



Documentation

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Deepansh J. Srivastava

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About

The `csdmpy` package is the Python support for the core scientific dataset (CSD) model file exchange-format¹. The package is based on the core scientific dataset (CSD) model, which is designed as a building block in the development of a more sophisticated portable scientific dataset file standard. The CSD model is capable of handling a wide variety of scientific datasets both within and across disciplinary fields.

The main objective of this python package is to facilitate an easy import and export of the CSD model serialized files for Python users. The package utilizes Numpy library and, therefore, offers the end-users versatility to process or visualize the imported datasets with any third-party package(s) compatible with Numpy.

View the core scientific dataset model (CSDM) [examples gallery](#).

[Tutorial](#) on generating and serializing CSDM objects from Numpy arrays

¹ Srivastava D.J., Vosegaard T., Massiot D., Grandinetti P.J. (2020) Core Scientific Dataset Model: A lightweight and portable model and file format for multi-dimensional scientific data. *PLOS ONE* 15(1): e0225953.

INTRODUCTION TO CSDM FORMAT

The core scientific dataset (CSD) model is a *light-weight, portable, versatile, and standalone* data model capable of handling a variety of scientific datasets. The model only encapsulates data values and the minimum metadata to accurately represent a p -component dependent variable, $(\mathbf{U}_0, \dots, \mathbf{U}_q, \dots, \mathbf{U}_{p-1})$, discretely sampled at M unique points in a d -dimensional coordinate space, $(\mathbf{X}_0, \mathbf{X}_1, \dots, \mathbf{X}_k, \dots, \mathbf{X}_{d-1})$. The model is not intended to encapsulate any information on how the data might be acquired, processed, or visualized.

The data model is *versatile* in allowing many use cases for most spectroscopy, diffraction, and imaging techniques. As such the model supports multi-component datasets associated with continuous physical quantities that are discretely sampled in a multi-dimensional space associated with other carefully controlled quantities, for e.g., a mass as a function of temperature, a current as a function of voltage and time, a signal voltage as a function of magnetic field gradient strength, a color image with a red, green, and blue (RGB) light intensity components as a function of two independent spatial dimensions, or the six components of the symmetric second-rank diffusion tensor MRI as a function of three independent spatial dimensions. Additionally, the model supports multiple dependent variables sharing the same d -dimensional coordinate space. For example, a simultaneous measurement of current and voltage as a function of time, simultaneous acquisition of air temperature, pressure, wind velocity, and solar-flux as a function of Earth's latitude and longitude coordinates. We refer to these dependent variables as *correlated-datasets*.

The CSD model is independent of the hardware, operating system, application software, programming language, and the object-oriented file-serialization format utilized in serializing the CSD model to the file. Out of numerous file serialization formats, XML, JSON, property list, we chose the data-exchange oriented JSON (JavaScript Object Notation) file-serialization format because it is *human-readable* and *easily integrable* with any number of programming languages and field related application-software.

1.1 CSDM

1.1.1 Description

The root level object of the CSD model.

1.1.2 Attributes

Name	Type	Description
version	String	A <i>required</i> version number of CSDM file-exchange format.
dimensions	<i>[Dimension, ...]</i>	A <i>required</i> ordered and unique array of dimension objects. An empty array is a valid value.
dependent_variables	<i>[DependentVariable, ...]</i>	A <i>required</i> array of dependent-variable objects. An empty array is a valid value.
tags	[String, ...]	An <i>optional</i> list of keywords associated with the dataset.
read_only	Boolean	An <i>optional</i> value with default as False. If true, the serialized file is archived.
timestamp	String	An <i>optional</i> UTC ISO-8601 format timestamp from when the CSDM-compliant file was last serialized.
geographic_coordinate	geographic_coordinate	An <i>optional</i> object with attributes required to describe the location from where the CSDM-compliant file was last serialized.
description	String	An <i>optional</i> description of the datasets in the CSD model.
application	Generic	An <i>optional</i> generic dictionary object containing application specific metadata describing the CSDM object.

1.2 Dimension

A generalized object describing a dimension of a multi-dimensional grid/space.

1.2.1 Attributes

Name	Type	Description
type	<i>DimObjectSubtype</i>	A <i>required</i> enumeration literal with a valid dimension subtype.
label	String	An <i>optional</i> label of the dimension.
description	String	An <i>optional</i> description of the dimension.
application	Generic	An <i>optional</i> generic dictionary object containing application specific metadata describing the dimension.

1.2.2 Specialized Class

LinearDimension

Description

A LinearDimension is where the coordinates along the dimension follow a linear relationship with the indexes, \mathbf{J}_k , along the dimension. Let Δx_k be the *increment*, $N_k \geq 1$, the number of points (*counts*), b_k , the *coordinates offset*, and o_k , the *origin offset* along the k^{th} dimension, then the corresponding coordinates along the dimension, \mathbf{X}_k , are given as

$$\mathbf{X}_k = \Delta x_k (\mathbf{J}_k - Z_k) + b_k \mathbf{1}, \quad (1.1)$$

and the absolute coordinates as,

$$\mathbf{X}_k^{\text{abs}} = \mathbf{X}_k + o_k \mathbf{1}. \quad (1.2)$$

Here, $\mathbf{1}$ is an array of ones, and \mathbf{J}_k is the array of indexes along the k^{th} dimension given as

$$\mathbf{J}_k = [0, 1, 2, 3, \dots, N_k - 1]. \quad (1.3)$$

The term, Z_k , is an integer with a value of $Z_k = 0$ or $\frac{T_k}{2}$ when the value of `complex_fft` attribute of the corresponding dimension object is false or true, respectively. Here, $T_k = N_k$ and $N_k - 1$ for even and odd value of N_k , respectively.

Note: When the value of the `complex_fft` attribute is true, and N_k is even, the dependent variable value corresponding to the index $\pm N_k/2$ is an alias.

Attributes

Name	Type	Description
count	Integer	A <i>required</i> number of points, N_k , along the dimension.
increment	<i>ScalarQuantity</i>	A <i>required</i> increment, Δx_k , along the dimension.
coordinates_offset	<i>ScalarQuantity</i>	An <i>optional</i> coordinate, b_k , corresponding to the zero of the indexes array, \mathbf{J}_k . The default value is a physical quantity with zero numerical value.
origin_offset	<i>ScalarQuantity</i>	An <i>optional</i> origin offset, o_k , along the dimension. The default value is a physical quantity with zero numerical value.
quantity_name	String	An <i>optional</i> quantity name associated with the physical quantities describing the dimension.
period	<i>ScalarQuantity</i>	An <i>optional</i> period of the dimension. By default, the dimension is considered non-periodic.
complex_fft	Boolean	An <i>optional</i> boolean with default value as False. If true, the coordinates along the dimension are evaluated as the output of a complex fast Fourier transform (FFT) routine. See the description.
reciprocal	ReciprocalDimension	An <i>optional</i> object with attributes required to describe the reciprocal dimension.

Example

The following LinearDimension object,

```
{
  "type": "linear",
  "count": 10,
  "increment": "2 μA",
  "coordinates_offset": "0.1 μA"
}
```

will generate a dimension, where the coordinates \mathbf{X}_k are

```
[  
  "0.1 μA",  
  "2.1 μA",  
  "4.1 μA",  
  "6.1 μA",  
  "8.1 μA",  
  "10.1 μA",  
  "12.1 μA",  
  "14.1 μA",  
  "16.1 μA",  
  "18.1 μA"  
]
```

MonotonicDimension

Description

A monotonic dimension is a quantitative dimension where the coordinates along the dimension are explicitly defined and, unlike a `LinearDimension`, may not be derivable from the ordered array of indexes along the dimension. Let \mathbf{A}_k be an ordered set of strictly ascending or descending physical quantities and, o_k , the origin offset along the k^{th} dimension, then the coordinates, \mathbf{X}_k , and the absolute coordinates, $\mathbf{X}_k^{\text{abs}}$, along a monotonic dimension follow

$$\begin{aligned}\mathbf{X}_k &= \mathbf{A}_k \text{ and} \\ \mathbf{X}_k^{\text{abs}} &= \mathbf{X}_k + o_k \mathbf{1},\end{aligned}\tag{1.4}$$

respectively, where $\mathbf{1}$ is an array of ones.

