...  (ad1, da1, dd1)]
```

The abbreviations refer to

`aa` = approx. on 1st dim, approx. on 2nd dim (approximation),

`ad` = approx. on 1st dim, detail on 2nd dim (horizontal),

`da` = detail on 1st dim, approx. on 2nd dim (vertical),

`dd` = detail on 1st dim, detail on 2nd dim (diagonal),

In 3D:

```
[aaaN, (aadN, adaN, addN, daaN, dadN, ddaN, dddN), ...
(aad1, ada1, add1, daa1, dad1, dda1, ddd1)]
```

The abbreviations refer to

`aaa` = approx. on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`aad` = approx. on 1st dim, approx. on 2nd dim, detail on 3rd dim,

`ada` = approx. on 1st dim, detail on 3nd dim, approx. on 3rd dim,

`add` = approx. on 1st dim, detail on 3nd dim, detail on 3rd dim,

`daa` = detail on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`dad` = detail on 1st dim, approx. on 2nd dim, detail on 3rd dim,

`dda` = detail on 1st dim, detail on 2nd dim, approx. on 3rd dim,

`ddd` = detail on 1st dim, detail on 2nd dim, detail on 3rd dim,

`N` refers to the number of scaling levels

coeff_size_list

`odl.trafos.wavelet.`**`coeff_size_list`**(*shape*, *nscales*, *wbasis*, *mode*)

Construct a size list from given wavelet coefficients.

Related to 1D, 2D and 3D multidimensional wavelet transforms that utilize PyWavelets.

Parametersshape : `tuple`

Number of pixels/voxels in the image. Its length must be 1, 2 or 3.

nscales : `int`

Number of scales in the multidimensional wavelet transform. This parameter is checked against the maximum number of scales returned by `pywt.dwt_max_level`. For more information see the PyWavelets documentation on the maximum level of scales.

wbasis : `pywt.Wavelet`

Selected wavelet basis. For more information see the PyWavelets documentation on wavelet bases.

mode : `str`

Signal extention mode. Possible extension modes are

'zpd': zero-padding – signal is extended by adding zero samples

'cpd': constant padding – border values are replicated

'sym': symmetric padding – signal extension by mirroring samples

'ppd': periodic padding – signal is trated as a periodic one

'sp1': smooth padding – signal is extended according to the first derivatives calculated on the edges (straight line)

'per': periodization – like periodic-padding but gives the smallest possible number of decomposition coefficients.

Returnssize_list : `list`

A list containing the sizes of the wavelet (approximation and detail) coefficients at different scaling levels:

`size_list[0]` = size of approximation coefficients at the coarsest level

`size_list[1]` = size of the detail coefficients at the coarsest level

...

`size_list[N]` = size of the detail coefficients at the finest level

`size_list[N+1]` = size of the original image

`N` = number of scaling levels = nscales

pywt_coeff_to_array

`odl.trafos.wavelet.`**`pywt_coeff_to_array`**(*coeff*, *size_list*)

Convert a Pywavelets coefficient list into a flat array.

Related to 1D, 2D and 3D multilevel discrete wavelet transforms.

Parameterscoeff : ordered `list`

Coefficient are organized in the list in the following way:

In 1D:

`[aN, (dN), ..., (d1)]`

The abbreviations refer to

`a` = approximation,

`d` = detail

In 2D:

`[aaN, (adN, daN, ddN), ..., (ad1, da1, dd1)]`

The abbreviations refer to

`aa` = approx. on 1st dim, approx. on 2nd dim (approximation),

`ad` = approx. on 1st dim, detail on 2nd dim (horizontal),

`da` = detail on 1st dim, approx. on 2nd dim (vertical),

`dd` = detail on 1st dim, detail on 2nd dim (diagonal),

In 3D:

```
[aaaN, (aadN, adaN, addN, daaN, dadN, ddaN, dddN), ...
(aad1, ada1, add1, daa1, dad1, dda1, ddd1)]
```

The abbreviations refer to

`aaa` = approx. on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`aad` = approx. on 1st dim, approx. on 2nd dim, detail on 3rd dim,

`ada` = approx. on 1st dim, detail on 3nd dim, approx. on 3rd dim,

`add` = approx. on 1st dim, detail on 3nd dim, detail on 3rd dim,

`daa` = detail on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`dad` = detail on 1st dim, approx. on 2nd dim, detail on 3rd dim,

`dda` = detail on 1st dim, detail on 2nd dim, approx. on 3rd dim,

`ddd` = detail on 1st dim, detail on 2nd dim, detail on 3rd dim,

`N` refers to the number of scaling levels

size_list : `list`

A list containing the sizes of the wavelet (approximation and detail) coefficients at different scaling levels.

`size_list[0]` = size of approximation coefficients at the coarsest level,

`size_list[1]` = size of the detailed coefficients at the coarsest level,

`size_list[N]` = size of the detailed coefficients at the finest level,

`size_list[N+1]` = size of original image,

`N` = the number of scaling levels

Returnsarr : `numpy.ndarray`

Flattened and concatenated coefficient array The length of the array depends on the size of input image to be transformed and on the chosen wavelet basis.

wavelet_decomposition3d

`odl.trafos.wavelet.`**`wavelet_decomposition3d`**(*x*, *wbasis*, *mode*, *nscales*)

Discrete 3D multiresolution wavelet decomposition.

Compute the discrete 3D multiresolution wavelet decomposition at the given level (nscales) for a given 3D image. Utilizes a n-dimensional PyWavelet function `pywt.dwtn`.

Parametersx : *DiscreteLpVector*

wbasis : `pywt.Wavelet`

Selected wavelet basis. For more information see the PyWavelets documentation on wavelet bases.

mode : `str`

Signal extention mode. For possible extensions see the Pywavelets documentation on signal extenstion modes.

nscales : `int`

Number of scales in the coefficient list.

Returnscoeff_list : `list`

A list of coefficient organized in the following way `'[aaaN, (aadN, adaN, addN, daaN, dadN, ddaN, dddN), ... (aad1, ada1, add1, daa1, dad1, dda1, ddd1)]'`.

The abbreviations refer to

`aaa` = approx. on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`aad` = approx. on 1st dim, approx. on 2nd dim, detail on 3rd dim,

`ada` = approx. on 1st dim, detail on 3nd dim, approx. on 3rd dim,

`add` = approx. on 1st dim, detail on 3nd dim, detail on 3rd dim,

`daa` = detail on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`dad` = detail on 1st dim, approx. on 2nd dim, detail on 3rd dim,

`dda` = detail on 1st dim, detail on 2nd dim, approx. on 3rd dim,

`ddd` = detail on 1st dim, detail on 2nd dim, detail on 3rd dim,

`N` = the number of scaling levels

wavelet_reconstruction3d

`odl.trafos.wavelet.`**`wavelet_reconstruction3d`**(*coeff_list*, *wbasis*, *mode*, *nscales*)

Discrete 3D multiresolution wavelet reconstruction

Compute a discrete 3D multiresolution wavelet reconstruction from a given wavelet coefficient list. Utilizes a PyWavelet function `pywt.dwtn`

Parameterscoeff_list : `list`

A list of wavelet approximation and detail coefficients organized in the following way `'[caaaN, (aadN, adaN, addN, daaN, dadN, ddaN, dddN), ... (aad1, ada1, add1, daa1, dad1, dda1, ddd1)]'`.

The abbreviations refer to

`aaa` = approx. on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`aad` = approx. on 1st dim, approx. on 2nd dim, detail on3rd dim,

`ada` = approx. on 1st dim, detail on 3nd dim, approx. on 3rd dim,

`add` = approx. on 1st dim, detail on 3nd dim, detail on 3rd dim,

`daa` = detail on 1st dim, approx. on 2nd dim, approx. on 3rd dim,

`dad` = detail on 1st dim, approx. on 2nd dim, detail on 3rd dim,

`dda` = detail on 1st dim, detail on 2nd dim, approx. on 3rd dim,

`ddd` = detail on 1st dim, detail on 2nd dim, detail on 3rd dim,

`N` = the number of scaling levels

wbasis : `_pywt.Wavelet`

Describes properties of a selected wavelet basis. For more information see PyWavelet documentation

mode : `str`

Signal extention mode. For possible extensions see the signal extenstion modes of PyWavelets.

nscales : `int`

Number of scales in the coefficient list.

Returnsx : `numpy.ndarray`.

A wavalet reconstruction.

8.9 util

Utility library for ODL, only for internal use.

Modules

8.9.1 graphics

Functions for graphical output.

Functions

show_discrete_data(values, grid[, title, ...])	Display a discrete 1d or 2d function.

show_discrete_data

odl.util.graphics.**show_discrete_data**(*values*, *grid*, *title=None*, *method=''*, *show=False*, *fig=None*, ***kwargs*)

Display a discrete 1d or 2d function.

Parametersvalues : `numpy.ndarray`

The values to visualize

grid : *RegularGrid*

Grid of the values

title : `str`, optional

Set the title of the figure

method : `str`, optional

1d methods:

'plot' : graph plot

'scatter' : scattered 2d points (2nd axis <-> value)

2d methods:

'imshow' : image plot with coloring according to value, including a colorbar.

'scatter' : cloud of scattered 3d points (3rd axis <-> value)

'wireframe', 'plot_wireframe' : surface plot

show : `bool`, optional

If the plot should be showed now or deferred until later

fig : `matplotlib.figure.Figure`

The figure to show in. Expected to be of same "style", as the figure given by this function. The most common usecase is that fig is the return value from an earlier call to this function.

interp : {'nearest', 'linear'}

Interpolation method to use.

axis_labels : `str`

Axis labels, default: ['x', 'y']

kwargs : {'figsize', 'saveto', ...}

Extra keyword arguments passed on to display method See the Matplotlib functions for documentation of extra options.

Returnsfig : `matplotlib.figure.Figure`

The resulting figure. It is also shown to the user.

colorbar : `matplotlib.colorbar.Colorbar`

The colorbar

See also:

`matplotlib.pyplot.plot` Show graph plot

`matplotlib.pyplot.imshow` Show data as image

`matplotlib.pyplot.scatter` Show scattered 3d points

8.9.2 numerics

Numerical helper functions for convenience or speed.

Functions

apply_on_boundary(array, func[, only_once, ...])	Apply a function of the boundary of an n-dimensional array.
fast_1d_tensor_mult(ndarr, onedim_arrs[, ...])	Fast multiplication of an n-dim array with an outer product.

apply_on_boundary

odl.util.numerics.**apply_on_boundary**(*array*, *func*, *only_once=True*, *which_boundaries=None*, *axis_order=None*, *out=None*)

Apply a function of the boundary of an n-dimensional array.

All other values are preserved as is.

Parametersarray : array-like

Modify the boundary of this array

func : `callable` or `sequence`

If a single function is given, assign `array[slice] = func(array[slice])` on the boundary slices, e.g. use `lamda x: x / 2` to divide values by 2. A sequence of functions is applied per axis separately. It must have length `array.ndim` and may consist of one function or a 2-tuple of functions per axis. `None` entries in a sequence cause the axis (side) to be skipped.

only_once : `bool`, optional

If `True`, ensure that each boundary point appears in exactly one slice. If `func` is a list of functions, the `axis_order` determines which functions are applied to nodes which appear in multiple slices, according to the principle "first-come, first-served".

which_boundaries : `sequence`, optional

If provided, this sequence determines per axis whether to apply the function at the boundaries in each axis. The entry in each axis may consist in a single `bool` or a 2-tuple of `bool`. In the latter case, the first tuple entry decides for the left, the second for the right boundary. The length of the sequence must be `array.ndim`. `None` is interpreted as 'all boundaries'.

axis_order : `sequence` of `int`, optional

Permutation of `range(array.ndim)` defining the order in which to process the axes. If combined with `only_once` and a function list, this determines which function is evaluated in the points that are potentially processed multiple times.

out : `numpy.ndarray`, optional

Location in which to store the result, can be the same as `array`. Default: copy of `array`

Examples

```
>>> import numpy as np
>>> arr = np.ones((3, 3))
>>> apply_on_boundary(arr, lambda x: x / 2)
array([[ 0.5,  0.5,  0.5],
       [ 0.5,  1. ,  0.5],
       [ 0.5,  0.5,  0.5]])
```

If called with `only_once=False`, applies function repeatedly

```
>>> apply_on_boundary(arr, lambda x: x / 2, only_once=False)
array([[ 0.25,  0.5 ,  0.25],
       [ 0.5 ,  1.  ,  0.5 ],
       [ 0.25,  0.5 ,  0.25]])
```

```
>>> apply_on_boundary(arr, lambda x: x / 2, only_once=True,
...                   which_boundaries=((True, False), True))
array([[ 0.5,  0.5,  0.5],
       [ 0.5,  1. ,  0.5],
       [ 0.5,  1. ,  0.5]])
```

Also accepts out parameter:

```
>>> out = np.empty_like(arr)
>>> result = apply_on_boundary(arr, lambda x: x / 2, out=out)
>>> result
array([[ 0.5,  0.5,  0.5],
       [ 0.5,  1. ,  0.5],
       [ 0.5,  0.5,  0.5]])
>>> result is out
True
```

fast_1d_tensor_mult

odl.util.numerics.**fast_1d_tensor_mult**(*ndarr*, *onedim_arrs*, *axes=None*, *out=None*)

Fast multiplication of an n-dim array with an outer product.

This method implements the multiplication of an n-dimensional array with an outer product of one-dimensional arrays, e.g.:

```
a = np.ones((10, 10, 10))
x = np.random.rand(10)
a *= x[:, None, None] * x[None, :, None] * x[None, None, :]
```

Basically, there are two ways to do such an operation:

1. First calculate the factor on the right-hand side and do one "big" multiplication; or
2. Multiply by one factor at a time.

The procedure of building up the large factor in the first method is relatively cheap if the number of 1d arrays is smaller than the number of dimensions. For exactly n vectors, the second method is faster, although it loops of the array `a` n times.

This implementation combines the two ideas into a hybrid scheme:

- If there are less 1d arrays than dimensions, choose 1.
- Otherwise, calculate the factor array for n-1 arrays and multiply it to the large array. Finally, multiply with the last 1d array.

The advantage of this approach is that it is memory-friendly and loops over the big array only twice.

Parametersndarr : *array-like*

Array to multiply to

onedim_arrs : sequence of array-like

One-dimensional arrays to be multiplied with `ndarr`. The sequence may not be longer than `ndarr.ndim`.

axes : sequence of `int`, optional

Take the 1d transform along these axes. `None` corresponds to the last `len(onedim_arrs)` axes, in ascending order.

out : `numpy.ndarray`, optional

Array in which the result is stored

Returnsout : `numpy.ndarray`

Result of the modification. If `out` was given, the returned object is a reference to it.

8.9.3 phantom

Some useful phantoms, mostly for tomography tests.

Functions

cuboid(discr_space, begin, end)	Rectangular cuboid.
derenzo_sources(space)	Create the PET/SPECT Derenzo sources phantom.
ellipse_phantom_2d(space, ellipses)	Create an ellipse phantom in 2d space.
ellipse_phantom_3d(space, ellipses)	Create an ellipse phantom in 3d space.
indicate_proj_axis(discr_space[, ...])	Phantom indicating along which axis it is projected.
phantom(space, ellipses)	Return a phantom given by ellipses.
shepp_logan(space[, modified])	Create a Shepp-Logan phantom.
submarine_phantom(discr[, smooth, taper])	Return a 'submarine' phantom consisting in an ellipsoid and a box.

cuboid

odl.util.phantom.**cuboid**(*discr_space*, *begin*, *end*)

Rectangular cuboid.

Parametersdiscr_space : *Discretization*

Discretized space in which the phantom is supposed to be created

begin : array-like or `float` in [0, 1]

The lower left corner of the cuboid within the space grid relative to the extend of the grid

end : array-like or `float` in [0, 1]

The upper right corner of the cuboid within the space grid relative to the extend of the grid

Returnsphantom : *LinearSpaceVector*

Returns an element in `discr_space`

Examples

```
>>> import odl
>>> space = odl.uniform_discr(0, 1, 6, dtype='float32')
>>> print(cuboid(space, 0.5, 1))
[0.0, 0.0, 0.0, 1.0, 1.0, 1.0]
>>> space = odl.uniform_discr([0, 0], [1, 1], [4, 6], dtype='float32')
>>> print(cuboid(space, [0.25, 0], [0.75, 0.5]))
[[0.0, 0.0, 0.0, 0.0, 0.0, 0.0],
 [1.0, 1.0, 1.0, 0.0, 0.0, 0.0],
```