Attributes

Name	Type	Description
coordinates	<i>[ScalarQuantity, ScalarQuantity, ...]</i>	A <i>required</i> array of strictly ascending or descending <code>ScalarQuantity</code> .
origin_offset	<i>ScalarQuantity</i>	An <i>optional</i> origin offset, o_k , along the dimension. The default value is a physical quantity with zero numerical value.
quantity_name	String	An <i>optional</i> quantity name associated with the physical quantities describing the dimension.
period	<i>ScalarQuantity</i>	An <i>optional</i> period of the dimension. By default, the dimension is considered non-periodic.
reciprocal	<code>ReciprocalDimension</code>	An <i>optional</i> object with attributes required to describe the reciprocal dimension.

Example

The following MonotonicDimension object,

```
{
  "type": "monotonic",
  "coordinates": ["1 μs", "10 μs", "100 μs", "1 ms", "10 ms", "100 ms", "1 s", "10 s", "100 s"]
}
```

will generate a dimension, where the coordinates \mathbf{X}_k are

```
["1 μs", "10 μs", "100 μs", "1 ms", "10 ms", "100 ms", "1 s", "10 s", "100 s"]
```

LabeledDimension

Description

A labeled dimension is a qualitative dimension where the coordinates along the dimension are explicitly defined as labels. Let \mathbf{A}_k be an ordered set of unique labels along the k^{th} dimension, then the coordinates, \mathbf{X}_k , along a labeled dimension are

$$\mathbf{X}_k = \mathbf{A}_k. \quad (1.5)$$

Attributes

Name	Type	Description
labels	[String, String, ...]	A <i>required</i> ordered array of labels along the dimension.

Example

The following LabeledDimension object,

```
{
  "type": "labeled",
  "labels": ["Cu", "Fe", "Si", "H", "Li"]
}
```

will generate a dimension, where the coordinates \mathbf{X}_k are

```
["Cu", "Fe", "Si", "H", "Li"]
```

1.3 DependentVariable

1.3.1 Description

A generalized object describing a dependent variable of the dataset, which holds an ordered list of p components, indexed as $q=0$ to $p-1$, as

$$[\mathbf{U}_0, \dots \mathbf{U}_q, \dots \mathbf{U}_{p-1}]. \quad (1.6)$$

1.3.2 Attributes

Name	Type	Description
type	<i>DVObjectSubtype</i>	An enumeration literal with a valid dependent variable subtype.
name	String	Name of the dependent variable.
unit	String	The unit associated with the physical quantities describing the dependent variable.
quantity_name	String	Quantity name associated with the physical quantities describing the dependent variable.
numeric_type	<i>NumericType</i>	An enumeration literal with a valid numeric type.
quantity_type	<i>QuantityType</i>	An enumeration literal with a valid quantity type.
component_labels	[String, String, ...]	Ordered array of labels associated with ordered array of components of the dependent variable.
sparse_sampling	<i>SparseSampling</i>	Object with attribute required to describe a sparsely sampled dependent variable components.
description	String	Description of the dependent variable.
application	Generic	Generic dictionary object containing application specific metadata describing the dependent variable.

1.3.3 Specialized Class

InternalDependentVariable

Description

An InternalDependentVariable is where the components of the dependent variable are defined within the object as the value of the *components* key, along with other metadata describing the dependent variable.

Attributes

Name	Type	Description
components	[String, String, ...]	A <i>required</i> attribute. The value is an array of base64 encoded strings where each string is a component of the dependent variable and decodes to a binary array of M data values. This value is only <i>valid</i> only when the corresponding value of the <i>encoding</i> attribute is <i>base64</i> .
components	[[Float, Float, ...], [Float, Float, ...], ...]	A <i>required</i> attribute. The value is an array of arrays where each inner array is a component of the dependent variable with M data values. This value is <i>valid</i> only when the value of <i>encoding</i> is <i>none</i> .
encoding	String	A required enumeration literal, where the valid literals are <i>none</i> or <i>base64</i> .

ExternalDependentVariable

Description

An ExternalDependentVariable is where the components of the dependent variable are defined in an external file whose location is defined as the value of the `components_url` key.

Attributes

Name	Type	Description
components_url	String	A <i>required</i> URL location where the components of the dependent variable are serialized as a binary data.

SparseSampling

Description

A SparseSampling object describes the dimensions indexes and grid vertexes where the components of the dependent variable are sparsely sampled.

Attributes

Name	Type	Description
dimension_indexes	[Integer, Integer, ...]	A <i>required</i> array of integers indicating along which dimensions the <i>DependentVariable</i> is sparsely sampled.
sparse_grid_vertexes	[Integer, Integer, ...]	A required flattened array of integer indexes along the sparse dimensions where the components of the dependent variable are sampled. This is only <i>valid</i> when the encoding from the corresponding SparseSampling object is <i>none</i> .
sparse_grid_vertexes	String	A <i>required</i> base64 string of a flattened binary array of integer indexes along the sparse dimensions where the components of the dependent variable are sampled. This is only <i>valid</i> when the encoding from the corresponding SparseSampling object is <i>base64</i> .
encoding	String	A <i>required</i> enumeration with the following valid literals. <i>none</i> , <i>base64</i>
unsigned_integer_type	String	A <i>required</i> enumeration with the following valid literals. <i>uint8</i> , <i>uint16</i> , <i>uint32</i> , <i>uint64</i>
description	String	An <i>optional</i> description of the dependent variable.
application	Generic	An <i>optional</i> generic dictionary object containing application specific metadata describing the SparseSampling object.

1.4 Enumeration

1.4.1 DimObjectSubtype

An enumeration with literals as the value of the *Dimension* objects' *type* attribute.

Literal	Description
linear	Literal specifying an instance of a <i>LinearDimension</i> object.
monotonic	Literal specifying an instance of a <i>MonotonicDimension</i> object.
labeled	Literal specifying an instance of a <i>LabeledDimension</i> object.

1.4.2 DVObjectSubtype

An enumeration with literals as the values of the *DependentVariable* object' *type* attribute.

Literal	Description
internal	Literal specifying an instance of an <i>InternalDependentVariable</i> object.
external	Literal specifying an instance of an <i>ExternalDependentVariable</i> object.

1.4.3 NumericType

An enumeration with literals as the value of the *DependentVariable* objects' *numeric_type* attribute.

Literal	Description
uint8	8-bit unsigned integer
uint16	16-bit unsigned integer
uint32	32-bit unsigned integer
uint64	64-bit unsigned integer
int8	8-bit signed integer
int16	16-bit signed integer
int32	32-bit signed integer
int64	64-bit signed integer
float32	32-bit floating point number
float64	64-bit floating point number
complex64	two 32-bit floating points numbers
complex128	two 64-bit floating points numbers

1.4.4 QuantityType

An enumeration with literals as the value of the *DependentVariable* objects' *quantity_type* attribute. The value is used in interpreting the p -components of the dependent variable.

- scalar
A dependent variable with $p = 1$ component interpret as a scalar, $\mathcal{S}_i = U_{0,i}$.
- vector_n
A dependent variable with $p = n$ components interpret as vector components, $\mathcal{V}_i = [U_{0,i}, U_{1,i}, \dots, U_{n-1,i}]$.
- matrix_n_m
A dependent variable with $p = mn$ components interpret as a $n \times m$ matrix as follows,

$$M_i = \begin{bmatrix} U_{0,i} & U_{1,i} & \dots & U_{(n-1)m,i} \\ U_{1,i} & U_{m+1,i} & \dots & U_{(n-1)m+1,i} \\ \vdots & \vdots & \ddots & \vdots \\ U_{m-1,i} & U_{2m-1,i} & \dots & U_{nm-1,i} \end{bmatrix} \quad (1.7)$$

- symmetric_matrix_n
A dependent variable with $p = n^2$ components interpret as a matrix symmetric about its leading diagonal as shown below,

$$M_i^{(s)} = \begin{bmatrix} U_{0,i} & U_{1,i} & \dots & U_{n-1,i} \\ U_{1,i} & U_{n,i} & \dots & U_{2n-2,i} \\ \vdots & \vdots & \ddots & \vdots \\ U_{n-1,i} & U_{2n-2,i} & \dots & U_{\frac{n(n+1)}{2}-1,i} \end{bmatrix} \quad (1.8)$$

- pixel_n
A dependent variable with $p = n$ components interpret as image/pixel components, $\mathcal{P}_i = [U_{0,i}, U_{1,i}, \dots, U_{n-1,i}]$.

Here, the terms n and m are integers.

1.5 ScalarQuantity

ScalarQuantity is an object composed of a numerical value and any valid SI unit symbol or any number of accepted non-SI unit symbols. It is serialized in the JSON file as a string containing a numerical value followed by the unit symbol, for example,

- “3.4 m” (SI)
- “2.3 bar” (non-SI)

INSTALLATION

2.1 Requirements

`csdmpy` has the following strict requirements:

- [Python](#) 3.6 or later
- [Numpy](#) 1.17 or later

Other requirements include:

- [requests](#) `>=2.21.0` (for downloading files from server)
- [astropy](#) `>=3.0` (for astropy units module)
- [matplotlib](#) `>=3.0` (for rendering plots)

2.2 Installing `csdmpy`

2.2.1 On Local machine (Using `pip`)

PIP is a package manager for Python packages and is included with python version 3.4 and higher. PIP is the easiest way to install python packages.

```
$ pip install csdmpy
```

If you get a `PermissionError`, it usually means that you do not have the required administrative access to install new packages to your Python installation. In this case, you may consider adding the `--user` option, at the end of the statement, to install the package into your home directory. You can read more about how to do this in the [pip documentation](#).

```
$ pip install csdmpy --user
```

Upgrading to a newer version

To upgrade, type the following in the terminal/Prompt

```
$ pip install csdmpy -U
```

2.2.2 On Google Colab Notebook

Colaboratory is a Google research project. It is a Jupyter notebook environment that runs entirely in the cloud. Launch a new notebook on [Colab](#). To install the package, type

```
!pip install csdmpy
```

in the first cell, and execute. All done! You may now start using the library.

GETTING STARTED WITH *CSDMPY* PACKAGE

We have put together a set of guidelines for importing the *csdmpy* package and related methods and attributes. We encourage the users to follow these guidelines to promote consistency, amongst others. Import the package using

```
>>> import csdmpy as cp
```

To load a *.csdf* or a *.csdfe* file, use the *load()* method of the *csdmpy* module. In the following example, we load a sample test file.

```
>>> filename = "https://www.ssnmr.org/sites/default/files/CSDM/test/test01.csdf"
>>> testdata1 = cp.load(filename)
```

Here, *testdata1* is an instance of the *CSDM* class.

At the root level, the *CSDM* object includes various useful optional attributes that may contain additional information about the dataset. One such useful attribute is the *description* key, which briefs the end-users on the contents of the dataset. To access the value of this attribute use,

```
>>> testdata1.description
'A simulated sine curve.'
```

3.1 Accessing dimensions and dependent variables of the dataset

An instance of the *CSDM* object may include multiple dimensions and dependent variables. Collectively, the dimensions form a multi-dimensional grid system, and the dependent variables populate this grid. In *csdmpy*, dimensions and dependent variables are structured as list object. To access these lists, use the *dimensions* and *dependent_variables* attribute of the *CSDM* object, respectively. For example,

```
>>> x = testdata1.dimensions
>>> y = testdata1.dependent_variables
```

In this example, the dataset contains one dimension and one dependent variable.

You may access the instances of individual dimension and dependent variable by using the proper indexing. For example, the dimension and dependent variable at index 0 may be accessed using *x[0]* and *y[0]*, respectively.

Every instance of the *Dimension* object has its own set of attributes that further describe the respective dimension. For example, a *Dimension* object may have an optional *description* attribute,

```
>>> x[0].description
'A temporal dimension.'
```

Similarly, every instance of the *DependentVariable* object has its own set of attributes. In this example, the *description* attribute from the dependent variable is

```
>>> y[0].description
'A response dependent variable.'
```

3.1.1 Coordinates along the dimension

Every dimension object contains a list of coordinates associated with every grid index along the dimension. To access these coordinates, use the *coordinates* attribute of the respective *Dimension* instance. In this example, the coordinates are

```
>>> x[0].coordinates
<Quantity [0. , 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9] s>
```

Note: `x[0].coordinates` returns a *Quantity* instance from the *Astropy* package. The *csdmpy* module utilizes the *units* library from *astropy.units* module to handle physical quantities. The numerical *value* and the *unit* of the physical quantities are accessed through the *Quantity* instance, using the *value* and the *unit* attributes, respectively. Please refer to the *astropy.units* documentation for details. In the *csdmpy* module, the *Quantity.value* is a *Numpy array*. For instance, in the above example, the underlying *Numpy array* from the *coordinates* attribute is accessed as

```
>>> x[0].coordinates.value
array([0. , 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9])
```

3.1.2 Components of the dependent variable

Every dependent variable object has at least one component. The number of components of the dependent variable is determined from the *quantity_type* attribute of the dependent variable object. For example, a scalar quantity has one-component, while a vector quantity may have multiple components. To access the components of the dependent variable, use the *components* attribute of the respective *DependentVariable* instance. For example,

```
>>> y[0].components
array([[ 0.0000000e+00,  5.8778524e-01,  9.5105654e-01,  9.5105654e-01,
         5.8778524e-01,  1.2246469e-16, -5.8778524e-01, -9.5105654e-01,
        -9.5105654e-01, -5.8778524e-01]], dtype=float32)
```

The *components* attribute is a *Numpy array*. Note, the number of dimensions of this array is $d + 1$, where d is the number of *Dimension* objects from the *dimensions* attribute. The additional dimension in the *Numpy array* corresponds to the number of components of the dependent variable. For instance, in this example, there is a single dimension, *i.e.*, $d = 1$ and, therefore, the value of the *components* attribute holds a two-dimensional *Numpy array* of shape

```
>>> y[0].components.shape
(1, 10)
```

where the first element of the shape tuple, 1 , is the number of components of the dependent variable and the second element, 10 , is the number of points along the dimension, *i.e.*, `x[0].coordinates`.