```
    [1.0, 1.0, 1.0, 0.0, 0.0, 0.0],
    [0.0, 0.0, 0.0, 0.0, 0.0, 0.0]]
```

derenzo_sources

odl.util.phantom.**derenzo_sources**(*space*)
Create the PET/SPECT Derenzo sources phantom.

The Derenzo phantom contains a series of circles of decreasing size.

In 3d the phantom is simply the 2d phantom extended in the z direction as cylinders.

ellipse_phantom_2d

odl.util.phantom.**ellipse_phantom_2d**(*space*, *ellipses*)
Create an ellipse phantom in 2d space.

Parametersspace : *DiscreteLp*

The space the phantom should be generated in.

ellipses : list of lists

Each row should contain: 'value', 'axis_1', 'axis_2', 'center_x', 'center_y', 'rotation' The ellipses should be contained the he rectangle [-1, -1] x [1, 1].

Returnsphantom : *DiscreteLpVector*

The phantom

ellipse_phantom_3d

odl.util.phantom.**ellipse_phantom_3d**(*space*, *ellipses*)
Create an ellipse phantom in 3d space.

Parametersspace : *DiscreteLp*

The space the phantom should be generated in.

ellipses : list of lists

Each row should contain: 'value', 'axis_1', 'axis_2', 'axis_2', 'center_x', 'center_y', 'center_z', 'rotation_phi', 'rotation_theta', 'rotation_psi' The ellipses should be contained the he rectangle [-1, -1, -1] x [1, 1, 1].

Returnsphantom : *DiscreteLpVector*

The phantom

indicate_proj_axis

odl.util.phantom.**indicate_proj_axis**(*discr_space*, *scale_structures=0.5*)
Phantom indicating along which axis it is projected.

The number (n) of rectangles in a parallel-beam projection along a main axis (0, 1, or 2) indicates the projection to be along the (n-1)the dimension.

Parametersdiscr_space : *Discretization*

Discretized space in which the phantom is supposed to be created

scale_structures : positive `float` in (0, 1]

Scales objects (cube, cuboids)

Returnsphantom : *LinearSpaceVector*

Returns an element in `discr_space`

Examples

```
>>> import odl
>>> space = odl.uniform_discr([0] * 3, [1] * 3, [8, 8, 8])
>>> phan = indicate_proj_axis(space).asarray()
>>> print(np.sum(phan, 0))
[[ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  3.  3.  0.  0.  0.]
 [ 0.  0.  0.  3.  3.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]]
>>> print(np.sum(phan, 1))
[[ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  2.  2.  0.  0.  0.]
 [ 0.  0.  0.  2.  2.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  1.  1.  0.  0.  0.]
 [ 0.  0.  0.  1.  1.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]]
>>> print(np.sum(phan, 2))
[[ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  2.  2.  0.  0.  0.]
 [ 0.  0.  0.  2.  2.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  2.  0.  0.  0.]
 [ 0.  0.  0.  2.  0.  0.  0.  0.]
 [ 0.  0.  0.  0.  0.  0.  0.  0.]]
```

phantom

odl.util.phantom.**phantom**(*space*, *ellipses*)

Return a phantom given by ellipses.

shepp_logan

odl.util.phantom.**shepp_logan**(*space*, *modified=False*)

Create a Shepp-Logan phantom.

The standard Shepp-Logan phantom in 2 or 3 dimensions.

References

Wikipedia : https://en.wikipedia.org/wiki/Shepp%E2%80%93Logan_phantom

submarine_phantom

odl.util.phantom.**submarine_phantom**(*discr*, *smooth=True*, *taper=20.0*)
Return a 'submarine' phantom consisting in an ellipsoid and a box.

This phantom is used in *[Okt2015]* for shape-based reconstruction.

Parametersdiscr : *DiscreteLp*

Discretized space in which the phantom is supposed to be created

smooth : bool, optional

If True, the boundaries are smoothed out. Otherwise, the function steps from 0 to 1 at the boundaries.

taper : float, optional

Tapering parameter for the boundary smoothing. Larger values mean faster taper, i.e. sharper boundaries.

Returnsphantom : *DiscreteLpVector*

8.9.4 testutils

Utilities for internal use.

Classes

FailCounter([err_msg])	Used to count the number of failures of something
ProgressBar([text])	A simple command-line progress bar.
ProgressRange(text, n)	Simple range sequence with progress bar output.
Timer([name])	A timer context manager.

FailCounter

class odl.util.testutils.**FailCounter**(*err_msg=None*)
Bases: object

Used to count the number of failures of something

Useage:

```
with FailCounter() as counter:
    # Do stuff

    counter.fail()
```

When done, it prints

```
*** FAILED 1 TEST CASE(S) ***
```

Methods

__eq__	Return self==value.
fail([string])	Add failure with reason as string.

FailCounter.fail

FailCounter.**fail**(*string=None*)
Add failure with reason as string.

__init__(*err_msg=None*)

ProgressBar

class odl.util.testutils.**ProgressBar**(*text='progress'*, **njobs*)
Bases: object

A simple command-line progress bar.

Usage:

```
>>> progress = ProgressBar('Reading data', 10)
```

Reading data: [ ] Starting

```
>>> progress.update(4) #halfway, zero indexing
```

Reading data: [###############] 50.0%

Multi-indices, from slowest to fastest:

```
>>> progress = ProgressBar('Reading data', 10, 10)
```

Reading data: [ ] Starting

```
>>> progress.update(9, 8)
```

Reading data: [##############################] 99.0%

Supports simply calling update, which moves the counter forward:

```
>>> progress = ProgressBar('Reading data', 10, 10)
```

Reading data: [ ] Starting

```
>>> progress.update()
```

Reading data: [ ] 1.0%

Methods

__eq__	Return self==value.

Continued on next page

Table 8.297 – continued from previous page

start()	Print the initial bar.
update(*indices)	Update the bar according to `indices`.

ProgressBar.start

`ProgressBar.`**`start`**`()`
Print the initial bar.

ProgressBar.update

`ProgressBar.`**`update`**`(`**indices*`)`
Update the bar according to `indices`.

`__init__``(`*text='progress'*, **njobs*`)`
Initialize a new instance.

ProgressRange

class `odl.util.testutils.`**`ProgressRange`**`(`*text*, *n*`)`
Bases: `object`

Simple range sequence with progress bar output.

Methods

`__eq__`	Return self==value.

`__init__``(`*text*, *n*`)`
Initialize a new instance.

Timer

class `odl.util.testutils.`**`Timer`**`(`*name=None*`)`
Bases: `object`

A timer context manager.

Usage:

```
with Timer('name'):
    # Do stuff
```

Prints the time stuff took to execute.

Methods

`__eq__`	Return self==value.

__init__(*name=None*)

Functions

all_almost_equal(iter1, iter2[, places])	`True` if all elements in `a` and `b` are almost equal.
all_almost_equal_array(v1, v2, places)	
all_equal(iter1, iter2)	`True` if all elements in `a` and `b` are equal.
almost_equal(a, b[, places])	`True` if scalars a and b are almost equal.
is_subdict(subdict, dictionary)	`True` if all items of `subdict` are in `dictionary`.
run_doctests()	Avoid all the copy and paste in the last 3 module lines.
skip_if_no_benchmark(function)	Trivial decorator used if pytest marks are not available.
skip_if_no_cuda(function)	Trivial decorator used if pytest marks are not available.
skip_if_no_largescale(function)	Trivial decorator used if pytest marks are not available.
skip_if_no_pyfftw(function)	Trivial decorator used if pytest marks are not available.
skip_if_no_pywavelets(function)	Trivial decorator used if pytest marks are not available.
timeit(arg)	A timer decorator.

all_almost_equal

odl.util.testutils.**all_almost_equal**(*iter1*, *iter2*, *places=None*)
`True` if all elements in `a` and `b` are almost equal.

all_almost_equal_array

odl.util.testutils.**all_almost_equal_array**(*v1*, *v2*, *places*)

all_equal

odl.util.testutils.**all_equal**(*iter1*, *iter2*)
`True` if all elements in `a` and `b` are equal.

almost_equal

odl.util.testutils.**almost_equal**(*a*, *b*, *places=None*)
`True` if scalars a and b are almost equal.

is_subdict

odl.util.testutils.**is_subdict**(*subdict*, *dictionary*)
`True` if all items of `subdict` are in `dictionary`.

run_doctests

odl.util.testutils.**run_doctests**()
Avoid all the copy and paste in the last 3 module lines.

skip_if_no_benchmark

odl.util.testutils.**skip_if_no_benchmark**(*function*)
Trivial decorator used if pytest marks are not available.

skip_if_no_cuda

odl.util.testutils.**skip_if_no_cuda**(*function*)
Trivial decorator used if pytest marks are not available.

skip_if_no_largescale

odl.util.testutils.**skip_if_no_largescale**(*function*)
Trivial decorator used if pytest marks are not available.

skip_if_no_pyfftw

odl.util.testutils.**skip_if_no_pyfftw**(*function*)
Trivial decorator used if pytest marks are not available.

skip_if_no_pywavelets

odl.util.testutils.**skip_if_no_pywavelets**(*function*)
Trivial decorator used if pytest marks are not available.

timeit

odl.util.testutils.**timeit**(*arg*)
A timer decorator.

Usage:

```
@timeit
def myfunction(...):
    ...