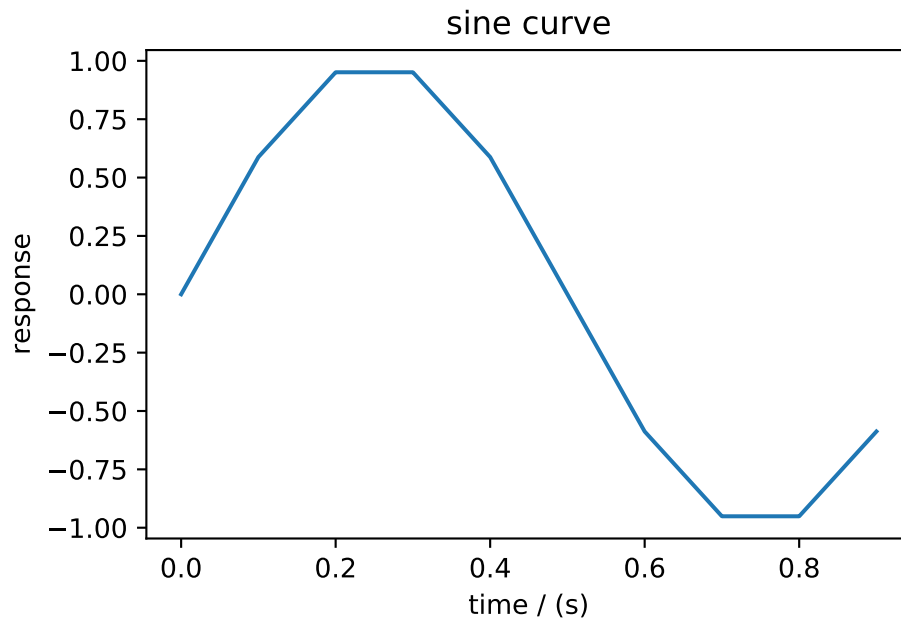
3.2 Plotting the dataset

It is always helpful to represent a scientific dataset with visual aids such as a plot or a figure instead of columns of numbers. As such, throughout this documentation, we provide a figure or two for every example dataset. We make use of Python's [Matplotlib library](#) for generating these figures. The users may, however, use their favorite plotting library.

The following snippet plots the dataset from this example. Here, the *axis_label* is an attribute of both *Dimension* and *DependentVariable* instances, and the *name* is an attribute of the *DependentVariable* instance.

```
>>> import matplotlib.pyplot as plt

>>> plt.figure(figsize=(5, 3.5))
>>> plt.plot(x[0].coordinates, y[0].components[0])
>>> plt.xlabel(x[0].axis_label)
>>> plt.ylabel(y[0].axis_label[0])
>>> plt.title(y[0].name)
>>> plt.tight_layout()
>>> plt.show()
```



See also:

CSDM, *Dimension*, *DependentVariable*, *Quantity*, *numpy array*, *Matplotlib library*

EXAMPLE GALLERY

In this section, we present illustrative examples for importing files serialized with the CSD model, using the *csdmpy* package. Because the CSD model allows multi-dimensional datasets with multiple dependent variables, we use a shorthand notation of $dD\{p\}$ to indicate that a dataset has a p -component dependent variable defined on a d -dimensional coordinate grid. In the case of *correlated datasets*, the number of components in each dependent variable is given as a list within the curly braces, *i.e.*, $dD\{p_0, p_1, p_2, \dots\}$.

4.1 Scalar, 1D{1} datasets

The 1D{1} datasets are one dimensional, $d = 1$, with one single-component, $p = 1$, dependent variable. These datasets are the most common, and we, therefore, provide a few examples from various fields of science.

4.1.1 Global Mean Sea Level rise dataset

The following dataset is the Global Mean Sea Level (GMSL) rise from the late 19th to the Early 21st Century¹. The *original dataset* was downloaded as a CSV file and subsequently converted to the CSD model format.

Let's import this file.

```
import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/gmsl/GMSL.csd"
sea_level = cp.load(filename)
```

The variable *filename* is a string with the address to the *.csdf* file. The *load()* method of the *csdmpy* module reads the file and returns an instance of the *CSDM* class, in this case, as a variable *sea_level*. For a quick preview of the data structure, use the *data_structure* attribute of this instance.

```
print(sea_level.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2019-05-21T13:43:00Z",
    "tags": [
```

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¹ Church JA, White NJ. Sea-Level Rise from the Late 19th to the Early 21st Century. *Surveys in Geophysics*. 2011;32:585602. DOI:10.1007/s10712-011-9119-1.

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```

        "Jason-2",
        "satellite altimetry",
        "mean sea level",
        "climate"
    ],
    "description": "Global Mean Sea Level (GMSL) rise from the late 19th to the Early↵
↵21st Century.",
    "dimensions": [
        {
            "type": "linear",
            "count": 1608,
            "increment": "0.0833333333333333 yr",
            "coordinates_offset": "1880.04166666667 yr",
            "quantity_name": "time",
            "reciprocal": {
                "quantity_name": "frequency"
            }
        }
    ],
    "dependent_variables": [
        {
            "type": "internal",
            "name": "Global Mean Sea Level",
            "unit": "mm",
            "quantity_name": "length",
            "numeric_type": "float32",
            "quantity_type": "scalar",
            "component_labels": [
                "GMSL"
            ],
            "components": [
                [
                    "-183.0, -171.125, ..., 59.6875, 58.5"
                ]
            ]
        }
    ]
}

```

Warning: The serialized string from the `data_structure` attribute is not the same as the JSON serialization on the file. This attribute is only intended for a quick preview of the data structure and avoids displaying large datasets. Do not use the value of this attribute to save the data to the file. Instead, use the `save()` method of the `CSDM` class.

The tuple of the dimensions and dependent variables, from this example, are

```

x = sea_level.dimensions
y = sea_level.dependent_variables

```

respectively. The coordinates along the dimension and the component of the dependent variable are

```

print(x[0].coordinates)

```

Out:


```
[1880.04166667 1880.125      1880.20833333 ... 2013.79166666 2013.87499999
 2013.95833333] yr
```

and

```
print(y[0].components[0])
```

Out:

```
[-183.      -171.125  -164.25   ...   66.375   59.6875  58.5    ]
```

respectively.

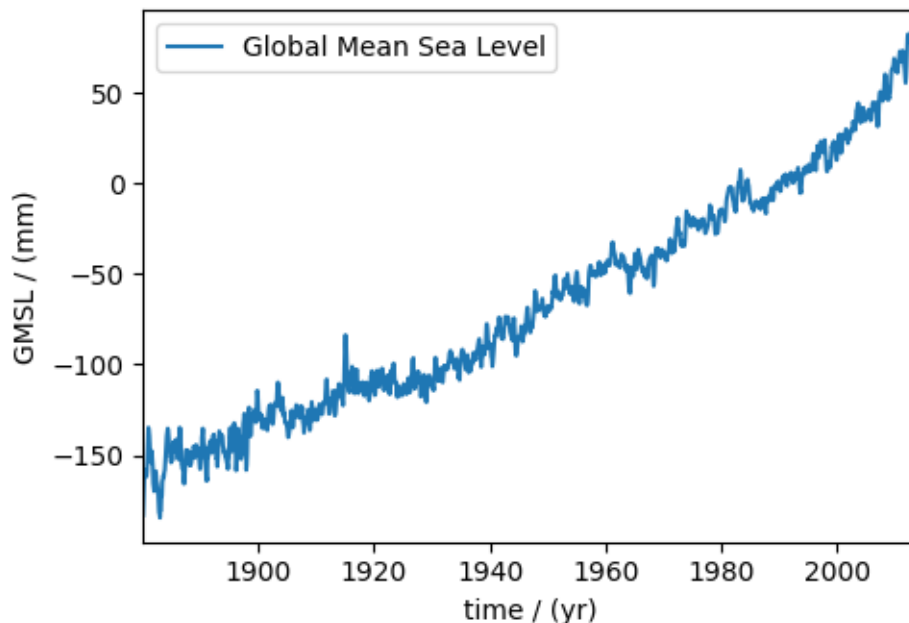
Plotting the data

Note: The following code is only for illustrative purposes. The users may use any plotting library to visualize their datasets.

```
import matplotlib.pyplot as plt

plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")

# csdmpy is compatible with matplotlib function. Use the csdm object as the argument
# of the matplotlib function.
ax.plot(sea_level)
plt.tight_layout()
plt.show()
```



The following is a quick description of the above code. Within the code, we make use of the `csdm` instance's attributes in addition to the matplotlib functions. The first line is an import call for the matplotlib functions. The following line generates a plot of the coordinates along the dimension verse the component of the dependent variable. The next line sets the x-range. For labeling the axes, use the `axis_label` attribute of both dimension and dependent variable instances.

For the figure title, use the `name` attribute of the dependent variable instance. The next statement adds the grid lines. For additional information, refer to [Matplotlib](#) documentation.

See also:

Getting started with csdmpy package

Citation

Total running time of the script: (0 minutes 0.859 seconds)

4.1.2 Nuclear Magnetic Resonance (NMR) dataset

The following dataset is a ^{13}C time-domain NMR Bloch decay signal of ethanol. Let's load this data file and take a quick look at its data structure. We follow the steps described in the previous example.

```
import matplotlib.pyplot as plt

import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/NMR/blochDecay/blochDecay.csd"
NMR_data = cp.load(filename)
print(NMR_data.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2016-03-12T16:41:00Z",
    "geographic_coordinate": {
      "altitude": "238.9719543457031 m",
      "longitude": "-83.05154573892345 °",
      "latitude": "39.97968794964322 °"
    },
    "tags": [
      "13C",
      "NMR",
      "spectrum",
      "ethanol"
    ],
    "description": "A time domain NMR 13C Bloch decay signal of ethanol.",
    "dimensions": [
      {
        "type": "linear",
        "count": 4096,
        "increment": "0.1 ms",
        "coordinates_offset": "-0.3 ms",
        "quantity_name": "time",
        "reciprocal": {
          "coordinates_offset": "-3005.363 Hz",
          "origin_offset": "75426328.86 Hz",
          "quantity_name": "frequency",
          "label": "13C frequency shift"
        }
      }
    ]
  }
}
```

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```

    }
  ],
  "dependent_variables": [
    {
      "type": "internal",
      "numeric_type": "complex128",
      "quantity_type": "scalar",
      "components": [
        "(-8899.40625-1276.7734375j), (-4606.88037109375-742.4124755859375j), ...,
↪ (37.548492431640625+20.156890869140625j), (-193.9228515625-67.06524658203125j)"
      ]
    }
  ]
}

```

This particular example illustrates two additional attributes of the CSD model, namely, the *geographic_coordinate* and *tags*. The *geographic_coordinate* described the location where the CSDM file was last serialized. You may access this attribute through,

```
print(NMR_data.geographic_coordinate)
```

Out:

```

{'altitude': '238.9719543457031 m', 'longitude': '-83.05154573892345 °', 'latitude':
↪ '39.97968794964322 °'}

```

The *tags* attribute is a list of keywords that best describe the dataset. The *tags* attribute is accessed through,

```
print(NMR_data.tags)
```

Out:

```
['13C', 'NMR', 'spectrum', 'ethanol']
```

You may add additional tags, if so desired, using the *append* method of python's list class, for example,

```

NMR_data.tags.append("Bloch decay")
print(NMR_data.tags)

```

Out:

```
['13C', 'NMR', 'spectrum', 'ethanol', 'Bloch decay']
```

The coordinates along the dimension are

```

x = NMR_data.dimensions
x0 = x[0].coordinates
print(x0)

```

Out:

```
[-3.000e-01 -2.000e-01 -1.000e-01 ... 4.090e+02 4.091e+02 4.092e+02] ms
```

Unlike the previous example, the data structure of an NMR measurement is a complex-valued dependent variable. The numeric type of the components from a dependent variable is accessed through the `numeric_type` attribute.

```
y = NMR_data.dependent_variables
print(y[0].numeric_type)
```

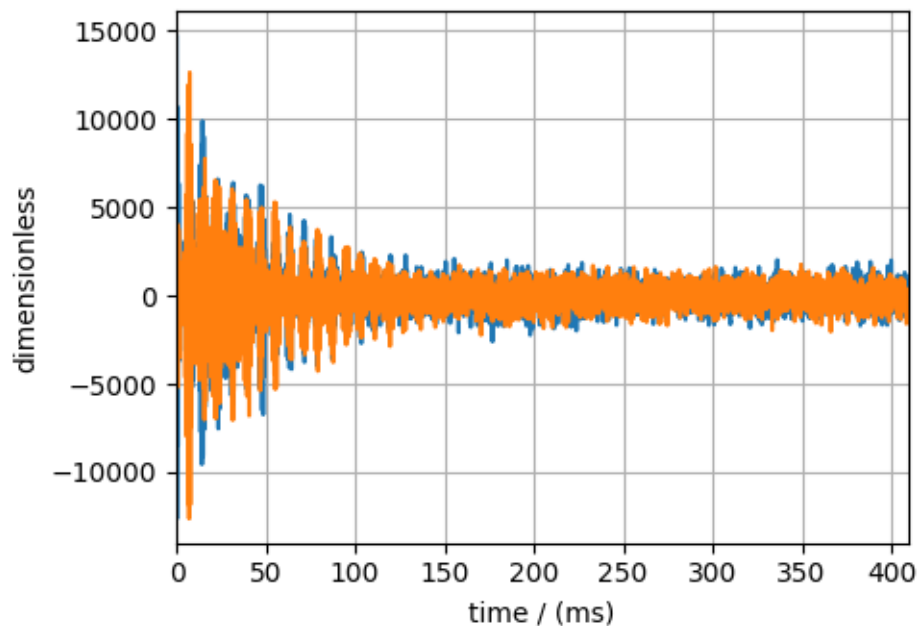
Out:

```
complex128
```

Visualizing the dataset

In the previous example, we illustrated a matplotlib script for plotting 1D data. Here, we use the csdmpy `plot()` method, which is a supplementary method for plotting 1D and 2D datasets only.

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(NMR_data.real, label="real")
ax.plot(NMR_data.imag, label="imag")
plt.grid()
plt.tight_layout()
plt.show()
```



Reciprocal dimension object

When observing the dimension instance of *NMR_data*,

```
print(x[0].data_structure)
```

Out:

```
{
  "type": "linear",
  "count": 4096,
  "increment": "0.1 ms",
  "coordinates_offset": "-0.3 ms",
  "quantity_name": "time",
  "reciprocal": {
    "coordinates_offset": "-3005.363 Hz",
    "origin_offset": "75426328.86 Hz",
    "quantity_name": "frequency",
    "label": "13C frequency shift"
  }
}
```

notice, the reciprocal keyword. The `reciprocal` attribute is useful for datasets that frequently transform to a reciprocal domain, such as the NMR dataset. The value of the reciprocal attribute is the reciprocal object, which contains metadata for describing the reciprocal coordinates, such as the *coordinates_offset*, *origin_offset* of the reciprocal dimension.

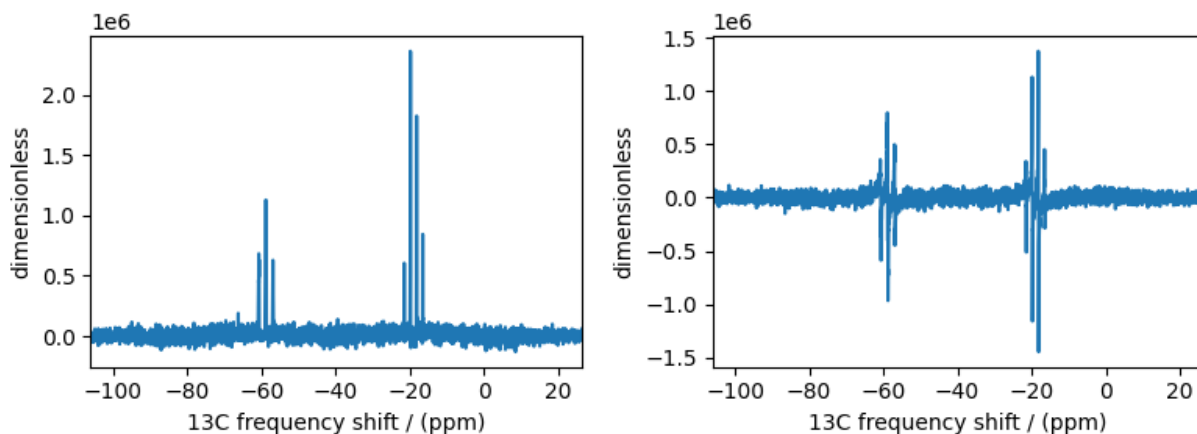
You may perform a fourier transform to visualize the NMR spectrum. Use the `fft()` method on the `csdm` object *NMR_data* as follows