@timeit('info string')
def myfunction(...):
    ...
```

8.9.5 ufuncs

UFuncs for ODL vectors.

These functions are internal and should only be used as methods on *NtuplesBaseVector* type spaces.

See numpy.ufuncs for more information.

Notes

The default implementation of these methods make heavy use of the `NtuplesBaseVector.__array__` to extract a `numpy.ndarray` from the vector, and then apply a ufunc to it. Afterwards, `NtuplesBaseVector.__array_wrap__` is used to re-wrap the data into the appropriate space.

Classes

CudaNtuplesUFuncs(vector)	UFuncs for *CudaNtuplesVector* objects.
DiscreteLpUFuncs(vector)	UFuncs for *DiscreteLpVector* objects.
NtuplesBaseUFuncs(vector)	UFuncs for *NtuplesBaseVector* objects.
NtuplesUFuncs(vector)	UFuncs for *NtuplesVector* objects.
ProductSpaceUFuncs(vector)	UFuncs for *ProductSpaceVector* objects.

CudaNtuplesUFuncs

class `odl.util.ufuncs.`**CudaNtuplesUFuncs**(*vector*)

Bases: *odl.util.ufuncs.NtuplesBaseUFuncs*

UFuncs for *CudaNtuplesVector* objects.

Internal object, should not be created except in *CudaNtuplesVector*.

Methods

`__eq__`	Return self==value.
absolute([out])	Calculate the absolute value element-wise.
add(x2[, out])	Add arguments element-wise.
arccos([out])	Trigonometric inverse cosine, element-wise.
arccosh([out])	Inverse hyperbolic cosine, element-wise.
arcsin([out])	Inverse sine, element-wise.
arcsinh([out])	Inverse hyperbolic sine element-wise.
arctan([out])	Trigonometric inverse tangent, element-wise.
arctan2(x2[, out])	Element-wise arc tangent of `x1/x2` choosing the quadrant correctly.
arctanh([out])	Inverse hyperbolic tangent element-wise.
bitwise_and(x2[, out])	Compute the bit-wise AND of two arrays element-wise.
bitwise_or(x2[, out])	Compute the bit-wise OR of two arrays element-wise.
bitwise_xor(x2[, out])	Compute the bit-wise XOR of two arrays element-wise.
ceil([out])	Return the ceiling of the input, element-wise.
conj([out])	Return the complex conjugate, element-wise.
copysign(x2[, out])	Change the sign of x1 to that of x2, element-wise.
cos([out])	Cosine element-wise.
cosh([out])	Hyperbolic cosine, element-wise.
deg2rad([out])	Convert angles from degrees to radians.
divide(x2[, out])	Returns a true division of the inputs, element-wise.
equal(x2[, out])	Return (x1 == x2) element-wise.
exp([out])	Calculate the exponential of all elements in the input array.
exp2([out])	Calculate `2**p` for all `p` in the input array.
expm1([out])	Calculate `exp(x) - 1` for all elements in the array.

Continued on next page

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floor([out])	Return the floor of the input, element-wise.
floor_divide(x2[, out])	Return the largest integer smaller or equal to the division of the
fmax(x2[, out])	Element-wise maximum of array elements.
fmin(x2[, out])	Element-wise minimum of array elements.
fmod(x2[, out])	Return the element-wise remainder of division.
greater(x2[, out])	Return the truth value of (x1 > x2) element-wise.
greater_equal(x2[, out])	Return the truth value of (x1 >= x2) element-wise.
hypot(x2[, out])	Given the "legs" of a right triangle, return its hypotenuse.
invert([out])	Compute bit-wise inversion, or bit-wise NOT, element-wise.
isfinite([out])	Test element-wise for finiteness (not infinity or not Not a Number).
isinf([out])	Test element-wise for positive or negative infinity.
isnan([out])	Test element-wise for NaN and return result as a boolean array.
left_shift(x2[, out])	Shift the bits of an integer to the left.
less(x2[, out])	Return the truth value of (x1 < x2) element-wise.
less_equal(x2[, out])	Return the truth value of (x1 =< x2) element-wise.
log([out])	Natural logarithm, element-wise.
log10([out])	Return the base 10 logarithm of the input array, element-wise.
log1p([out])	Return the natural logarithm of one plus the input array, element-wise.
log2([out])	Base-2 logarithm of x.
logaddexp(x2[, out])	Logarithm of the sum of exponentiations of the inputs.
logaddexp2(x2[, out])	Logarithm of the sum of exponentiations of the inputs in base-2.
logical_and(x2[, out])	Compute the truth value of x1 AND x2 element-wise.
logical_not([out])	Compute the truth value of NOT x element-wise.
logical_or(x2[, out])	Compute the truth value of x1 OR x2 element-wise.
logical_xor(x2[, out])	Compute the truth value of x1 XOR x2, element-wise.
max()	Maximum value in array.
maximum(x2[, out])	Element-wise maximum of array elements.
min()	Minimum value in array.
minimum(x2[, out])	Element-wise minimum of array elements.
mod(x2[, out])	Return element-wise remainder of division.
modf([out1, out2])	Return the fractional and integral parts of an array, element-wise.
multiply(x2[, out])	Multiply arguments element-wise.
negative([out])	Numerical negative, element-wise.
not_equal(x2[, out])	Return (x1 != x2) element-wise.
power(x2[, out])	First array elements raised to powers from second array, element-wise.
prod()	Product of array elements.
rad2deg([out])	Convert angles from radians to degrees.
reciprocal([out])	Return the reciprocal of the argument, element-wise.
remainder(x2[, out])	Return element-wise remainder of division.
right_shift(x2[, out])	Shift the bits of an integer to the right.
rint([out])	Round elements of the array to the nearest integer.
sign([out])	Returns an element-wise indication of the sign of a number.
signbit([out])	Returns element-wise True where signbit is set (less than zero).
sin([out])	Trigonometric sine, element-wise.
sinh([out])	Hyperbolic sine, element-wise.
sqrt([out])	Return the positive square-root of an array, element-wise.
square([out])	Return the element-wise square of the input.
subtract(x2[, out])	Subtract arguments, element-wise.
sum()	Sum of array elements.
tan([out])	Compute tangent element-wise.

Continued on next page

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tanh([out])	Compute hyperbolic tangent element-wise.
true_divide(x2[, out])	Returns a true division of the inputs, element-wise.
trunc([out])	Return the truncated value of the input, element-wise.

CudaNtuplesUFuncs.absolute

CudaNtuplesUFuncs.**absolute**(*out=None*)

Calculate the absolute value element-wise.

See also:

numpy.absolute

CudaNtuplesUFuncs.add

CudaNtuplesUFuncs.**add**(*x2*, *out=None*)

Add arguments element-wise.

See also:

numpy.add

CudaNtuplesUFuncs.arccos

CudaNtuplesUFuncs.**arccos**(*out=None*)

Trigonometric inverse cosine, element-wise.

See also:

numpy.arccos

CudaNtuplesUFuncs.arccosh

CudaNtuplesUFuncs.**arccosh**(*out=None*)

Inverse hyperbolic cosine, element-wise.

See also:

numpy.arccosh

CudaNtuplesUFuncs.arcsin

CudaNtuplesUFuncs.**arcsin**(*out=None*)

Inverse sine, element-wise.

See also:

numpy.arcsin

CudaNtuplesUFuncs.arcsinh

CudaNtuplesUFuncs.**arcsinh**(*out=None*)

Inverse hyperbolic sine element-wise.

See also:

numpy.arcsinh

CudaNtuplesUFuncs.arctan
CudaNtuplesUFuncs.**arctan**(*out=None*)
Trigonometric inverse tangent, element-wise.

See also:

numpy.arctan

CudaNtuplesUFuncs.arctan2
CudaNtuplesUFuncs.**arctan2**(*x2*, *out=None*)
Element-wise arc tangent of x1/x2 choosing the quadrant correctly.

See also:

numpy.arctan2

CudaNtuplesUFuncs.arctanh
CudaNtuplesUFuncs.**arctanh**(*out=None*)
Inverse hyperbolic tangent element-wise.

See also:

numpy.arctanh

CudaNtuplesUFuncs.bitwise_and
CudaNtuplesUFuncs.**bitwise_and**(*x2*, *out=None*)
Compute the bit-wise AND of two arrays element-wise.

See also:

numpy.bitwise_and

CudaNtuplesUFuncs.bitwise_or
CudaNtuplesUFuncs.**bitwise_or**(*x2*, *out=None*)
Compute the bit-wise OR of two arrays element-wise.

See also:

numpy.bitwise_or

CudaNtuplesUFuncs.bitwise_xor
CudaNtuplesUFuncs.**bitwise_xor**(*x2*, *out=None*)
Compute the bit-wise XOR of two arrays element-wise.

See also:

numpy.bitwise_xor

CudaNtuplesUFuncs.ceil
CudaNtuplesUFuncs.**ceil**(*out=None*)
Return the ceiling of the input, element-wise.

See also:

numpy.ceil

CudaNtuplesUFuncs.conj
CudaNtuplesUFuncs.**conj**(*out=None*)
Return the complex conjugate, element-wise.

See also:

numpy.conj

CudaNtuplesUFuncs.copysign
CudaNtuplesUFuncs.**copysign**(*x2*, *out=None*)
Change the sign of x1 to that of x2, element-wise.

See also:

numpy.copysign

CudaNtuplesUFuncs.cos
CudaNtuplesUFuncs.**cos**(*out=None*)
Cosine element-wise.

See also:

numpy.cos

CudaNtuplesUFuncs.cosh
CudaNtuplesUFuncs.**cosh**(*out=None*)
Hyperbolic cosine, element-wise.

See also:

numpy.cosh

CudaNtuplesUFuncs.deg2rad
CudaNtuplesUFuncs.**deg2rad**(*out=None*)
Convert angles from degrees to radians.

See also:

numpy.deg2rad

CudaNtuplesUFuncs.divide
CudaNtuplesUFuncs.**divide**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

numpy.divide

CudaNtuplesUFuncs.equal
CudaNtuplesUFuncs.**equal**(*x2*, *out=None*)
Return (x1 == x2) element-wise.

See also:

numpy.equal

CudaNtuplesUFuncs.exp
CudaNtuplesUFuncs.**exp**(*out=None*)
Calculate the exponential of all elements in the input array.

See also:

numpy.exp

CudaNtuplesUFuncs.exp2
CudaNtuplesUFuncs.**exp2**(*out=None*)
Calculate `2**p` for all `p` in the input array.

See also:

numpy.exp2

CudaNtuplesUFuncs.expm1
CudaNtuplesUFuncs.**expm1**(*out=None*)
Calculate `exp(x) - 1` for all elements in the array.

See also:

numpy.expm1

CudaNtuplesUFuncs.floor
CudaNtuplesUFuncs.**floor**(*out=None*)
Return the floor of the input, element-wise.

See also:

numpy.floor

CudaNtuplesUFuncs.floor_divide
CudaNtuplesUFuncs.**floor_divide**(*x2*, *out=None*)
Return the largest integer smaller or equal to the division of the

See also:

numpy.floor_divide

CudaNtuplesUFuncs.fmax
CudaNtuplesUFuncs.**fmax**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.fmax

CudaNtuplesUFuncs.fmin
CudaNtuplesUFuncs.**fmin**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.fmin

CudaNtuplesUFuncs.fmod
CudaNtuplesUFuncs.**fmod**(*x2*, *out=None*)
Return the element-wise remainder of division.

See also:

numpy.fmod

CudaNtuplesUFuncs.greater
CudaNtuplesUFuncs.**greater**(*x2*, *out=None*)
Return the truth value of (x1 > x2) element-wise.

See also:

numpy.greater

CudaNtuplesUFuncs.greater_equal
CudaNtuplesUFuncs.**greater_equal**(*x2*, *out=None*)
Return the truth value of (x1 >= x2) element-wise.

See also:

numpy.greater_equal

CudaNtuplesUFuncs.hypot
CudaNtuplesUFuncs.**hypot**(*x2*, *out=None*)
Given the "legs" of a right triangle, return its hypotenuse.

See also:

numpy.hypot

CudaNtuplesUFuncs.invert
CudaNtuplesUFuncs.**invert**(*out=None*)
Compute bit-wise inversion, or bit-wise NOT, element-wise.

See also:

numpy.invert

CudaNtuplesUFuncs.isfinite
CudaNtuplesUFuncs.**isfinite**(*out=None*)
Test element-wise for finiteness (not infinity or not Not a Number).

See also:

numpy.isfinite

CudaNtuplesUFuncs.isinf
CudaNtuplesUFuncs.**isinf**(*out=None*)
Test element-wise for positive or negative infinity.

See also:

numpy.isinf

CudaNtuplesUFuncs.isnan
CudaNtuplesUFuncs.**isnan**(*out=None*)
Test element-wise for NaN and return result as a boolean array.

See also:

numpy.isnan

CudaNtuplesUFuncs.left_shift
CudaNtuplesUFuncs.**left_shift**(*x2*, *out=None*)
Shift the bits of an integer to the left.

See also:

numpy.left_shift

CudaNtuplesUFuncs.less
CudaNtuplesUFuncs.**less**(*x2*, *out=None*)
Return the truth value of (x1 < x2) element-wise.

See also:

numpy.less

CudaNtuplesUFuncs.less_equal
CudaNtuplesUFuncs.**less_equal**(*x2*, *out=None*)
Return the truth value of (x1 =< x2) element-wise.

See also:

numpy.less_equal

CudaNtuplesUFuncs.log
CudaNtuplesUFuncs.**log**(*out=None*)
Natural logarithm, element-wise.

See also:

numpy.log

CudaNtuplesUFuncs.log10
CudaNtuplesUFuncs.**log10**(*out=None*)
Return the base 10 logarithm of the input array, element-wise.

See also:

numpy.log10

CudaNtuplesUFuncs.log1p
CudaNtuplesUFuncs.**log1p**(*out=None*)
Return the natural logarithm of one plus the input array, element-wise.

See also:

numpy.log1p

CudaNtuplesUFuncs.log2
CudaNtuplesUFuncs.**log2**(*out=None*)
Base-2 logarithm of x.

See also:

numpy.log2

CudaNtuplesUFuncs.logaddexp
CudaNtuplesUFuncs.**logaddexp**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs.

See also:

numpy.logaddexp

CudaNtuplesUFuncs.logaddexp2
CudaNtuplesUFuncs.**logaddexp2**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs in base-2.

See also:

numpy.logaddexp2

CudaNtuplesUFuncs.logical_and
CudaNtuplesUFuncs.**logical_and**(*x2*, *out=None*)
Compute the truth value of x1 AND x2 element-wise.

See also:

numpy.logical_and

CudaNtuplesUFuncs.logical_not
CudaNtuplesUFuncs.**logical_not**(*out=None*)
Compute the truth value of NOT x element-wise.

See also:

numpy.logical_not

CudaNtuplesUFuncs.logical_or
CudaNtuplesUFuncs.**logical_or**(*x2*, *out=None*)
Compute the truth value of x1 OR x2 element-wise.

See also:

numpy.logical_or

CudaNtuplesUFuncs.logical_xor
CudaNtuplesUFuncs.**logical_xor**(*x2*, *out=None*)
Compute the truth value of x1 XOR x2, element-wise.

See also:

numpy.logical_xor

CudaNtuplesUFuncs.max
CudaNtuplesUFuncs.**max**()
Maximum value in array.

See also:

numpy.amax

CudaNtuplesUFuncs.maximum
CudaNtuplesUFuncs.**maximum**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.maximum

CudaNtuplesUFuncs.min
CudaNtuplesUFuncs.**min**()
Minimum value in array.

See also:

numpy.amin

CudaNtuplesUFuncs.minimum
CudaNtuplesUFuncs.**minimum**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.minimum

CudaNtuplesUFuncs.mod
CudaNtuplesUFuncs.**mod**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.mod

CudaNtuplesUFuncs.modf
CudaNtuplesUFuncs.**modf**(*out1=None*, *out2=None*)
Return the fractional and integral parts of an array, element-wise.

See also:

numpy.modf

CudaNtuplesUFuncs.multiply
CudaNtuplesUFuncs.**multiply**(*x2*, *out=None*)
Multiply arguments element-wise.

See also:

numpy.multiply

CudaNtuplesUFuncs.negative
CudaNtuplesUFuncs.**negative**(*out=None*)
Numerical negative, element-wise.

See also:

numpy.negative

CudaNtuplesUFuncs.not_equal
CudaNtuplesUFuncs.**not_equal**(*x2*, *out=None*)
Return (x1 != x2) element-wise.

See also:

numpy.not_equal

CudaNtuplesUFuncs.power
CudaNtuplesUFuncs.**power**(*x2*, *out=None*)
First array elements raised to powers from second array, element-wise.

See also:

numpy.power

CudaNtuplesUFuncs.prod
CudaNtuplesUFuncs.**prod**()
Product of array elements.

See also:

numpy.prod

CudaNtuplesUFuncs.rad2deg
CudaNtuplesUFuncs.**rad2deg**(*out=None*)
Convert angles from radians to degrees.

See also:

numpy.rad2deg

CudaNtuplesUFuncs.reciprocal
CudaNtuplesUFuncs.**reciprocal**(*out=None*)
Return the reciprocal of the argument, element-wise.

See also:

numpy.reciprocal

CudaNtuplesUFuncs.remainder
CudaNtuplesUFuncs.**remainder**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.remainder

CudaNtuplesUFuncs.right_shift
CudaNtuplesUFuncs.**right_shift**(*x2*, *out=None*)
Shift the bits of an integer to the right.

See also:

numpy.right_shift

CudaNtuplesUFuncs.rint
CudaNtuplesUFuncs.**rint**(*out=None*)
Round elements of the array to the nearest integer.

See also:

numpy.rint

CudaNtuplesUFuncs.sign
CudaNtuplesUFuncs.**sign**(*out=None*)
Returns an element-wise indication of the sign of a number.

See also:

numpy.sign

CudaNtuplesUFuncs.signbit
CudaNtuplesUFuncs.**signbit**(*out=None*)
Returns element-wise True where signbit is set (less than zero).

See also:

numpy.signbit

CudaNtuplesUFuncs.sin
CudaNtuplesUFuncs.**sin**(*out=None*)
Trigonometric sine, element-wise.

See also:

numpy.sin

CudaNtuplesUFuncs.sinh
CudaNtuplesUFuncs.**sinh**(*out=None*)
Hyperbolic sine, element-wise.

See also:

numpy.sinh

CudaNtuplesUFuncs.sqrt
CudaNtuplesUFuncs.**sqrt**(*out=None*)
Return the positive square-root of an array, element-wise.

See also:

numpy.sqrt

CudaNtuplesUFuncs.square
CudaNtuplesUFuncs.**square**(*out=None*)
Return the element-wise square of the input.

See also:

numpy.square

CudaNtuplesUFuncs.subtract
CudaNtuplesUFuncs.**subtract**(*x2*, *out=None*)
Subtract arguments, element-wise.

See also:

numpy.subtract

CudaNtuplesUFuncs.sum
CudaNtuplesUFuncs.**sum**()
Sum of array elements.

See also:

numpy.sum

CudaNtuplesUFuncs.tan
CudaNtuplesUFuncs.**tan**(*out=None*)
Compute tangent element-wise.

See also:

numpy.tan

CudaNtuplesUFuncs.tanh
CudaNtuplesUFuncs.**tanh**(*out=None*)
Compute hyperbolic tangent element-wise.

See also:

numpy.tanh

CudaNtuplesUFuncs.true_divide
CudaNtuplesUFuncs.**true_divide**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

numpy.true_divide

CudaNtuplesUFuncs.trunc
CudaNtuplesUFuncs.**trunc**(*out=None*)
Return the truncated value of the input, element-wise.

See also:

numpy.trunc
__init__(*vector*)
Create ufunc wrapper for vector.

DiscreteLpUFuncs

class odl.util.ufuncs.**DiscreteLpUFuncs**(*vector*)

Bases: *odl.util.ufuncs.NtuplesBaseUFuncs*

UFuncs for *DiscreteLpVector* objects.

Internal object, should not be created except in *DiscreteLpVector*.

Methods

__eq__	Return self==value.
absolute([out])	Calculate the absolute value element-wise.
add(x2[, out])	Add arguments element-wise.
arccos([out])	Trigonometric inverse cosine, element-wise.
arccosh([out])	Inverse hyperbolic cosine, element-wise.
arcsin([out])	Inverse sine, element-wise.
arcsinh([out])	Inverse hyperbolic sine element-wise.
arctan([out])	Trigonometric inverse tangent, element-wise.
arctan2(x2[, out])	Element-wise arc tangent of `x1/x2` choosing the quadrant correctly.
arctanh([out])	Inverse hyperbolic tangent element-wise.
bitwise_and(x2[, out])	Compute the bit-wise AND of two arrays element-wise.
bitwise_or(x2[, out])	Compute the bit-wise OR of two arrays element-wise.
bitwise_xor(x2[, out])	Compute the bit-wise XOR of two arrays element-wise.
ceil([out])	Return the ceiling of the input, element-wise.
conj([out])	Return the complex conjugate, element-wise.
copysign(x2[, out])	Change the sign of x1 to that of x2, element-wise.
cos([out])	Cosine element-wise.
cosh([out])	Hyperbolic cosine, element-wise.
deg2rad([out])	Convert angles from degrees to radians.
divide(x2[, out])	Returns a true division of the inputs, element-wise.
equal(x2[, out])	Return (x1 == x2) element-wise.
exp([out])	Calculate the exponential of all elements in the input array.
exp2([out])	Calculate `2**p` for all `p` in the input array.
expm1([out])	Calculate `exp(x) - 1` for all elements in the array.
floor([out])	Return the floor of the input, element-wise.
floor_divide(x2[, out])	Return the largest integer smaller or equal to the division of the
fmax(x2[, out])	Element-wise maximum of array elements.
fmin(x2[, out])	Element-wise minimum of array elements.
fmod(x2[, out])	Return the element-wise remainder of division.
greater(x2[, out])	Return the truth value of (x1 > x2) element-wise.
greater_equal(x2[, out])	Return the truth value of (x1 >= x2) element-wise.
hypot(x2[, out])	Given the "legs" of a right triangle, return its hypotenuse.
invert([out])	Compute bit-wise inversion, or bit-wise NOT, element-wise.
isfinite([out])	Test element-wise for finiteness (not infinity or not Not a Number).
isinf([out])	Test element-wise for positive or negative infinity.
isnan([out])	Test element-wise for NaN and return result as a boolean array.
left_shift(x2[, out])	Shift the bits of an integer to the left.
less(x2[, out])	Return the truth value of (x1 < x2) element-wise.
less_equal(x2[, out])	Return the truth value of (x1 =< x2) element-wise.
log([out])	Natural logarithm, element-wise.

Continued on next page

Table 8.303 – continued from previous page

log10([out])	Return the base 10 logarithm of the input array, element-wise.
log1p([out])	Return the natural logarithm of one plus the input array, element-wise.
log2([out])	Base-2 logarithm of x.
logaddexp(x2[, out])	Logarithm of the sum of exponentiations of the inputs.
logaddexp2(x2[, out])	Logarithm of the sum of exponentiations of the inputs in base-2.
logical_and(x2[, out])	Compute the truth value of x1 AND x2 element-wise.
logical_not([out])	Compute the truth value of NOT x element-wise.
logical_or(x2[, out])	Compute the truth value of x1 OR x2 element-wise.
logical_xor(x2[, out])	Compute the truth value of x1 XOR x2, element-wise.
max()	Maximum value in array.
maximum(x2[, out])	Element-wise maximum of array elements.
min()	Minimum value in array.
minimum(x2[, out])	Element-wise minimum of array elements.
mod(x2[, out])	Return element-wise remainder of division.
modf([out1, out2])	Return the fractional and integral parts of an array, element-wise.
multiply(x2[, out])	Multiply arguments element-wise.
negative([out])	Numerical negative, element-wise.
not_equal(x2[, out])	Return (x1 != x2) element-wise.
power(x2[, out])	First array elements raised to powers from second array, element-wise.
prod()	Product of array elements.
rad2deg([out])	Convert angles from radians to degrees.
reciprocal([out])	Return the reciprocal of the argument, element-wise.
remainder(x2[, out])	Return element-wise remainder of division.
right_shift(x2[, out])	Shift the bits of an integer to the right.
rint([out])	Round elements of the array to the nearest integer.
sign([out])	Returns an element-wise indication of the sign of a number.
signbit([out])	Returns element-wise True where signbit is set (less than zero).
sin([out])	Trigonometric sine, element-wise.
sinh([out])	Hyperbolic sine, element-wise.
sqrt([out])	Return the positive square-root of an array, element-wise.
square([out])	Return the element-wise square of the input.
subtract(x2[, out])	Subtract arguments, element-wise.
sum()	Sum of array elements.
tan([out])	Compute tangent element-wise.
tanh([out])	Compute hyperbolic tangent element-wise.
true_divide(x2[, out])	Returns a true division of the inputs, element-wise.
trunc([out])	Return the truncated value of the input, element-wise.

DiscreteLpUFuncs.absolute

DiscreteLpUFuncs.**absolute**(*out=None*)

Calculate the absolute value element-wise.

See also:

numpy.absolute

DiscreteLpUFuncs.add

DiscreteLpUFuncs.**add**(*x2*, *out=None*)

Add arguments element-wise.

See also:

numpy.add

DiscreteLpUFuncs.arccos
DiscreteLpUFuncs.**arccos**(*out=None*)
Trigonometric inverse cosine, element-wise.

See also:

numpy.arccos

DiscreteLpUFuncs.arccosh
DiscreteLpUFuncs.**arccosh**(*out=None*)
Inverse hyperbolic cosine, element-wise.

See also:

numpy.arccosh

DiscreteLpUFuncs.arcsin
DiscreteLpUFuncs.**arcsin**(*out=None*)
Inverse sine, element-wise.

See also:

numpy.arcsin

DiscreteLpUFuncs.arcsinh
DiscreteLpUFuncs.**arcsinh**(*out=None*)
Inverse hyperbolic sine element-wise.

See also:

numpy.arcsinh

DiscreteLpUFuncs.arctan
DiscreteLpUFuncs.**arctan**(*out=None*)
Trigonometric inverse tangent, element-wise.

See also:

numpy.arctan

DiscreteLpUFuncs.arctan2
DiscreteLpUFuncs.**arctan2**(*x2*, *out=None*)
Element-wise arc tangent of `x1/x2` choosing the quadrant correctly.

See also:

numpy.arctan2

DiscreteLpUFuncs.arctanh
DiscreteLpUFuncs.**arctanh**(*out=None*)
Inverse hyperbolic tangent element-wise.

See also:

numpy.arctanh

DiscreteLpUFuncs.bitwise_and
DiscreteLpUFuncs.**bitwise_and**(*x2*, *out=None*)
Compute the bit-wise AND of two arrays element-wise.

See also:

numpy.bitwise_and

DiscreteLpUFuncs.bitwise_or
DiscreteLpUFuncs.**bitwise_or**(*x2*, *out=None*)
Compute the bit-wise OR of two arrays element-wise.

See also:

numpy.bitwise_or

DiscreteLpUFuncs.bitwise_xor
DiscreteLpUFuncs.**bitwise_xor**(*x2*, *out=None*)
Compute the bit-wise XOR of two arrays element-wise.

See also:

numpy.bitwise_xor

DiscreteLpUFuncs.ceil
DiscreteLpUFuncs.**ceil**(*out=None*)
Return the ceiling of the input, element-wise.

See also:

numpy.ceil

DiscreteLpUFuncs.conj
DiscreteLpUFuncs.**conj**(*out=None*)
Return the complex conjugate, element-wise.

See also:

numpy.conj

DiscreteLpUFuncs.copysign
DiscreteLpUFuncs.**copysign**(*x2*, *out=None*)
Change the sign of x1 to that of x2, element-wise.

See also:

numpy.copysign

DiscreteLpUFuncs.cos
DiscreteLpUFuncs.**cos**(*out=None*)
Cosine element-wise.

See also:

numpy.cos

DiscreteLpUFuncs.cosh
`DiscreteLpUFuncs.`**`cosh`**(*out=None*)
Hyperbolic cosine, element-wise.

See also:

`numpy.cosh`

DiscreteLpUFuncs.deg2rad
`DiscreteLpUFuncs.`**`deg2rad`**(*out=None*)
Convert angles from degrees to radians.

See also:

`numpy.deg2rad`

DiscreteLpUFuncs.divide
`DiscreteLpUFuncs.`**`divide`**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

`numpy.divide`

DiscreteLpUFuncs.equal
`DiscreteLpUFuncs.`**`equal`**(*x2*, *out=None*)
Return (x1 == x2) element-wise.

See also:

`numpy.equal`

DiscreteLpUFuncs.exp
`DiscreteLpUFuncs.`**`exp`**(*out=None*)
Calculate the exponential of all elements in the input array.

See also:

`numpy.exp`

DiscreteLpUFuncs.exp2
`DiscreteLpUFuncs.`**`exp2`**(*out=None*)
Calculate `2**p` for all `p` in the input array.

See also:

`numpy.exp2`

DiscreteLpUFuncs.expm1
`DiscreteLpUFuncs.`**`expm1`**(*out=None*)
Calculate `exp(x) - 1` for all elements in the array.

See also:

`numpy.expm1`

DiscreteLpUFuncs.floor
DiscreteLpUFuncs.**floor**(*out=None*)
Return the floor of the input, element-wise.

See also:

numpy.floor

DiscreteLpUFuncs.floor_divide
DiscreteLpUFuncs.**floor_divide**(*x2*, *out=None*)
Return the largest integer smaller or equal to the division of the

See also:

numpy.floor_divide

DiscreteLpUFuncs.fmax
DiscreteLpUFuncs.**fmax**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.fmax

DiscreteLpUFuncs.fmin
DiscreteLpUFuncs.**fmin**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.fmin

DiscreteLpUFuncs.fmod
DiscreteLpUFuncs.**fmod**(*x2*, *out=None*)
Return the element-wise remainder of division.

See also:

numpy.fmod

DiscreteLpUFuncs.greater
DiscreteLpUFuncs.**greater**(*x2*, *out=None*)
Return the truth value of (x1 > x2) element-wise.

See also:

numpy.greater

DiscreteLpUFuncs.greater_equal
DiscreteLpUFuncs.**greater_equal**(*x2*, *out=None*)
Return the truth value of (x1 >= x2) element-wise.

See also:

numpy.greater_equal

DiscreteLpUFuncs.hypot

DiscreteLpUFuncs.**hypot**(*x2*, *out=None*)

Given the "legs" of a right triangle, return its hypotenuse.

See also:

numpy.hypot

DiscreteLpUFuncs.invert

DiscreteLpUFuncs.**invert**(*out=None*)

Compute bit-wise inversion, or bit-wise NOT, element-wise.

See also:

numpy.invert

DiscreteLpUFuncs.isfinite

DiscreteLpUFuncs.**isfinite**(*out=None*)

Test element-wise for finiteness (not infinity or not Not a Number).

See also:

numpy.isfinite

DiscreteLpUFuncs.isinf

DiscreteLpUFuncs.**isinf**(*out=None*)

Test element-wise for positive or negative infinity.

See also:

numpy.isinf

DiscreteLpUFuncs.isnan

DiscreteLpUFuncs.**isnan**(*out=None*)

Test element-wise for NaN and return result as a boolean array.

See also:

numpy.isnan

DiscreteLpUFuncs.left_shift

DiscreteLpUFuncs.**left_shift**(*x2*, *out=None*)

Shift the bits of an integer to the left.

See also:

numpy.left_shift

DiscreteLpUFuncs.less

DiscreteLpUFuncs.**less**(*x2*, *out=None*)

Return the truth value of (x1 < x2) element-wise.

See also:

numpy.less

DiscreteLpUFuncs.less_equal
DiscreteLpUFuncs.**less_equal**(*x2*, *out=None*)
Return the truth value of (x1 =< x2) element-wise.

See also:

numpy.less_equal

DiscreteLpUFuncs.log
DiscreteLpUFuncs.**log**(*out=None*)
Natural logarithm, element-wise.

See also:

numpy.log

DiscreteLpUFuncs.log10
DiscreteLpUFuncs.**log10**(*out=None*)
Return the base 10 logarithm of the input array, element-wise.

See also:

numpy.log10

DiscreteLpUFuncs.log1p
DiscreteLpUFuncs.**log1p**(*out=None*)
Return the natural logarithm of one plus the input array, element-wise.

See also:

numpy.log1p

DiscreteLpUFuncs.log2
DiscreteLpUFuncs.**log2**(*out=None*)
Base-2 logarithm of x.

See also:

numpy.log2

DiscreteLpUFuncs.logaddexp
DiscreteLpUFuncs.**logaddexp**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs.

See also:

numpy.logaddexp

DiscreteLpUFuncs.logaddexp2
DiscreteLpUFuncs.**logaddexp2**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs in base-2.

See also:

numpy.logaddexp2

DiscreteLpUFuncs.logical_and
DiscreteLpUFuncs.**logical_and**(*x2*, *out=None*)
Compute the truth value of x1 AND x2 element-wise.

See also:

numpy.logical_and

DiscreteLpUFuncs.logical_not
DiscreteLpUFuncs.**logical_not**(*out=None*)
Compute the truth value of NOT x element-wise.

See also:

numpy.logical_not

DiscreteLpUFuncs.logical_or
DiscreteLpUFuncs.**logical_or**(*x2*, *out=None*)
Compute the truth value of x1 OR x2 element-wise.

See also:

numpy.logical_or

DiscreteLpUFuncs.logical_xor
DiscreteLpUFuncs.**logical_xor**(*x2*, *out=None*)
Compute the truth value of x1 XOR x2, element-wise.

See also:

numpy.logical_xor

DiscreteLpUFuncs.max
DiscreteLpUFuncs.**max**()
Maximum value in array.

See also:

numpy.amax

DiscreteLpUFuncs.maximum
DiscreteLpUFuncs.**maximum**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.maximum

DiscreteLpUFuncs.min
DiscreteLpUFuncs.**min**()
Minimum value in array.

See also:

numpy.amin

DiscreteLpUFuncs.minimum
DiscreteLpUFuncs.**minimum**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.minimum

DiscreteLpUFuncs.mod
DiscreteLpUFuncs.**mod**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.mod

DiscreteLpUFuncs.modf
DiscreteLpUFuncs.**modf**(*out1=None*, *out2=None*)
Return the fractional and integral parts of an array, element-wise.

See also:

numpy.modf

DiscreteLpUFuncs.multiply
DiscreteLpUFuncs.**multiply**(*x2*, *out=None*)
Multiply arguments element-wise.

See also:

numpy.multiply

DiscreteLpUFuncs.negative
DiscreteLpUFuncs.**negative**(*out=None*)
Numerical negative, element-wise.

See also:

numpy.negative

DiscreteLpUFuncs.not_equal
DiscreteLpUFuncs.**not_equal**(*x2*, *out=None*)
Return (x1 != x2) element-wise.

See also:

numpy.not_equal

DiscreteLpUFuncs.power
DiscreteLpUFuncs.**power**(*x2*, *out=None*)
First array elements raised to powers from second array, element-wise.

See also:

numpy.power

DiscreteLpUFuncs.prod
DiscreteLpUFuncs.**prod**()
Product of array elements.

See also:

numpy.prod

DiscreteLpUFuncs.rad2deg
DiscreteLpUFuncs.**rad2deg**(*out=None*)
Convert angles from radians to degrees.

See also:

numpy.rad2deg

DiscreteLpUFuncs.reciprocal
DiscreteLpUFuncs.**reciprocal**(*out=None*)
Return the reciprocal of the argument, element-wise.

See also:

numpy.reciprocal

DiscreteLpUFuncs.remainder
DiscreteLpUFuncs.**remainder**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.remainder

DiscreteLpUFuncs.right_shift
DiscreteLpUFuncs.**right_shift**(*x2*, *out=None*)
Shift the bits of an integer to the right.

See also:

numpy.right_shift

DiscreteLpUFuncs.rint
DiscreteLpUFuncs.**rint**(*out=None*)
Round elements of the array to the nearest integer.

See also:

numpy.rint

DiscreteLpUFuncs.sign
DiscreteLpUFuncs.**sign**(*out=None*)
Returns an element-wise indication of the sign of a number.

See also:

numpy.sign

DiscreteLpUFuncs.signbit
DiscreteLpUFuncs.**signbit**(*out=None*)
Returns element-wise True where signbit is set (less than zero).

See also:

numpy.signbit

DiscreteLpUFuncs.sin
DiscreteLpUFuncs.**sin**(*out=None*)
Trigonometric sine, element-wise.

See also:

numpy.sin

DiscreteLpUFuncs.sinh
DiscreteLpUFuncs.**sinh**(*out=None*)
Hyperbolic sine, element-wise.

See also:

numpy.sinh

DiscreteLpUFuncs.sqrt
DiscreteLpUFuncs.**sqrt**(*out=None*)
Return the positive square-root of an array, element-wise.

See also:

numpy.sqrt

DiscreteLpUFuncs.square
DiscreteLpUFuncs.**square**(*out=None*)
Return the element-wise square of the input.

See also:

numpy.square

DiscreteLpUFuncs.subtract
DiscreteLpUFuncs.**subtract**(*x2*, *out=None*)
Subtract arguments, element-wise.

See also:

numpy.subtract

DiscreteLpUFuncs.sum
DiscreteLpUFuncs.**sum**()
Sum of array elements.

See also:

numpy.sum

DiscreteLpUFuncs.tan
DiscreteLpUFuncs.**tan**(*out=None*)
Compute tangent element-wise.

See also:

numpy.tan

DiscreteLpUFuncs.tanh
DiscreteLpUFuncs.**tanh**(*out=None*)
Compute hyperbolic tangent element-wise.

See also:

numpy.tanh

DiscreteLpUFuncs.true_divide
DiscreteLpUFuncs.**true_divide**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

numpy.true_divide

DiscreteLpUFuncs.trunc
DiscreteLpUFuncs.**trunc**(*out=None*)
Return the truncated value of the input, element-wise.

See also:

numpy.trunc
__init__(*vector*)
Create ufunc wrapper for vector.

NtuplesBaseUFuncs

class odl.util.ufuncs.**NtuplesBaseUFuncs**(*vector*)
Bases: object

UFuncs for *NtuplesBaseVector* objects.

Internal object, should not be created except in *NtuplesBaseVector*.

Methods

__eq__	Return self==value.
absolute([out])	Calculate the absolute value element-wise.
add(x2[, out])	Add arguments element-wise.
arccos([out])	Trigonometric inverse cosine, element-wise.
arccosh([out])	Inverse hyperbolic cosine, element-wise.
arcsin([out])	Inverse sine, element-wise.
arcsinh([out])	Inverse hyperbolic sine element-wise.
arctan([out])	Trigonometric inverse tangent, element-wise.

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Table 8.304 – continued from previous page

arctan2(x2[, out])	Element-wise arc tangent of x1/x2 choosing the quadrant correctly.
arctanh([out])	Inverse hyperbolic tangent element-wise.
bitwise_and(x2[, out])	Compute the bit-wise AND of two arrays element-wise.
bitwise_or(x2[, out])	Compute the bit-wise OR of two arrays element-wise.
bitwise_xor(x2[, out])	Compute the bit-wise XOR of two arrays element-wise.
ceil([out])	Return the ceiling of the input, element-wise.
conj([out])	Return the complex conjugate, element-wise.
copysign(x2[, out])	Change the sign of x1 to that of x2, element-wise.
cos([out])	Cosine element-wise.
cosh([out])	Hyperbolic cosine, element-wise.
deg2rad([out])	Convert angles from degrees to radians.
divide(x2[, out])	Returns a true division of the inputs, element-wise.
equal(x2[, out])	Return (x1 == x2) element-wise.
exp([out])	Calculate the exponential of all elements in the input array.
exp2([out])	Calculate 2**p for all p in the input array.
expm1([out])	Calculate exp(x) - 1 for all elements in the array.
floor([out])	Return the floor of the input, element-wise.
floor_divide(x2[, out])	Return the largest integer smaller or equal to the division of the
fmax(x2[, out])	Element-wise maximum of array elements.
fmin(x2[, out])	Element-wise minimum of array elements.
fmod(x2[, out])	Return the element-wise remainder of division.
greater(x2[, out])	Return the truth value of (x1 > x2) element-wise.
greater_equal(x2[, out])	Return the truth value of (x1 >= x2) element-wise.
hypot(x2[, out])	Given the "legs" of a right triangle, return its hypotenuse.
invert([out])	Compute bit-wise inversion, or bit-wise NOT, element-wise.
isfinite([out])	Test element-wise for finiteness (not infinity or not Not a Number).
isinf([out])	Test element-wise for positive or negative infinity.
isnan([out])	Test element-wise for NaN and return result as a boolean array.
left_shift(x2[, out])	Shift the bits of an integer to the left.
less(x2[, out])	Return the truth value of (x1 < x2) element-wise.
less_equal(x2[, out])	Return the truth value of (x1 =< x2) element-wise.
log([out])	Natural logarithm, element-wise.
log10([out])	Return the base 10 logarithm of the input array, element-wise.
log1p([out])	Return the natural logarithm of one plus the input array, element-wise.
log2([out])	Base-2 logarithm of x.
logaddexp(x2[, out])	Logarithm of the sum of exponentiations of the inputs.
logaddexp2(x2[, out])	Logarithm of the sum of exponentiations of the inputs in base-2.
logical_and(x2[, out])	Compute the truth value of x1 AND x2 element-wise.
logical_not([out])	Compute the truth value of NOT x element-wise.
logical_or(x2[, out])	Compute the truth value of x1 OR x2 element-wise.
logical_xor(x2[, out])	Compute the truth value of x1 XOR x2, element-wise.
max()	Maximum value in array.
maximum(x2[, out])	Element-wise maximum of array elements.
min()	Minimum value in array.
minimum(x2[, out])	Element-wise minimum of array elements.
mod(x2[, out])	Return element-wise remainder of division.
modf([out1, out2])	Return the fractional and integral parts of an array, element-wise.
multiply(x2[, out])	Multiply arguments element-wise.
negative([out])	Numerical negative, element-wise.
not_equal(x2[, out])	Return (x1 != x2) element-wise.

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Table 8.304 – continued from previous page

power(x2[, out])	First array elements raised to powers from second array, element-wise.
prod()	Product of array elements.
rad2deg([out])	Convert angles from radians to degrees.
reciprocal([out])	Return the reciprocal of the argument, element-wise.
remainder(x2[, out])	Return element-wise remainder of division.
right_shift(x2[, out])	Shift the bits of an integer to the right.
rint([out])	Round elements of the array to the nearest integer.
sign([out])	Returns an element-wise indication of the sign of a number.
signbit([out])	Returns element-wise True where signbit is set (less than zero).
sin([out])	Trigonometric sine, element-wise.
sinh([out])	Hyperbolic sine, element-wise.
sqrt([out])	Return the positive square-root of an array, element-wise.
square([out])	Return the element-wise square of the input.
subtract(x2[, out])	Subtract arguments, element-wise.
sum()	Sum of array elements.
tan([out])	Compute tangent element-wise.
tanh([out])	Compute hyperbolic tangent element-wise.
true_divide(x2[, out])	Returns a true division of the inputs, element-wise.
trunc([out])	Return the truncated value of the input, element-wise.

NtuplesBaseUFuncs.absolute

NtuplesBaseUFuncs.**absolute**(*out=None*)

Calculate the absolute value element-wise.

See also:

numpy.absolute

NtuplesBaseUFuncs.add

NtuplesBaseUFuncs.**add**(*x2*, *out=None*)

Add arguments element-wise.

See also:

numpy.add

NtuplesBaseUFuncs.arccos

NtuplesBaseUFuncs.**arccos**(*out=None*)

Trigonometric inverse cosine, element-wise.

See also:

numpy.arccos

NtuplesBaseUFuncs.arccosh

NtuplesBaseUFuncs.**arccosh**(*out=None*)

Inverse hyperbolic cosine, element-wise.

See also:

numpy.arccosh

NtuplesBaseUFuncs.arcsin
NtuplesBaseUFuncs.**arcsin**(*out=None*)
Inverse sine, element-wise.

See also:

numpy.arcsin

NtuplesBaseUFuncs.arcsinh
NtuplesBaseUFuncs.**arcsinh**(*out=None*)
Inverse hyperbolic sine element-wise.

See also:

numpy.arcsinh

NtuplesBaseUFuncs.arctan
NtuplesBaseUFuncs.**arctan**(*out=None*)
Trigonometric inverse tangent, element-wise.

See also:

numpy.arctan

NtuplesBaseUFuncs.arctan2
NtuplesBaseUFuncs.**arctan2**(*x2*, *out=None*)
Element-wise arc tangent of x1/x2 choosing the quadrant correctly.

See also:

numpy.arctan2

NtuplesBaseUFuncs.arctanh
NtuplesBaseUFuncs.**arctanh**(*out=None*)
Inverse hyperbolic tangent element-wise.

See also:

numpy.arctanh

NtuplesBaseUFuncs.bitwise_and
NtuplesBaseUFuncs.**bitwise_and**(*x2*, *out=None*)
Compute the bit-wise AND of two arrays element-wise.

See also:

numpy.bitwise_and

NtuplesBaseUFuncs.bitwise_or
NtuplesBaseUFuncs.**bitwise_or**(*x2*, *out=None*)
Compute the bit-wise OR of two arrays element-wise.

See also:

numpy.bitwise_or

NtuplesBaseUFuncs.bitwise_xor
NtuplesBaseUFuncs.**bitwise_xor**(*x2*, *out=None*)
Compute the bit-wise XOR of two arrays element-wise.

See also:

numpy.bitwise_xor

NtuplesBaseUFuncs.ceil
NtuplesBaseUFuncs.**ceil**(*out=None*)
Return the ceiling of the input, element-wise.

See also:

numpy.ceil

NtuplesBaseUFuncs.conj
NtuplesBaseUFuncs.**conj**(*out=None*)
Return the complex conjugate, element-wise.

See also:

numpy.conj

NtuplesBaseUFuncs.copysign
NtuplesBaseUFuncs.**copysign**(*x2*, *out=None*)
Change the sign of x1 to that of x2, element-wise.

See also:

numpy.copysign

NtuplesBaseUFuncs.cos
NtuplesBaseUFuncs.**cos**(*out=None*)
Cosine element-wise.

See also:

numpy.cos

NtuplesBaseUFuncs.cosh
NtuplesBaseUFuncs.**cosh**(*out=None*)
Hyperbolic cosine, element-wise.

See also:

numpy.cosh

NtuplesBaseUFuncs.deg2rad
NtuplesBaseUFuncs.**deg2rad**(*out=None*)
Convert angles from degrees to radians.

See also:

numpy.deg2rad

NtuplesBaseUFuncs.divide
NtuplesBaseUFuncs.**divide**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

numpy.divide

NtuplesBaseUFuncs.equal
NtuplesBaseUFuncs.**equal**(*x2*, *out=None*)
Return (x1 == x2) element-wise.

See also:

numpy.equal

NtuplesBaseUFuncs.exp
NtuplesBaseUFuncs.**exp**(*out=None*)
Calculate the exponential of all elements in the input array.

See also:

numpy.exp

NtuplesBaseUFuncs.exp2
NtuplesBaseUFuncs.**exp2**(*out=None*)
Calculate `2**p` for all `p` in the input array.

See also:

numpy.exp2

NtuplesBaseUFuncs.expm1
NtuplesBaseUFuncs.**expm1**(*out=None*)
Calculate `exp(x) - 1` for all elements in the array.

See also:

numpy.expm1

NtuplesBaseUFuncs.floor
NtuplesBaseUFuncs.**floor**(*out=None*)
Return the floor of the input, element-wise.

See also:

numpy.floor

NtuplesBaseUFuncs.floor_divide
NtuplesBaseUFuncs.**floor_divide**(*x2*, *out=None*)
Return the largest integer smaller or equal to the division of the

See also:

numpy.floor_divide

NtuplesBaseUFuncs.fmax
NtuplesBaseUFuncs.**fmax**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.fmax

NtuplesBaseUFuncs.fmin
NtuplesBaseUFuncs.**fmin**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.fmin

NtuplesBaseUFuncs.fmod
NtuplesBaseUFuncs.**fmod**(*x2*, *out=None*)
Return the element-wise remainder of division.

See also:

numpy.fmod

NtuplesBaseUFuncs.greater
NtuplesBaseUFuncs.**greater**(*x2*, *out=None*)
Return the truth value of (x1 > x2) element-wise.

See also:

numpy.greater

NtuplesBaseUFuncs.greater_equal
NtuplesBaseUFuncs.**greater_equal**(*x2*, *out=None*)
Return the truth value of (x1 >= x2) element-wise.

See also:

numpy.greater_equal

NtuplesBaseUFuncs.hypot