```
fft_NMR_data = NMR_data.fft()
```

By default, the unit associated with a dimension after FFT is the reciprocal of the unit associated with the dimension before FFT. In this case, the dimension unit after FFT is Hz. NMR datasets are often visualized as a dimension frequency scale. To convert the dimension's unit to ppm use,

```
fft_NMR_data.dimensions[0].to("ppm", "nmr_frequency_ratio")

# plot of the frequency domain data after FFT.
fig, ax = plt.subplots(1, 2, figsize=(8, 3), subplot_kw={"projection": "csdm"})
ax[0].plot(fft_NMR_data.real, label="real")
plt.grid()
ax[1].plot(fft_NMR_data.imag, label="imag")
plt.grid()
plt.tight_layout()
plt.show()
```

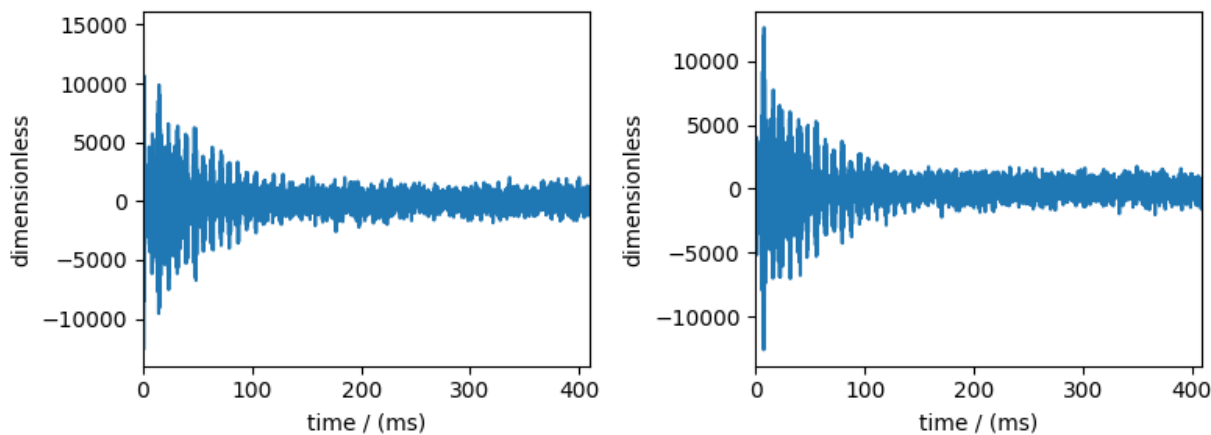


In the above plot, the plot metadata is taken from the reciprocal object such as the x-axis label.

To return to time domain signal, once again use the `fft()` method on the `fft_NMR_data` object. We use the CSDM object's `complex_fft` attribute to determine the FFT or iFFT operation.

```
NMR_data_2 = fft_NMR_data.fft()

# plot of the frequency domain data.
fig, ax = plt.subplots(1, 2, figsize=(8, 3), subplot_kw={"projection": "csdm"})
ax[0].plot(NMR_data_2.real, label="real")
plt.grid()
ax[1].plot(NMR_data_2.imag, label="imag")
plt.grid()
plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 0.805 seconds)

4.1.3 Electron Paramagnetic Resonance (EPR) dataset

The following is a simulation of the [EPR dataset](#), originally obtained as a JCAMP-DX file, and subsequently converted to the CSD model file-format. The data structure of this dataset follows,

```
import matplotlib.pyplot as plt

import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/EPR/AmanitaMuscaria_base64.csd"
EPR_data = cp.load(filename)
print(EPR_data.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2015-02-26T16:41:00Z",
    "description": "A Electron Paramagnetic Resonance simulated dataset.",
    "dimensions": [
      {
        "type": "linear",
        "count": 298,
        "increment": "4.0 G",
        "coordinates_offset": "2750.0 G",
        "quantity_name": "magnetic flux density",
        "reciprocal": {
          "quantity_name": "electrical mobility"
        }
      }
    ],
    "dependent_variables": [
      {
        "type": "internal",
        "name": "Amanita.muscaria",
        "numeric_type": "float32",
        "quantity_type": "scalar",
        "component_labels": [
          "Intensity Derivative"
        ],
        "components": [
          [
            "0.067, 0.136, ..., -0.035, -0.137"
          ]
        ]
      }
    ]
  }
}
```

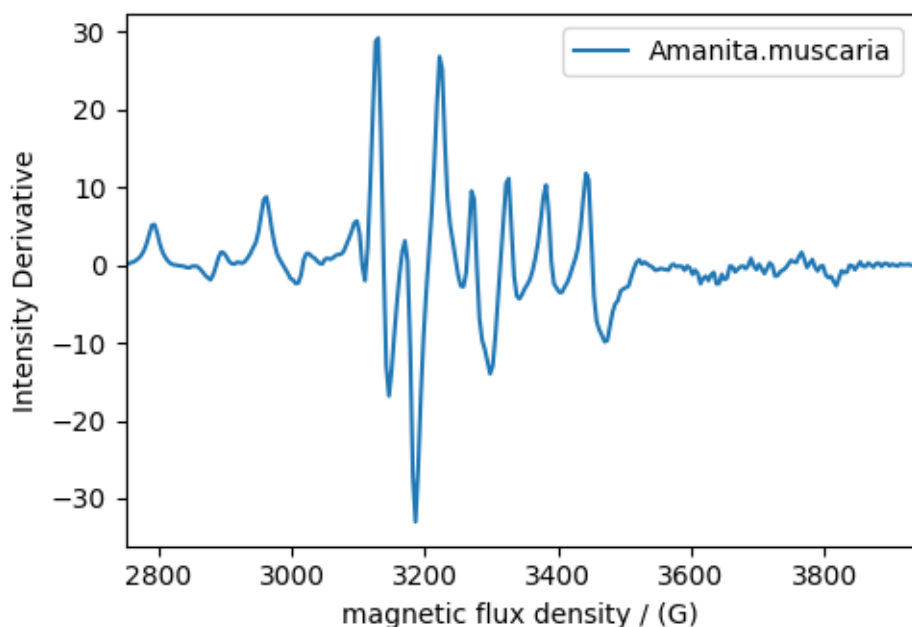
and the corresponding plot.

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(EPR_data)
```

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```
plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 0.246 seconds)

4.1.4 Gas Chromatography dataset

The following Gas Chromatography dataset was obtained as a JCAMP-DX file, and subsequently converted to the CSD model file-format. The data structure of the gas chromatography dataset follows,

```
import matplotlib.pyplot as plt

import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/GC/cinnamon_base64.csd"
GCData = cp.load(filename)
print(GCData.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2011-12-16T12:24:10Z",
    "description": "A Gas Chromatography dataset of cinnamon stick.",
    "dimensions": [
      {
        "type": "linear",
        "count": 6001,
        "increment": "0.0034 min",
```

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```

    "quantity_name": "time",
    "reciprocal": {
        "quantity_name": "frequency"
    }
},
],
"dependent_variables": [
    {
        "type": "internal",
        "name": "Headspace from cinnamon stick",
        "numeric_type": "float32",
        "quantity_type": "scalar",
        "component_labels": [
            "monotonic"
        ],
        "components": [
            [
                "48453.0, 48444.0, ..., 48040.0, 48040.0"
            ]
        ]
    }
]
}
}

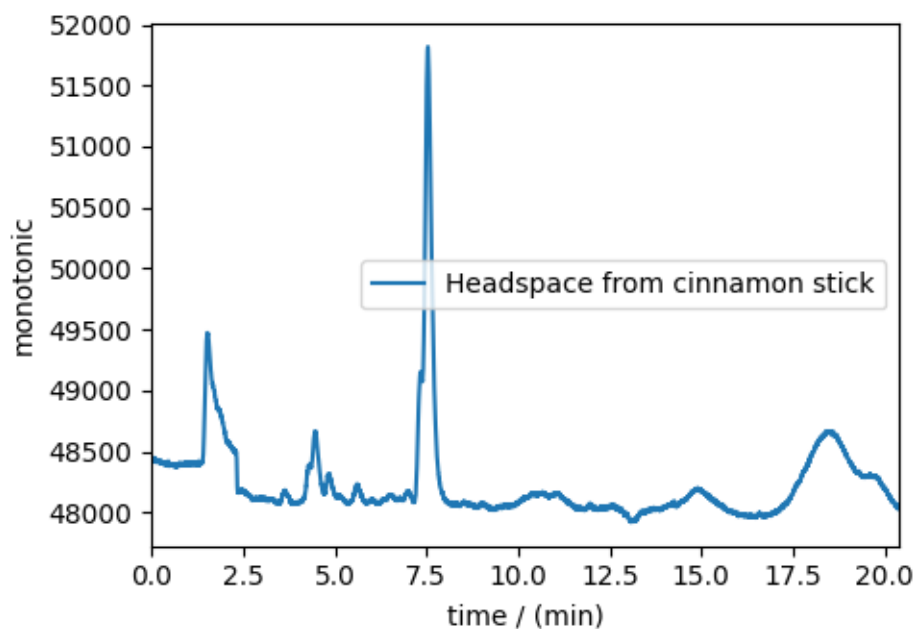
```

and the corresponding plot

```

plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(GCData)
plt.tight_layout()
plt.show()

```



Total running time of the script: (0 minutes 0.300 seconds)

4.1.5 Fourier Transform Infrared Spectroscopy (FTIR) dataset

The following [FTIR dataset](#), was obtained as a JCAMP-DX file, and subsequently converted to the CSD model file-format. The data structure of the FTIR dataset follows,

```
import matplotlib.pyplot as plt

import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/ir/caffeine_base64.csd"
FTIR_data = cp.load(filename)
print(FTIR_data.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2019-07-01T21:03:42Z",
    "description": "An IR spectrum of caffeine.",
    "dimensions": [
      {
        "type": "linear",
        "count": 1842,
        "increment": "1.930548614883216 cm^-1",
        "coordinates_offset": "449.41 cm^-1",
        "quantity_name": "wavenumber",
        "reciprocal": {
          "quantity_name": "length"
        }
      }
    ],
    "dependent_variables": [
      {
        "type": "internal",
        "name": "Caffeine",
        "numeric_type": "float32",
        "quantity_type": "scalar",
        "component_labels": [
          "Transmittance"
        ],
        "components": [
          [
            "99.31053, 99.08212, ..., 100.22944, 100.22944"
          ]
        ]
      }
    ]
  }
}
```

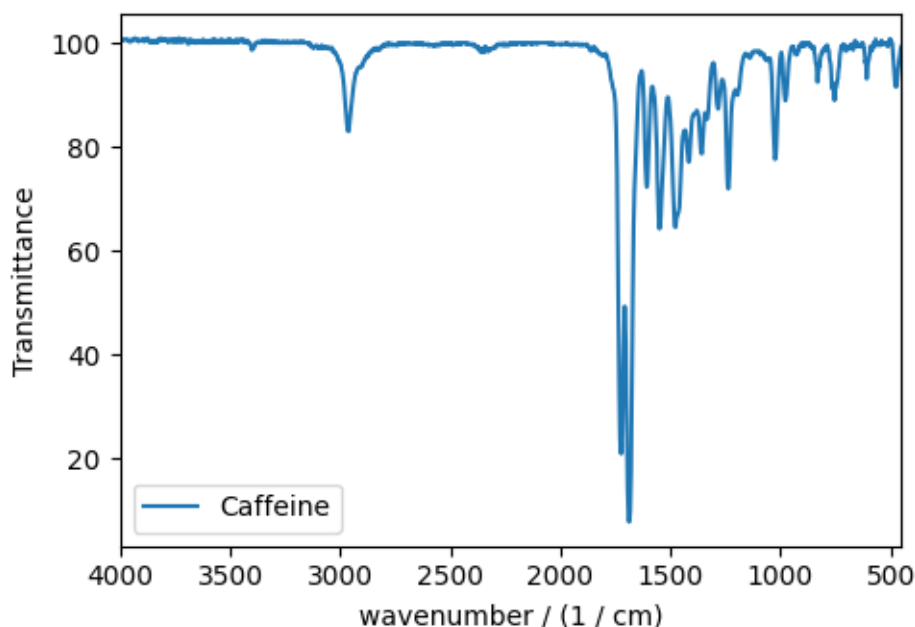
and the corresponding plot.

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(FTIR_data)
ax.invert_xaxis()
```

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```
plt.tight_layout()
plt.show()
```



Because, FTIR spectrum is conventionally displayed on a reverse axis, an optional *reverse_axis* argument is provided to the `plot()` method. Its value is an order list of boolean, corresponding to the order of the dimensions.

Total running time of the script: (0 minutes 0.236 seconds)

4.1.6 Ultraviolet-visible (UV-vis) dataset

The following UV-vis dataset was obtained as a JCAMP-DX file, and subsequently converted to the CSD model file-format. The data structure of the UV-vis dataset follows,

```
import matplotlib.pyplot as plt

import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/UV-vis/benzeneVapour_base64.csd"
UV_data = cp.load(filename)
print(UV_data.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2014-09-30T11:16:33Z",
    "description": "A UV-vis spectra of benzene vapours.",
    "dimensions": [
      {
```