NtuplesBaseUFuncs.**hypot**(*x2*, *out=None*)
Given the "legs" of a right triangle, return its hypotenuse.

See also:

numpy.hypot

NtuplesBaseUFuncs.invert
NtuplesBaseUFuncs.**invert**(*out=None*)
Compute bit-wise inversion, or bit-wise NOT, element-wise.

See also:

numpy.invert

NtuplesBaseUFuncs.isfinite
NtuplesBaseUFuncs.**isfinite**(*out=None*)
Test element-wise for finiteness (not infinity or not Not a Number).

See also:

numpy.isfinite

NtuplesBaseUFuncs.isinf
NtuplesBaseUFuncs.**isinf**(*out=None*)
Test element-wise for positive or negative infinity.

See also:

numpy.isinf

NtuplesBaseUFuncs.isnan
NtuplesBaseUFuncs.**isnan**(*out=None*)
Test element-wise for NaN and return result as a boolean array.

See also:

numpy.isnan

NtuplesBaseUFuncs.left_shift
NtuplesBaseUFuncs.**left_shift**(*x2*, *out=None*)
Shift the bits of an integer to the left.

See also:

numpy.left_shift

NtuplesBaseUFuncs.less
NtuplesBaseUFuncs.**less**(*x2*, *out=None*)
Return the truth value of (x1 < x2) element-wise.

See also:

numpy.less

NtuplesBaseUFuncs.less_equal
NtuplesBaseUFuncs.**less_equal**(*x2*, *out=None*)
Return the truth value of (x1 =< x2) element-wise.

See also:

numpy.less_equal

NtuplesBaseUFuncs.log
NtuplesBaseUFuncs.**log**(*out=None*)
Natural logarithm, element-wise.

See also:

numpy.log

NtuplesBaseUFuncs.log10
NtuplesBaseUFuncs.**log10**(*out=None*)
Return the base 10 logarithm of the input array, element-wise.

See also:

numpy.log10

NtuplesBaseUFuncs.log1p
NtuplesBaseUFuncs.**log1p**(*out=None*)
Return the natural logarithm of one plus the input array, element-wise.

See also:

numpy.log1p

NtuplesBaseUFuncs.log2
NtuplesBaseUFuncs.**log2**(*out=None*)
Base-2 logarithm of x.

See also:

numpy.log2

NtuplesBaseUFuncs.logaddexp
NtuplesBaseUFuncs.**logaddexp**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs.

See also:

numpy.logaddexp

NtuplesBaseUFuncs.logaddexp2
NtuplesBaseUFuncs.**logaddexp2**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs in base-2.

See also:

numpy.logaddexp2

NtuplesBaseUFuncs.logical_and
NtuplesBaseUFuncs.**logical_and**(*x2*, *out=None*)
Compute the truth value of x1 AND x2 element-wise.

See also:

numpy.logical_and

NtuplesBaseUFuncs.logical_not
NtuplesBaseUFuncs.**logical_not**(*out=None*)
Compute the truth value of NOT x element-wise.

See also:

numpy.logical_not

NtuplesBaseUFuncs.logical_or
NtuplesBaseUFuncs.**logical_or**(*x2*, *out=None*)
Compute the truth value of x1 OR x2 element-wise.

See also:

numpy.logical_or

NtuplesBaseUFuncs.logical_xor
NtuplesBaseUFuncs.**logical_xor**(*x2*, *out=None*)
Compute the truth value of x1 XOR x2, element-wise.

See also:

numpy.logical_xor

NtuplesBaseUFuncs.max
NtuplesBaseUFuncs.**max**()
Maximum value in array.

See also:

numpy.amax

NtuplesBaseUFuncs.maximum
NtuplesBaseUFuncs.**maximum**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.maximum

NtuplesBaseUFuncs.min
NtuplesBaseUFuncs.**min**()
Minimum value in array.

See also:

numpy.amin

NtuplesBaseUFuncs.minimum
NtuplesBaseUFuncs.**minimum**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.minimum

NtuplesBaseUFuncs.mod
NtuplesBaseUFuncs.**mod**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.mod

NtuplesBaseUFuncs.modf
NtuplesBaseUFuncs.**modf**(*out1=None*, *out2=None*)
Return the fractional and integral parts of an array, element-wise.

See also:

numpy.modf

NtuplesBaseUFuncs.multiply
NtuplesBaseUFuncs.**multiply**(*x2*, *out=None*)
Multiply arguments element-wise.

See also:

numpy.multiply

NtuplesBaseUFuncs.negative
NtuplesBaseUFuncs.**negative**(*out=None*)
Numerical negative, element-wise.

See also:

numpy.negative

NtuplesBaseUFuncs.not_equal
NtuplesBaseUFuncs.**not_equal**(*x2*, *out=None*)
Return (x1 != x2) element-wise.

See also:

numpy.not_equal

NtuplesBaseUFuncs.power
NtuplesBaseUFuncs.**power**(*x2*, *out=None*)
First array elements raised to powers from second array, element-wise.

See also:

numpy.power

NtuplesBaseUFuncs.prod
NtuplesBaseUFuncs.**prod**()
Product of array elements.

See also:

numpy.prod

NtuplesBaseUFuncs.rad2deg
NtuplesBaseUFuncs.**rad2deg**(*out=None*)
Convert angles from radians to degrees.

See also:

numpy.rad2deg

NtuplesBaseUFuncs.reciprocal
NtuplesBaseUFuncs.**reciprocal**(*out=None*)
Return the reciprocal of the argument, element-wise.

See also:

numpy.reciprocal

NtuplesBaseUFuncs.remainder
NtuplesBaseUFuncs.**remainder**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.remainder

NtuplesBaseUFuncs.right_shift
NtuplesBaseUFuncs.**right_shift**(*x2*, *out=None*)
Shift the bits of an integer to the right.

See also:

numpy.right_shift

NtuplesBaseUFuncs.rint
NtuplesBaseUFuncs.**rint**(*out=None*)
Round elements of the array to the nearest integer.

See also:

numpy.rint

NtuplesBaseUFuncs.sign
NtuplesBaseUFuncs.**sign**(*out=None*)
Returns an element-wise indication of the sign of a number.

See also:

numpy.sign

NtuplesBaseUFuncs.signbit
NtuplesBaseUFuncs.**signbit**(*out=None*)
Returns element-wise True where signbit is set (less than zero).

See also:

numpy.signbit

NtuplesBaseUFuncs.sin
NtuplesBaseUFuncs.**sin**(*out=None*)
Trigonometric sine, element-wise.

See also:

numpy.sin

NtuplesBaseUFuncs.sinh
NtuplesBaseUFuncs.**sinh**(*out=None*)
Hyperbolic sine, element-wise.

See also:

numpy.sinh

NtuplesBaseUFuncs.sqrt
NtuplesBaseUFuncs.**sqrt**(*out=None*)
Return the positive square-root of an array, element-wise.

See also:

numpy.sqrt

NtuplesBaseUFuncs.square
NtuplesBaseUFuncs.**square**(*out=None*)
Return the element-wise square of the input.

See also:

numpy.square

NtuplesBaseUFuncs.subtract
NtuplesBaseUFuncs.**subtract**(*x2*, *out=None*)
Subtract arguments, element-wise.

See also:

numpy.subtract

NtuplesBaseUFuncs.sum
NtuplesBaseUFuncs.**sum**()
Sum of array elements.

See also:

numpy.sum

NtuplesBaseUFuncs.tan
NtuplesBaseUFuncs.**tan**(*out=None*)
Compute tangent element-wise.

See also:

numpy.tan

NtuplesBaseUFuncs.tanh
NtuplesBaseUFuncs.**tanh**(*out=None*)
Compute hyperbolic tangent element-wise.

See also:

numpy.tanh

NtuplesBaseUFuncs.true_divide
NtuplesBaseUFuncs.**true_divide**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

numpy.true_divide

NtuplesBaseUFuncs.trunc
NtuplesBaseUFuncs.**trunc**(*out=None*)
Return the truncated value of the input, element-wise.

See also:

numpy.trunc
__init__(*vector*)
Create ufunc wrapper for vector.

NtuplesUFuncs

class odl.util.ufuncs.**NtuplesUFuncs**(*vector*)
Bases: *odl.util.ufuncs.NtuplesBaseUFuncs*

UFuncs for *NtuplesVector* objects.

Internal object, should not be created except in *NtuplesVector*.

Methods

__eq__	Return self==value.
absolute([out])	Calculate the absolute value element-wise.
add(x2[, out])	Add arguments element-wise.
arccos([out])	Trigonometric inverse cosine, element-wise.
arccosh([out])	Inverse hyperbolic cosine, element-wise.
arcsin([out])	Inverse sine, element-wise.
arcsinh([out])	Inverse hyperbolic sine element-wise.
arctan([out])	Trigonometric inverse tangent, element-wise.
arctan2(x2[, out])	Element-wise arc tangent of x1/x2 choosing the quadrant correctly.
arctanh([out])	Inverse hyperbolic tangent element-wise.
bitwise_and(x2[, out])	Compute the bit-wise AND of two arrays element-wise.
bitwise_or(x2[, out])	Compute the bit-wise OR of two arrays element-wise.
bitwise_xor(x2[, out])	Compute the bit-wise XOR of two arrays element-wise.
ceil([out])	Return the ceiling of the input, element-wise.
conj([out])	Return the complex conjugate, element-wise.
copysign(x2[, out])	Change the sign of x1 to that of x2, element-wise.
cos([out])	Cosine element-wise.
cosh([out])	Hyperbolic cosine, element-wise.
deg2rad([out])	Convert angles from degrees to radians.
divide(x2[, out])	Returns a true division of the inputs, element-wise.
equal(x2[, out])	Return (x1 == x2) element-wise.
exp([out])	Calculate the exponential of all elements in the input array.
exp2([out])	Calculate 2**p for all p in the input array.

Continued on next page

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expm1([out])	Calculate exp(x) - 1 for all elements in the array.
floor([out])	Return the floor of the input, element-wise.
floor_divide(x2[, out])	Return the largest integer smaller or equal to the division of the
fmax(x2[, out])	Element-wise maximum of array elements.
fmin(x2[, out])	Element-wise minimum of array elements.
fmod(x2[, out])	Return the element-wise remainder of division.
greater(x2[, out])	Return the truth value of (x1 > x2) element-wise.
greater_equal(x2[, out])	Return the truth value of (x1 >= x2) element-wise.
hypot(x2[, out])	Given the "legs" of a right triangle, return its hypotenuse.
invert([out])	Compute bit-wise inversion, or bit-wise NOT, element-wise.
isfinite([out])	Test element-wise for finiteness (not infinity or not Not a Number).
isinf([out])	Test element-wise for positive or negative infinity.
isnan([out])	Test element-wise for NaN and return result as a boolean array.
left_shift(x2[, out])	Shift the bits of an integer to the left.
less(x2[, out])	Return the truth value of (x1 < x2) element-wise.
less_equal(x2[, out])	Return the truth value of (x1 =< x2) element-wise.
log([out])	Natural logarithm, element-wise.
log10([out])	Return the base 10 logarithm of the input array, element-wise.
log1p([out])	Return the natural logarithm of one plus the input array, element-wise.
log2([out])	Base-2 logarithm of x.
logaddexp(x2[, out])	Logarithm of the sum of exponentiations of the inputs.
logaddexp2(x2[, out])	Logarithm of the sum of exponentiations of the inputs in base-2.
logical_and(x2[, out])	Compute the truth value of x1 AND x2 element-wise.
logical_not([out])	Compute the truth value of NOT x element-wise.
logical_or(x2[, out])	Compute the truth value of x1 OR x2 element-wise.
logical_xor(x2[, out])	Compute the truth value of x1 XOR x2, element-wise.
max()	Maximum value in array.
maximum(x2[, out])	Element-wise maximum of array elements.
min()	Minimum value in array.
minimum(x2[, out])	Element-wise minimum of array elements.
mod(x2[, out])	Return element-wise remainder of division.
modf([out1, out2])	Return the fractional and integral parts of an array, element-wise.
multiply(x2[, out])	Multiply arguments element-wise.
negative([out])	Numerical negative, element-wise.
not_equal(x2[, out])	Return (x1 != x2) element-wise.
power(x2[, out])	First array elements raised to powers from second array, element-wise.
prod()	Product of array elements.
rad2deg([out])	Convert angles from radians to degrees.
reciprocal([out])	Return the reciprocal of the argument, element-wise.
remainder(x2[, out])	Return element-wise remainder of division.
right_shift(x2[, out])	Shift the bits of an integer to the right.
rint([out])	Round elements of the array to the nearest integer.
sign([out])	Returns an element-wise indication of the sign of a number.
signbit([out])	Returns element-wise True where signbit is set (less than zero).
sin([out])	Trigonometric sine, element-wise.
sinh([out])	Hyperbolic sine, element-wise.
sqrt([out])	Return the positive square-root of an array, element-wise.
square([out])	Return the element-wise square of the input.
subtract(x2[, out])	Subtract arguments, element-wise.
sum()	Sum of array elements.

Continued on next page

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tan([out])	Compute tangent element-wise.
tanh([out])	Compute hyperbolic tangent element-wise.
true_divide(x2[, out])	Returns a true division of the inputs, element-wise.
trunc([out])	Return the truncated value of the input, element-wise.

NtuplesUFuncs.absolute

NtuplesUFuncs.**absolute**(*out=None*)

Calculate the absolute value element-wise.

See also:

numpy.absolute

NtuplesUFuncs.add

NtuplesUFuncs.**add**(*x2*, *out=None*)

Add arguments element-wise.

See also:

numpy.add

NtuplesUFuncs.arccos

NtuplesUFuncs.**arccos**(*out=None*)

Trigonometric inverse cosine, element-wise.

See also:

numpy.arccos

NtuplesUFuncs.arccosh

NtuplesUFuncs.**arccosh**(*out=None*)

Inverse hyperbolic cosine, element-wise.

See also:

numpy.arccosh

NtuplesUFuncs.arcsin

NtuplesUFuncs.**arcsin**(*out=None*)

Inverse sine, element-wise.

See also:

numpy.arcsin

NtuplesUFuncs.arcsinh

NtuplesUFuncs.**arcsinh**(*out=None*)

Inverse hyperbolic sine element-wise.

See also:

numpy.arcsinh

NtuplesUFuncs.arctan
NtuplesUFuncs.**arctan**(*out=None*)
Trigonometric inverse tangent, element-wise.

See also:

numpy.arctan

NtuplesUFuncs.arctan2
NtuplesUFuncs.**arctan2**(*x2*, *out=None*)
Element-wise arc tangent of x1/x2 choosing the quadrant correctly.

See also:

numpy.arctan2

NtuplesUFuncs.arctanh
NtuplesUFuncs.**arctanh**(*out=None*)
Inverse hyperbolic tangent element-wise.

See also:

numpy.arctanh

NtuplesUFuncs.bitwise_and
NtuplesUFuncs.**bitwise_and**(*x2*, *out=None*)
Compute the bit-wise AND of two arrays element-wise.

See also:

numpy.bitwise_and

NtuplesUFuncs.bitwise_or
NtuplesUFuncs.**bitwise_or**(*x2*, *out=None*)
Compute the bit-wise OR of two arrays element-wise.

See also:

numpy.bitwise_or

NtuplesUFuncs.bitwise_xor
NtuplesUFuncs.**bitwise_xor**(*x2*, *out=None*)
Compute the bit-wise XOR of two arrays element-wise.

See also:

numpy.bitwise_xor

NtuplesUFuncs.ceil
NtuplesUFuncs.**ceil**(*out=None*)
Return the ceiling of the input, element-wise.

See also:

numpy.ceil

NtuplesUFuncs.conj
NtuplesUFuncs.**conj**(*out=None*)
Return the complex conjugate, element-wise.

See also:

numpy.conj

NtuplesUFuncs.copysign
NtuplesUFuncs.**copysign**(*x2*, *out=None*)
Change the sign of x1 to that of x2, element-wise.

See also:

numpy.copysign

NtuplesUFuncs.cos
NtuplesUFuncs.**cos**(*out=None*)
Cosine element-wise.

See also:

numpy.cos

NtuplesUFuncs.cosh
NtuplesUFuncs.**cosh**(*out=None*)
Hyperbolic cosine, element-wise.

See also:

numpy.cosh

NtuplesUFuncs.deg2rad
NtuplesUFuncs.**deg2rad**(*out=None*)
Convert angles from degrees to radians.

See also:

numpy.deg2rad

NtuplesUFuncs.divide
NtuplesUFuncs.**divide**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

numpy.divide

NtuplesUFuncs.equal
NtuplesUFuncs.**equal**(*x2*, *out=None*)
Return (x1 == x2) element-wise.

See also:

numpy.equal

NtuplesUFuncs.exp
NtuplesUFuncs.**exp**(*out=None*)
Calculate the exponential of all elements in the input array.

See also:

numpy.exp

NtuplesUFuncs.exp2
NtuplesUFuncs.**exp2**(*out=None*)
Calculate `2**p` for all `p` in the input array.

See also:

numpy.exp2

NtuplesUFuncs.expm1
NtuplesUFuncs.**expm1**(*out=None*)
Calculate `exp(x) - 1` for all elements in the array.

See also:

numpy.expm1

NtuplesUFuncs.floor
NtuplesUFuncs.**floor**(*out=None*)
Return the floor of the input, element-wise.

See also:

numpy.floor

NtuplesUFuncs.floor_divide
NtuplesUFuncs.**floor_divide**(*x2*, *out=None*)
Return the largest integer smaller or equal to the division of the

See also:

numpy.floor_divide

NtuplesUFuncs.fmax
NtuplesUFuncs.**fmax**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.fmax

NtuplesUFuncs.fmin
NtuplesUFuncs.**fmin**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.fmin

NtuplesUFuncs.fmod
NtuplesUFuncs.**fmod**(*x2*, *out=None*)
Return the element-wise remainder of division.

See also:

numpy.fmod

NtuplesUFuncs.greater
NtuplesUFuncs.**greater**(*x2*, *out=None*)
Return the truth value of (x1 > x2) element-wise.

See also:

numpy.greater

NtuplesUFuncs.greater_equal
NtuplesUFuncs.**greater_equal**(*x2*, *out=None*)
Return the truth value of (x1 >= x2) element-wise.

See also:

numpy.greater_equal

NtuplesUFuncs.hypot
NtuplesUFuncs.**hypot**(*x2*, *out=None*)
Given the "legs" of a right triangle, return its hypotenuse.

See also:

numpy.hypot

NtuplesUFuncs.invert
NtuplesUFuncs.**invert**(*out=None*)
Compute bit-wise inversion, or bit-wise NOT, element-wise.

See also:

numpy.invert

NtuplesUFuncs.isfinite
NtuplesUFuncs.**isfinite**(*out=None*)
Test element-wise for finiteness (not infinity or not Not a Number).

See also:

numpy.isfinite

NtuplesUFuncs.isinf
NtuplesUFuncs.**isinf**(*out=None*)
Test element-wise for positive or negative infinity.

See also:

numpy.isinf

NtuplesUFuncs.isnan
NtuplesUFuncs.**isnan**(*out=None*)
Test element-wise for NaN and return result as a boolean array.

See also:

numpy.isnan

NtuplesUFuncs.left_shift
NtuplesUFuncs.**left_shift**(*x2*, *out=None*)
Shift the bits of an integer to the left.

See also:

numpy.left_shift

NtuplesUFuncs.less
NtuplesUFuncs.**less**(*x2*, *out=None*)
Return the truth value of (x1 < x2) element-wise.

See also:

numpy.less

NtuplesUFuncs.less_equal
NtuplesUFuncs.**less_equal**(*x2*, *out=None*)
Return the truth value of (x1 =< x2) element-wise.

See also:

numpy.less_equal

NtuplesUFuncs.log
NtuplesUFuncs.**log**(*out=None*)
Natural logarithm, element-wise.

See also:

numpy.log

NtuplesUFuncs.log10
NtuplesUFuncs.**log10**(*out=None*)
Return the base 10 logarithm of the input array, element-wise.

See also:

numpy.log10

NtuplesUFuncs.log1p
NtuplesUFuncs.**log1p**(*out=None*)
Return the natural logarithm of one plus the input array, element-wise.

See also:

numpy.log1p

NtuplesUFuncs.log2
NtuplesUFuncs.**log2**(*out=None*)
Base-2 logarithm of x.

See also:

numpy.log2

NtuplesUFuncs.logaddexp
NtuplesUFuncs.**logaddexp**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs.

See also:

numpy.logaddexp

NtuplesUFuncs.logaddexp2
NtuplesUFuncs.**logaddexp2**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs in base-2.

See also:

numpy.logaddexp2

NtuplesUFuncs.logical_and
NtuplesUFuncs.**logical_and**(*x2*, *out=None*)
Compute the truth value of x1 AND x2 element-wise.

See also:

numpy.logical_and

NtuplesUFuncs.logical_not
NtuplesUFuncs.**logical_not**(*out=None*)
Compute the truth value of NOT x element-wise.

See also:

numpy.logical_not

NtuplesUFuncs.logical_or
NtuplesUFuncs.**logical_or**(*x2*, *out=None*)
Compute the truth value of x1 OR x2 element-wise.

See also:

numpy.logical_or

NtuplesUFuncs.logical_xor
NtuplesUFuncs.**logical_xor**(*x2*, *out=None*)
Compute the truth value of x1 XOR x2, element-wise.

See also:

numpy.logical_xor

NtuplesUFuncs.max
NtuplesUFuncs.**max**()
Maximum value in array.

See also:

numpy.amax

NtuplesUFuncs.maximum
NtuplesUFuncs.**maximum**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

numpy.maximum

NtuplesUFuncs.min
NtuplesUFuncs.**min**()
Minimum value in array.

See also:

numpy.amin

NtuplesUFuncs.minimum
NtuplesUFuncs.**minimum**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

numpy.minimum

NtuplesUFuncs.mod
NtuplesUFuncs.**mod**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.mod

NtuplesUFuncs.modf
NtuplesUFuncs.**modf**(*out1=None*, *out2=None*)
Return the fractional and integral parts of an array, element-wise.

See also:

numpy.modf

NtuplesUFuncs.multiply
NtuplesUFuncs.**multiply**(*x2*, *out=None*)
Multiply arguments element-wise.

See also:

numpy.multiply

NtuplesUFuncs.negative
NtuplesUFuncs.**negative**(*out=None*)
Numerical negative, element-wise.

See also:

numpy.negative

NtuplesUFuncs.not_equal
NtuplesUFuncs.**not_equal**(*x2*, *out=None*)
Return (x1 != x2) element-wise.

See also:

numpy.not_equal

NtuplesUFuncs.power
NtuplesUFuncs.**power**(*x2*, *out=None*)
First array elements raised to powers from second array, element-wise.

See also:

numpy.power

NtuplesUFuncs.prod
NtuplesUFuncs.**prod**()
Product of array elements.

See also:

numpy.prod

NtuplesUFuncs.rad2deg
NtuplesUFuncs.**rad2deg**(*out=None*)
Convert angles from radians to degrees.

See also:

numpy.rad2deg

NtuplesUFuncs.reciprocal
NtuplesUFuncs.**reciprocal**(*out=None*)
Return the reciprocal of the argument, element-wise.

See also:

numpy.reciprocal

NtuplesUFuncs.remainder
NtuplesUFuncs.**remainder**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

numpy.remainder

NtuplesUFuncs.right_shift
NtuplesUFuncs.**right_shift**(*x2*, *out=None*)
Shift the bits of an integer to the right.

See also:

numpy.right_shift

NtuplesUFuncs.rint
NtuplesUFuncs.**rint**(*out=None*)
Round elements of the array to the nearest integer.

See also:

numpy.rint

NtuplesUFuncs.sign
NtuplesUFuncs.**sign**(*out=None*)
Returns an element-wise indication of the sign of a number.

See also:

numpy.sign

NtuplesUFuncs.signbit
NtuplesUFuncs.**signbit**(*out=None*)
Returns element-wise True where signbit is set (less than zero).

See also:

numpy.signbit

NtuplesUFuncs.sin
NtuplesUFuncs.**sin**(*out=None*)
Trigonometric sine, element-wise.

See also:

numpy.sin

NtuplesUFuncs.sinh
NtuplesUFuncs.**sinh**(*out=None*)
Hyperbolic sine, element-wise.

See also:

numpy.sinh

NtuplesUFuncs.sqrt
NtuplesUFuncs.**sqrt**(*out=None*)
Return the positive square-root of an array, element-wise.

See also:

numpy.sqrt

NtuplesUFuncs.square
NtuplesUFuncs.**square**(*out=None*)
Return the element-wise square of the input.

See also:

numpy.square

NtuplesUFuncs.subtract
NtuplesUFuncs.**subtract**(*x2*, *out=None*)
Subtract arguments, element-wise.

See also:

numpy.subtract

NtuplesUFuncs.sum
NtuplesUFuncs.**sum**()
Sum of array elements.

See also:

numpy.sum

NtuplesUFuncs.tan
NtuplesUFuncs.**tan**(*out=None*)
Compute tangent element-wise.

See also:

numpy.tan

NtuplesUFuncs.tanh
NtuplesUFuncs.**tanh**(*out=None*)
Compute hyperbolic tangent element-wise.

See also:

numpy.tanh

NtuplesUFuncs.true_divide
NtuplesUFuncs.**true_divide**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

numpy.true_divide

NtuplesUFuncs.trunc
NtuplesUFuncs.**trunc**(*out=None*)
Return the truncated value of the input, element-wise.

See also:

numpy.trunc
__init__(*vector*)
Create ufunc wrapper for vector.

ProductSpaceUFuncs

class odl.util.ufuncs.**ProductSpaceUFuncs**(*vector*)

Bases: object

UFuncs for *ProductSpaceVector* objects.

Internal object, should not be created except in *ProductSpaceVector*.

Methods

__eq__	Return self==value.
absolute([out])	Calculate the absolute value element-wise.
add(x2[, out])	Add arguments element-wise.
arccos([out])	Trigonometric inverse cosine, element-wise.
arccosh([out])	Inverse hyperbolic cosine, element-wise.
arcsin([out])	Inverse sine, element-wise.
arcsinh([out])	Inverse hyperbolic sine element-wise.
arctan([out])	Trigonometric inverse tangent, element-wise.
arctan2(x2[, out])	Element-wise arc tangent of x1/x2 choosing the quadrant correctly.
arctanh([out])	Inverse hyperbolic tangent element-wise.
bitwise_and(x2[, out])	Compute the bit-wise AND of two arrays element-wise.
bitwise_or(x2[, out])	Compute the bit-wise OR of two arrays element-wise.
bitwise_xor(x2[, out])	Compute the bit-wise XOR of two arrays element-wise.
ceil([out])	Return the ceiling of the input, element-wise.
conj([out])	Return the complex conjugate, element-wise.
copysign(x2[, out])	Change the sign of x1 to that of x2, element-wise.
cos([out])	Cosine element-wise.
cosh([out])	Hyperbolic cosine, element-wise.
deg2rad([out])	Convert angles from degrees to radians.
divide(x2[, out])	Returns a true division of the inputs, element-wise.
equal(x2[, out])	Return (x1 == x2) element-wise.
exp([out])	Calculate the exponential of all elements in the input array.
exp2([out])	Calculate 2**p for all p in the input array.
expm1([out])	Calculate exp(x) - 1 for all elements in the array.
floor([out])	Return the floor of the input, element-wise.
floor_divide(x2[, out])	Return the largest integer smaller or equal to the division of the
fmax(x2[, out])	Element-wise maximum of array elements.
fmin(x2[, out])	Element-wise minimum of array elements.
fmod(x2[, out])	Return the element-wise remainder of division.
greater(x2[, out])	Return the truth value of (x1 > x2) element-wise.
greater_equal(x2[, out])	Return the truth value of (x1 >= x2) element-wise.
hypot(x2[, out])	Given the "legs" of a right triangle, return its hypotenuse.
invert([out])	Compute bit-wise inversion, or bit-wise NOT, element-wise.
isfinite([out])	Test element-wise for finiteness (not infinity or not Not a Number).
isinf([out])	Test element-wise for positive or negative infinity.
isnan([out])	Test element-wise for NaN and return result as a boolean array.
left_shift(x2[, out])	Shift the bits of an integer to the left.
less(x2[, out])	Return the truth value of (x1 < x2) element-wise.
less_equal(x2[, out])	Return the truth value of (x1 =< x2) element-wise.
log([out])	Natural logarithm, element-wise.

Continued on next page

Table 8.306 – continued from previous page

log10([out])	Return the base 10 logarithm of the input array, element-wise.
log1p([out])	Return the natural logarithm of one plus the input array, element-wise.
log2([out])	Base-2 logarithm of x.
logaddexp(x2[, out])	Logarithm of the sum of exponentiations of the inputs.
logaddexp2(x2[, out])	Logarithm of the sum of exponentiations of the inputs in base-2.
logical_and(x2[, out])	Compute the truth value of x1 AND x2 element-wise.
logical_not([out])	Compute the truth value of NOT x element-wise.
logical_or(x2[, out])	Compute the truth value of x1 OR x2 element-wise.
logical_xor(x2[, out])	Compute the truth value of x1 XOR x2, element-wise.
max()	Maximum value in array.
maximum(x2[, out])	Element-wise maximum of array elements.
min()	Minimum value in array.
minimum(x2[, out])	Element-wise minimum of array elements.
mod(x2[, out])	Return element-wise remainder of division.
modf([out1, out2])	Return the fractional and integral parts of an array, element-wise.
multiply(x2[, out])	Multiply arguments element-wise.
negative([out])	Numerical negative, element-wise.
not_equal(x2[, out])	Return (x1 != x2) element-wise.
power(x2[, out])	First array elements raised to powers from second array, element-wise.
prod()	Product of array elements.
rad2deg([out])	Convert angles from radians to degrees.
reciprocal([out])	Return the reciprocal of the argument, element-wise.
remainder(x2[, out])	Return element-wise remainder of division.
right_shift(x2[, out])	Shift the bits of an integer to the right.
rint([out])	Round elements of the array to the nearest integer.
sign([out])	Returns an element-wise indication of the sign of a number.
signbit([out])	Returns element-wise True where signbit is set (less than zero).
sin([out])	Trigonometric sine, element-wise.
sinh([out])	Hyperbolic sine, element-wise.
sqrt([out])	Return the positive square-root of an array, element-wise.
square([out])	Return the element-wise square of the input.
subtract(x2[, out])	Subtract arguments, element-wise.
sum()	Sum of array elements.
tan([out])	Compute tangent element-wise.
tanh([out])	Compute hyperbolic tangent element-wise.
true_divide(x2[, out])	Returns a true division of the inputs, element-wise.
trunc([out])	Return the truncated value of the input, element-wise.

ProductSpaceUFuncs.absolute

ProductSpaceUFuncs.**absolute**(*out=None*)

Calculate the absolute value element-wise.

See also:

numpy.absolute

ProductSpaceUFuncs.add

ProductSpaceUFuncs.**add**(*x2*, *out=None*)

Add arguments element-wise.

See also:

numpy.add

ProductSpaceUFuncs.arccos
`ProductSpaceUFuncs.`**`arccos`**(*out=None*)
Trigonometric inverse cosine, element-wise.

See also:

`numpy.arccos`

ProductSpaceUFuncs.arccosh
`ProductSpaceUFuncs.`**`arccosh`**(*out=None*)
Inverse hyperbolic cosine, element-wise.

See also:

`numpy.arccosh`

ProductSpaceUFuncs.arcsin
`ProductSpaceUFuncs.`**`arcsin`**(*out=None*)
Inverse sine, element-wise.

See also:

`numpy.arcsin`

ProductSpaceUFuncs.arcsinh
`ProductSpaceUFuncs.`**`arcsinh`**(*out=None*)
Inverse hyperbolic sine element-wise.

See also:

`numpy.arcsinh`

ProductSpaceUFuncs.arctan
`ProductSpaceUFuncs.`**`arctan`**(*out=None*)
Trigonometric inverse tangent, element-wise.

See also:

`numpy.arctan`

ProductSpaceUFuncs.arctan2
`ProductSpaceUFuncs.`**`arctan2`**(*x2*, *out=None*)
Element-wise arc tangent of `x1/x2` choosing the quadrant correctly.

See also:

`numpy.arctan2`

ProductSpaceUFuncs.arctanh
`ProductSpaceUFuncs.`**`arctanh`**(*out=None*)
Inverse hyperbolic tangent element-wise.

See also:

`numpy.arctanh`

ProductSpaceUFuncs.bitwise_and
`ProductSpaceUFuncs.`**`bitwise_and`**(*x2*, *out=None*)
Compute the bit-wise AND of two arrays element-wise.

See also:

`numpy.bitwise_and`

ProductSpaceUFuncs.bitwise_or
`ProductSpaceUFuncs.`**`bitwise_or`**(*x2*, *out=None*)
Compute the bit-wise OR of two arrays element-wise.

See also:

`numpy.bitwise_or`

ProductSpaceUFuncs.bitwise_xor
`ProductSpaceUFuncs.`**`bitwise_xor`**(*x2*, *out=None*)
Compute the bit-wise XOR of two arrays element-wise.

See also:

`numpy.bitwise_xor`

ProductSpaceUFuncs.ceil
`ProductSpaceUFuncs.`**`ceil`**(*out=None*)
Return the ceiling of the input, element-wise.

See also:

`numpy.ceil`

ProductSpaceUFuncs.conj
`ProductSpaceUFuncs.`**`conj`**(*out=None*)
Return the complex conjugate, element-wise.

See also:

`numpy.conj`

ProductSpaceUFuncs.copysign
`ProductSpaceUFuncs.`**`copysign`**(*x2*, *out=None*)
Change the sign of x1 to that of x2, element-wise.

See also:

`numpy.copysign`

ProductSpaceUFuncs.cos
`ProductSpaceUFuncs.`**`cos`**(*out=None*)
Cosine element-wise.

See also:

`numpy.cos`

ProductSpaceUFuncs.cosh
`ProductSpaceUFuncs.`**`cosh`**(*out=None*)
Hyperbolic cosine, element-wise.

See also:

`numpy.cosh`

ProductSpaceUFuncs.deg2rad
`ProductSpaceUFuncs.`**`deg2rad`**(*out=None*)
Convert angles from degrees to radians.

See also:

`numpy.deg2rad`

ProductSpaceUFuncs.divide
`ProductSpaceUFuncs.`**`divide`**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

`numpy.divide`

ProductSpaceUFuncs.equal
`ProductSpaceUFuncs.`**`equal`**(*x2*, *out=None*)
Return (x1 == x2) element-wise.

See also:

`numpy.equal`

ProductSpaceUFuncs.exp
`ProductSpaceUFuncs.`**`exp`**(*out=None*)
Calculate the exponential of all elements in the input array.

See also:

`numpy.exp`

ProductSpaceUFuncs.exp2
`ProductSpaceUFuncs.`**`exp2`**(*out=None*)
Calculate `2**p` for all `p` in the input array.

See also:

`numpy.exp2`

ProductSpaceUFuncs.expm1
`ProductSpaceUFuncs.`**`expm1`**(*out=None*)
Calculate `exp(x) - 1` for all elements in the array.

See also:

`numpy.expm1`

ProductSpaceUFuncs.floor
`ProductSpaceUFuncs.`**`floor`**(*out=None*)
Return the floor of the input, element-wise.

See also:

`numpy.floor`

ProductSpaceUFuncs.floor_divide
`ProductSpaceUFuncs.`**`floor_divide`**(*x2*, *out=None*)
Return the largest integer smaller or equal to the division of the

See also:

`numpy.floor_divide`

ProductSpaceUFuncs.fmax
`ProductSpaceUFuncs.`**`fmax`**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

`numpy.fmax`

ProductSpaceUFuncs.fmin
`ProductSpaceUFuncs.`**`fmin`**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

`numpy.fmin`

ProductSpaceUFuncs.fmod
`ProductSpaceUFuncs.`**`fmod`**(*x2*, *out=None*)
Return the element-wise remainder of division.

See also:

`numpy.fmod`

ProductSpaceUFuncs.greater
`ProductSpaceUFuncs.`**`greater`**(*x2*, *out=None*)
Return the truth value of (x1 > x2) element-wise.

See also:

`numpy.greater`

ProductSpaceUFuncs.greater_equal
`ProductSpaceUFuncs.`**`greater_equal`**(*x2*, *out=None*)
Return the truth value of (x1 >= x2) element-wise.

See also:

`numpy.greater_equal`

ProductSpaceUFuncs.hypot
`ProductSpaceUFuncs.`**`hypot`**(*x2*, *out=None*)
Given the "legs" of a right triangle, return its hypotenuse.

See also:

`numpy.hypot`

ProductSpaceUFuncs.invert
`ProductSpaceUFuncs.`**`invert`**(*out=None*)
Compute bit-wise inversion, or bit-wise NOT, element-wise.

See also:

`numpy.invert`

ProductSpaceUFuncs.isfinite
`ProductSpaceUFuncs.`**`isfinite`**(*out=None*)
Test element-wise for finiteness (not infinity or not Not a Number).

See also:

`numpy.isfinite`

ProductSpaceUFuncs.isinf
`ProductSpaceUFuncs.`**`isinf`**(*out=None*)
Test element-wise for positive or negative infinity.

See also:

`numpy.isinf`

ProductSpaceUFuncs.isnan
`ProductSpaceUFuncs.`**`isnan`**(*out=None*)
Test element-wise for NaN and return result as a boolean array.

See also:

`numpy.isnan`

ProductSpaceUFuncs.left_shift
`ProductSpaceUFuncs.`**`left_shift`**(*x2*, *out=None*)
Shift the bits of an integer to the left.

See also:

`numpy.left_shift`

ProductSpaceUFuncs.less
`ProductSpaceUFuncs.`**`less`**(*x2*, *out=None*)
Return the truth value of (x1 < x2) element-wise.

See also:

`numpy.less`

ProductSpaceUFuncs.less_equal
`ProductSpaceUFuncs.`**`less_equal`**(*x2*, *out=None*)
Return the truth value of (x1 =< x2) element-wise.

See also:

`numpy.less_equal`

ProductSpaceUFuncs.log
`ProductSpaceUFuncs.`**`log`**(*out=None*)
Natural logarithm, element-wise.

See also:

`numpy.log`

ProductSpaceUFuncs.log10
`ProductSpaceUFuncs.`**`log10`**(*out=None*)
Return the base 10 logarithm of the input array, element-wise.

See also:

`numpy.log10`

ProductSpaceUFuncs.log1p
`ProductSpaceUFuncs.`**`log1p`**(*out=None*)
Return the natural logarithm of one plus the input array, element-wise.

See also:

`numpy.log1p`

ProductSpaceUFuncs.log2
`ProductSpaceUFuncs.`**`log2`**(*out=None*)
Base-2 logarithm of `x`.

See also:

`numpy.log2`

ProductSpaceUFuncs.logaddexp
`ProductSpaceUFuncs.`**`logaddexp`**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs.

See also:

`numpy.logaddexp`

ProductSpaceUFuncs.logaddexp2
`ProductSpaceUFuncs.`**`logaddexp2`**(*x2*, *out=None*)
Logarithm of the sum of exponentiations of the inputs in base-2.

See also:

`numpy.logaddexp2`

ProductSpaceUFuncs.logical_and
`ProductSpaceUFuncs.`**`logical_and`**(*x2*, *out=None*)
Compute the truth value of x1 AND x2 element-wise.

See also:

`numpy.logical_and`

ProductSpaceUFuncs.logical_not
`ProductSpaceUFuncs.`**`logical_not`**(*out=None*)
Compute the truth value of NOT x element-wise.

See also:

`numpy.logical_not`

ProductSpaceUFuncs.logical_or
`ProductSpaceUFuncs.`**`logical_or`**(*x2*, *out=None*)
Compute the truth value of x1 OR x2 element-wise.

See also:

`numpy.logical_or`

ProductSpaceUFuncs.logical_xor
`ProductSpaceUFuncs.`**`logical_xor`**(*x2*, *out=None*)
Compute the truth value of x1 XOR x2, element-wise.

See also:

`numpy.logical_xor`

ProductSpaceUFuncs.max
`ProductSpaceUFuncs.`**`max`**()
Maximum value in array.

See also:

`numpy.amax`

ProductSpaceUFuncs.maximum
`ProductSpaceUFuncs.`**`maximum`**(*x2*, *out=None*)
Element-wise maximum of array elements.

See also:

`numpy.maximum`

ProductSpaceUFuncs.min
`ProductSpaceUFuncs.`**`min`**()
Minimum value in array.

See also:

`numpy.amin`

ProductSpaceUFuncs.minimum
`ProductSpaceUFuncs.`**`minimum`**(*x2*, *out=None*)
Element-wise minimum of array elements.

See also:

`numpy.minimum`

ProductSpaceUFuncs.mod
`ProductSpaceUFuncs.`**`mod`**(*x2*, *out=None*)
Return element-wise remainder of division.

See also:

`numpy.mod`

ProductSpaceUFuncs.modf
`ProductSpaceUFuncs.`**`modf`**(*out1=None*, *out2=None*)
Return the fractional and integral parts of an array, element-wise.

See also:

`numpy.modf`

ProductSpaceUFuncs.multiply
`ProductSpaceUFuncs.`**`multiply`**(*x2*, *out=None*)
Multiply arguments element-wise.

See also:

`numpy.multiply`

ProductSpaceUFuncs.negative
`ProductSpaceUFuncs.`**`negative`**(*out=None*)
Numerical negative, element-wise.

See also:

`numpy.negative`

ProductSpaceUFuncs.not_equal
`ProductSpaceUFuncs.`**`not_equal`**(*x2*, *out=None*)
Return (x1 != x2) element-wise.

See also:

`numpy.not_equal`

ProductSpaceUFuncs.power
`ProductSpaceUFuncs.`**`power`**(*x2*, *out=None*)
First array elements raised to powers from second array, element-wise.

See also:

`numpy.power`

ProductSpaceUFuncs.prod
`ProductSpaceUFuncs.`**`prod`**`()`
Product of array elements.

See also:

`numpy.prod`

ProductSpaceUFuncs.rad2deg
`ProductSpaceUFuncs.`**`rad2deg`**`(`*out=None*`)`
Convert angles from radians to degrees.

See also:

`numpy.rad2deg`

ProductSpaceUFuncs.reciprocal
`ProductSpaceUFuncs.`**`reciprocal`**`(`*out=None*`)`
Return the reciprocal of the argument, element-wise.

See also:

`numpy.reciprocal`

ProductSpaceUFuncs.remainder
`ProductSpaceUFuncs.`**`remainder`**`(`*x2*, *out=None*`)`
Return element-wise remainder of division.

See also:

`numpy.remainder`

ProductSpaceUFuncs.right_shift
`ProductSpaceUFuncs.`**`right_shift`**`(`*x2*, *out=None*`)`
Shift the bits of an integer to the right.

See also:

`numpy.right_shift`

ProductSpaceUFuncs.rint
`ProductSpaceUFuncs.`**`rint`**`(`*out=None*`)`
Round elements of the array to the nearest integer.

See also:

`numpy.rint`

ProductSpaceUFuncs.sign
`ProductSpaceUFuncs.`**`sign`**`(`*out=None*`)`
Returns an element-wise indication of the sign of a number.

See also:

`numpy.sign`

ProductSpaceUFuncs.signbit
`ProductSpaceUFuncs.`**`signbit`**(*out=None*)
Returns element-wise True where signbit is set (less than zero).

See also:

`numpy.signbit`

ProductSpaceUFuncs.sin
`ProductSpaceUFuncs.`**`sin`**(*out=None*)
Trigonometric sine, element-wise.

See also:

`numpy.sin`

ProductSpaceUFuncs.sinh
`ProductSpaceUFuncs.`**`sinh`**(*out=None*)
Hyperbolic sine, element-wise.

See also:

`numpy.sinh`

ProductSpaceUFuncs.sqrt
`ProductSpaceUFuncs.`**`sqrt`**(*out=None*)
Return the positive square-root of an array, element-wise.

See also:

`numpy.sqrt`

ProductSpaceUFuncs.square
`ProductSpaceUFuncs.`**`square`**(*out=None*)
Return the element-wise square of the input.

See also:

`numpy.square`

ProductSpaceUFuncs.subtract
`ProductSpaceUFuncs.`**`subtract`**(*x2*, *out=None*)
Subtract arguments, element-wise.

See also:

`numpy.subtract`

ProductSpaceUFuncs.sum
`ProductSpaceUFuncs.`**`sum`**()
Sum of array elements.

See also:

`numpy.sum`

ProductSpaceUFuncs.tan
`ProductSpaceUFuncs.`**`tan`**(*out=None*)
Compute tangent element-wise.

See also:

`numpy.tan`

ProductSpaceUFuncs.tanh
`ProductSpaceUFuncs.`**`tanh`**(*out=None*)
Compute hyperbolic tangent element-wise.

See also:

`numpy.tanh`

ProductSpaceUFuncs.true_divide
`ProductSpaceUFuncs.`**`true_divide`**(*x2*, *out=None*)
Returns a true division of the inputs, element-wise.

See also:

`numpy.true_divide`

ProductSpaceUFuncs.trunc
`ProductSpaceUFuncs.`**`trunc`**(*out=None*)
Return the truncated value of the input, element-wise.

See also:

`numpy.trunc`

`__init__`(*vector*)
Create ufunc wrapper for vector.

Functions

method(self)	Maximum value in array.
wrap_reduction_base(name, doc)	Add ufunc methods to *NtuplesBaseUFuncs*.
wrap_reduction_discretelp(name, doc)	
wrap_reduction_productspace(name, doc)	Add reduction methods to *ProductSpaceVector*.
wrap_ufunc_base(name, n_in, n_out, doc)	Add ufunc methods to *NtuplesBaseUFuncs*.
wrap_ufunc_discretelp(name, n_in, n_out, doc)	Add ufunc methods to *DiscreteLpUFuncs*.
wrap_ufunc_ntuples(name, n_in, n_out, doc)	Add ufunc methods to *NtuplesUFuncs*.
wrap_ufunc_productspace(name, n_in, n_out, doc)	Add ufunc methods to *ProductSpaceVector*.

method

`odl.util.ufuncs.`**`method`**(*self*)
Maximum value in array.

See also:

`numpy.amax`

wrap_reduction_base

odl.util.ufuncs.**wrap_reduction_base**(*name*, *doc*)
Add ufunc methods to *NtuplesBaseUFuncs*.

wrap_reduction_discretelp

odl.util.ufuncs.**wrap_reduction_discretelp**(*name*, *doc*)

wrap_reduction_productspace

odl.util.ufuncs.**wrap_reduction_productspace**(*name*, *doc*)
Add reduction methods to *ProductSpaceVector*.

wrap_ufunc_base

odl.util.ufuncs.**wrap_ufunc_base**(*name*, *n_in*, *n_out*, *doc*)
Add ufunc methods to *NtuplesBaseUFuncs*.

wrap_ufunc_discretelp

odl.util.ufuncs.**wrap_ufunc_discretelp**(*name*, *n_in*, *n_out*, *doc*)
Add ufunc methods to *DiscreteLpUFuncs*.

wrap_ufunc_ntuples

odl.util.ufuncs.**wrap_ufunc_ntuples**(*name*, *n_in*, *n_out*, *doc*)
Add ufunc methods to *NtuplesUFuncs*.

wrap_ufunc_productspace

odl.util.ufuncs.**wrap_ufunc_productspace**(*name*, *n_in*, *n_out*, *doc*)
Add ufunc methods to *ProductSpaceVector*.

8.9.6 utility

Utilities for internal use.

Functions

array1d_repr(array[, nprint])	Stringification of a 1D array, keeping byte / unicode.
array1d_str(array[, nprint])	Stringification of a 1D array, regardless of byte or unicode.
arraynd_repr(array[, nprint])	Stringification of an nD array, keeping byte / unicode.
arraynd_str(array[, nprint])	Stringification of an nD array, regardless of byte or unicode.

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Table 8.308 – continued from previous page

conj_exponent(exp)	The conjugate exponent p / (p-1).
dtype_repr(dtype)	Stringification of data type with default for `int` and `float`.
is_complex_floating_dtype(dtype)	`True` if `dtype` is complex floating-point, else `False`.
is_floating_dtype(dtype)	`True` if `dtype` is floating-point, else `False`.
is_int_dtype(dtype)	`True` if `dtype` is integer, else `False`.
is_real_dtype(dtype)	`True` if `dtype` is real (including integer), else `False`.
is_real_floating_dtype(dtype)	`True` if `dtype` is real floating-point, else `False`.
is_scalar_dtype(dtype)	`True` if `dtype` is scalar, else `False`.
preload_first_arg(instance, mode)	Decorator to preload the first argument of a call method.
with_metaclass(meta, *bases)	Function from jinja2/_compat.py.

array1d_repr

odl.util.utility.**array1d_repr**(*array*, *nprint=6*)
Stringification of a 1D array, keeping byte / unicode.

Parametersarray : array-like

The array to print

nprint : int

Maximum number of elements to print

array1d_str

odl.util.utility.**array1d_str**(*array*, *nprint=6*)
Stringification of a 1D array, regardless of byte or unicode.

Parametersarray : array-like

The array to print

nprint : int

Maximum number of elements to print

arraynd_repr

odl.util.utility.**arraynd_repr**(*array*, *nprint=None*)
Stringification of an nD array, keeping byte / unicode.

Parametersarray : array-like

The array to print

nprint : int

Maximum number of elements to print. Default: 6 if array.ndim <= 2, else 2

Examples

```
>>> print(arraynd_repr([[1, 2, 3], [4, 5, 6]]))
[[1, 2, 3],
 [4, 5, 6]]
>>> print(arraynd_repr([[1, 2, 3], [4, 5, 6], [7, 8, 9]]))
[[1, 2, 3],
 [4, 5, 6],
 [7, 8, 9]]
```

arraynd_str

odl.util.utility.**arraynd_str**(*array*, *nprint=None*)
Stringification of an nD array, regardless of byte or unicode.

Parametersarray : *array-like*

The array to print

nprint : int

Maximum number of elements to print. Default: 6 if array.ndim <= 2, else 2

Examples

```
>>> print(arraynd_str([[1, 2, 3], [4, 5, 6]]))
[[1, 2, 3],
 [4, 5, 6]]
>>> print(arraynd_str([[1, 2, 3], [4, 5, 6], [7, 8, 9]]))
[[1, 2, 3],
 [4, 5, 6],
 [7, 8, 9]]
```

conj_exponent

odl.util.utility.**conj_exponent**(*exp*)
The conjugate exponent p / (p-1).

Parametersexp : positive `float` or inf

Exponent for which to calculate the conjugate. Must be at least 1.0.

Returnsconj : positive `float` or inf

Conjugate exponent. For `exp=1`, return `float('inf')`, for `exp=float('inf')` return 1. In all other cases, return `exp / (exp - 1)`.

dtype_repr

odl.util.utility.**dtype_repr**(*dtype*)
Stringification of data type with default for `int` and `float`.

is_complex_floating_dtype

odl.util.utility.**is_complex_floating_dtype**(*dtype*)
`True` if `dtype` is complex floating-point, else `False`.

is_floating_dtype

odl.util.utility.**is_floating_dtype**(*dtype*)
`True` if `dtype` is floating-point, else `False`.

is_int_dtype

odl.util.utility.**is_int_dtype**(*dtype*)
`True` if `dtype` is integer, else `False`.

is_real_dtype

odl.util.utility.**is_real_dtype**(*dtype*)
`True` if `dtype` is real (including integer), else `False`.

is_real_floating_dtype

odl.util.utility.**is_real_floating_dtype**(*dtype*)
`True` if `dtype` is real floating-point, else `False`.

is_scalar_dtype

odl.util.utility.**is_scalar_dtype**(*dtype*)
`True` if `dtype` is scalar, else `False`.

preload_first_arg

odl.util.utility.**preload_first_arg**(*instance*, *mode*)
Decorator to preload the first argument of a call method.

Parametersinstance :

Class instance to preload the call with

mode : {'out-of-place', 'in-place'}

'out-of-place': call is out-of-place – `f(x, **kwargs)`

'in-place': call is in-place – `f(x, out, **kwargs)`

Notes

The decorated function has the signature according to `mode`.

Examples

Define two functions which need some instance to act on and decorate them manually:

```
>>> class A(object):
...     '''My name is A.'''
>>> a = A()
...
>>> def f_oop(inst, x):
...     print(inst.__doc__)
...
>>> def f_ip(inst, out, x):
...     print(inst.__doc__)
...
>>> f_oop_new = preload_first_arg(a, 'out-of-place')(f_oop)
>>> f_ip_new = preload_first_arg(a, 'in-place')(f_ip)
...
>>> f_oop_new(0)
My name is A.
>>> f_ip_new(0, out=1)
My name is A.
```

Decorate upon definition:

```
>>> @preload_first_arg(a, 'out-of-place')
... def set_x(obj, x):
...     '''Function to set x in ``obj`` to a given value.'''
...     obj.x = x
>>> set_x(0)
>>> a.x
0
```

The function's name and docstring are preserved:

```
>>> set_x.__name__
'set_x'
>>> set_x.__doc__
'Function to set x in ``obj`` to a given value.'
```

with_metaclass

odl.util.utility.**with_metaclass**(*meta*, **bases*)

Function from jinja2/_compat.py. License: BSD.

Use it like this:

```
class BaseForm(object):
    pass

class FormType(type):
    pass

class Form(with_metaclass(FormType, BaseForm)):
    pass
```

This requires a bit of explanation: the basic idea is to make a dummy metaclass for one level of class instantiation that replaces itself with the actual metaclass. Because of internal type checks we also need to make sure that we downgrade the custom metaclass for one level to something closer to type (that's why __call__ and __init__ comes back from type etc.).

This has the advantage over six.with_metaclass of not introducing dummy classes into the final MRO.

8.9.7 vectorization

Utilities for internal functionality connected to vectorization.

Classes

OptionalArgDecorator	Abstract class to create decorators with optional arguments.
vectorize	Decorator class for function vectorization.

OptionalArgDecorator

class odl.util.vectorization.**OptionalArgDecorator**

Bases: object

Abstract class to create decorators with optional arguments.

This class implements the functionality of a decorator that can be used with and without arguments, i.e. the following patterns both work:

```
@decorator
def myfunc(x, *args, **kwargs):
    pass

@decorator(param, **dec_kwargs)
def myfunc(x, *args, **kwargs):
    pass
```

The arguments to the decorator are passed on to the underlying wrapper.

To use this class, subclass it and implement the static `_wrapper` method.

Methods

__call__(func)	Return `self(func)`.
__eq__	Return self==value.

OptionalArgDecorator.__call__

OptionalArgDecorator.**__call__**(*func*)

Return `self(func)`.

This method is invoked when the decorator was created with arguments.

Parametersfunc : callable

Original function to be wrapped

Returnswrapped : callable

The wrapped function

vectorize

class odl.util.vectorization.**vectorize**
Bases: *odl.util.vectorization.OptionalArgDecorator*

Decorator class for function vectorization.

This vectorizer expects a function with exactly one positional argument (input) and optional keyword arguments. The decorated function has an optional `out` parameter for in-place evaluation.

Examples

Use the decorator witout arguments:

```
>>> @vectorize
... def f(x):
...     return x[0] + x[1] if x[0] < x[1] else x[0] - x[1]
>>>
>>> f([0, 1])  # np.vectorize'd functions always return an array
array(1)
>>> f([[0, -2], [1, 4]])  # corresponds to points [0, 1], [-2, 4]
array([1, 2])
```

The function may have `kwargs`:

```
>>> @vectorize
... def f(x, param=1.0):
...     return x[0] + x[1] if x[0] < param else x[0] - x[1]
>>>
>>> f([[0, -2], [1, 4]])
array([1, 2])
>>> f([[0, -2], [1, 4]], param=-1.0)
array([-1,  2])
```

You can pass arguments to the vectorizer, too:

```
>>> @vectorize(otypes=['float32'])
... def f(x):
...     return x[0] + x[1] if x[0] < x[1] else x[0] - x[1]
>>> f([[0, -2], [1, 4]])
array([ 1.,  2.], dtype=float32)
```

Methods

__call__(func)	Return `self(func)`.
__eq__	Return self==value.

vectorize.__call__

vectorize.**__call__**(*func*)
Return `self(func)`.

This method is invoked when the decorator was created with arguments.

Parametersfunc : `callable`

Original function to be wrapped

Returnswrapped : `callable`

The wrapped function

Functions

is_valid_input_array(x[, ndim])	Test if `x` is a correctly shaped point array in R^d.
is_valid_input_meshgrid(x, ndim)	Test if `x` is a *meshgrid* sequence for points in R^d.
out_shape_from_array(arr)	Get the output shape from an array.
out_shape_from_meshgrid(mesh)	Get the broadcast output shape from a *meshgrid*.

is_valid_input_array

odl.util.vectorization.**is_valid_input_array**(*x*, *ndim=None*)

Test if `x` is a correctly shaped point array in R^d.

is_valid_input_meshgrid

odl.util.vectorization.**is_valid_input_meshgrid**(*x*, *ndim*)

Test if `x` is a *meshgrid* sequence for points in R^d.

out_shape_from_array

odl.util.vectorization.**out_shape_from_array**(*arr*)

Get the output shape from an array.

out_shape_from_meshgrid

odl.util.vectorization.**out_shape_from_meshgrid**(*mesh*)

Get the broadcast output shape from a *meshgrid*.

CHAPTER 9

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