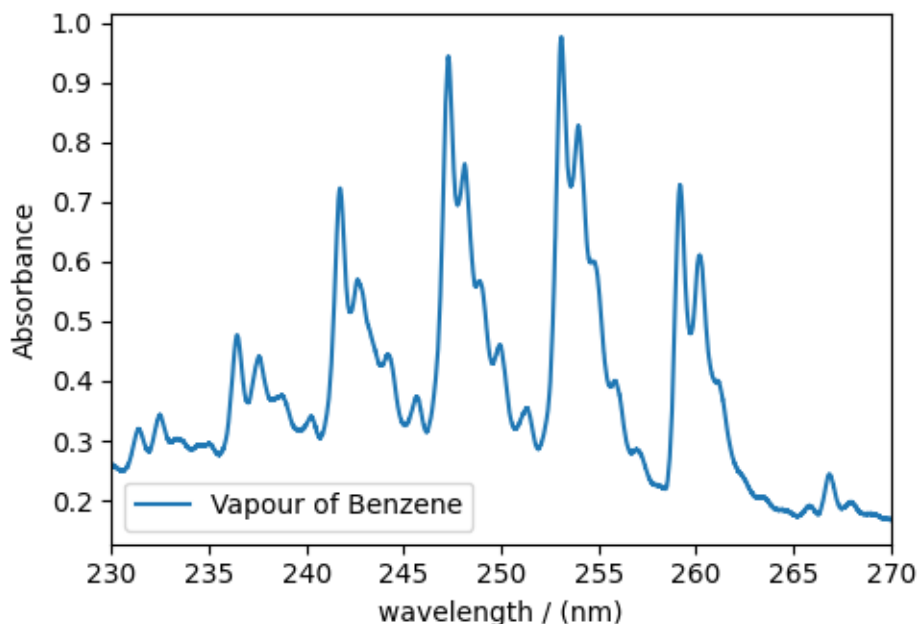
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```
        "type": "linear",
        "count": 4001,
        "increment": "0.01 nm",
        "coordinates_offset": "230.0 nm",
        "quantity_name": "length",
        "label": "wavelength",
        "reciprocal": {
            "quantity_name": "wavenumber"
        }
    },
    ],
    "dependent_variables": [
        {
            "type": "internal",
            "name": "Vapour of Benzene",
            "numeric_type": "float32",
            "quantity_type": "scalar",
            "component_labels": [
                "Absorbance"
            ],
            "components": [
                [
                    "0.25890622, 0.25923702, ..., 0.16814752, 0.16786034"
                ]
            ]
        }
    ]
}
```

and the corresponding plot

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(UV_data)
plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 0.278 seconds)

4.1.7 Mass spectrometry (sparse) dataset

The following mass spectrometry data of acetone is an example of a sparse dataset. Here, the CSDM data file holds a sparse dependent variable. Upon import, the components of the dependent variable sparsely populates the coordinate grid. The remaining unpopulated coordinates are assigned a zero value.

```
import matplotlib.pyplot as plt

import csdm as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/MassSpec/acetone.csdf"
mass_spec = cp.load(filename)
print(mass_spec.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2019-06-23T17:53:26Z",
    "description": "MASS spectrum of acetone",
    "dimensions": [
      {
        "type": "linear",
        "count": 51,
        "increment": "1.0",
        "coordinates_offset": "10.0",
        "label": "m/z"
      }
    ]
  },
}
```

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```

    "dependent_variables": [
      {
        "type": "internal",
        "name": "acetone",
        "numeric_type": "float32",
        "quantity_type": "scalar",
        "component_labels": [
          "relative abundance"
        ],
        "components": [
          [
            "0.0, 0.0, ..., 10.0, 0.0"
          ]
        ]
      }
    ]
  }
}

```

Here, the coordinates along the dimension are

```
print(mass_spec.dimensions[0].coordinates)
```

Out:

```

[10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27.
 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45.
 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60.]

```

and the corresponding components of the dependent variable,

```
print(mass_spec.dependent_variables[0].components[0])
```

Out:

```

[  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.   9.   9.  49.   0.   0.  79. 1000.  19.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 270.  10.   0.]

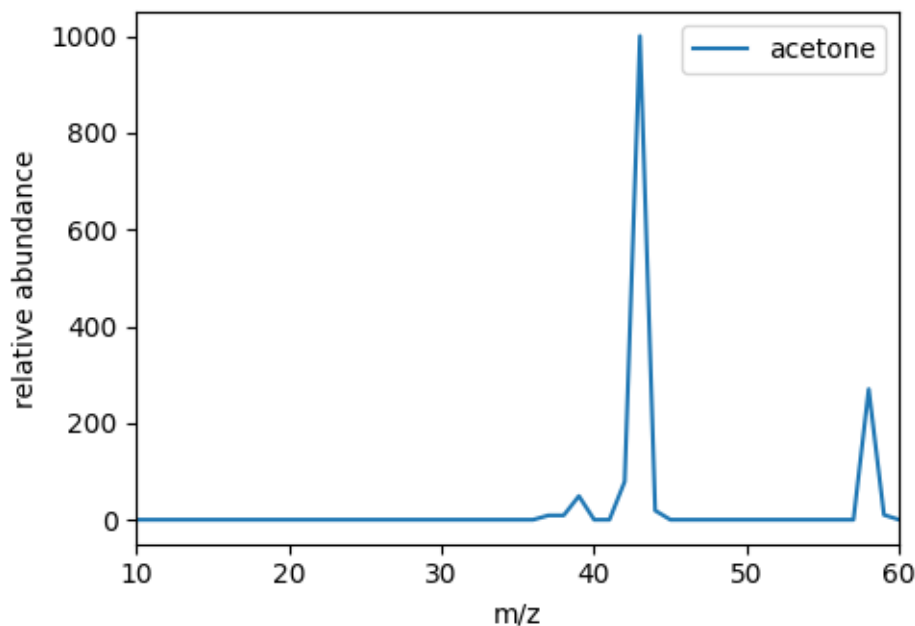
```

Note, only eight values were listed in the dependent variable's *components* attribute in the *.csdf* file. The remaining component values were set to zero.

```

plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(mass_spec)
plt.tight_layout()
plt.show()

```



Total running time of the script: (0 minutes 0.227 seconds)

4.2 Scalar, 2D{1} datasets

The 2D{1} datasets are two dimensional, $d = 2$, with one single-component dependent variable, $p = 1$. Following are some 2D{1} example datasets from various scientific fields expressed in CSDM format.

4.2.1 Astronomy dataset

The following dataset is a new observation of the Bubble Nebula acquired by [The Hubble Heritage Team](#), in February 2016. The original dataset was obtained in the FITS format and subsequently converted to the CSD model file-format. For the convenience of illustration, we have downsampled the original dataset.

Let's load the `.csdfe` file and look at its data structure.

```
import matplotlib.pyplot as plt

import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/BubbleNebula/Bubble_nebula.csdfe"
bubble_nebula = cp.load(filename)
print(bubble_nebula.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "timestamp": "2020-01-04T01:43:31Z",
    "description": "The dataset is a new observation of the Bubble Nebula acquired by
↳ The Hubble Heritage Team, in February 2016.",
  },
}
```

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```

"dimensions": [
  {
    "type": "linear",
    "count": 1024,
    "increment": "-0.0002581136196 °",
    "coordinates_offset": "350.311874957 °",
    "quantity_name": "plane angle",
    "label": "Right Ascension"
  },
  {
    "type": "linear",
    "count": 1024,
    "increment": "0.0001219957797701109 °",
    "coordinates_offset": "61.12851494969163 °",
    "quantity_name": "plane angle",
    "label": "Declination"
  }
],
"dependent_variables": [
  {
    "type": "internal",
    "name": "Bubble Nebula, 656nm",
    "numeric_type": "float32",
    "quantity_type": "scalar",
    "components": [
      [
        "0.0, 0.0, ..., 0.0, 0.0"
      ]
    ]
  }
]
}

```

Here, the variable `bubble_nebula` is an instance of the [CSDM](#) class. From the data structure, one finds two dimensions, labeled as *Right Ascension* and *Declination*, and one single-component dependent variable named *Bubble Nebula, 656nm*.

Let's get the tuple of the dimension and dependent variable instances from the `bubble_nebula` instance following,

```

x = bubble_nebula.dimensions
y = bubble_nebula.dependent_variables

```

There are two dimension instances in `x`. Let's look at the coordinates along each dimension, using the `coordinates` attribute of the respective instances.

```

print(x[0].coordinates[:10])

```

Out:

```

[350.31187496 350.31161684 350.31135873 350.31110062 350.3108425
 350.31058439 350.31032628 350.31006816 350.30981005 350.30955193] deg

```

```

print(x[1].coordinates[:10])

```

Out:


```
[61.12851495 61.12863695 61.12875894 61.12888094 61.12900293 61.12912493
 61.12924692 61.12936892 61.12949092 61.12961291] deg
```

Here, we only print the first ten coordinates along the respective dimensions.

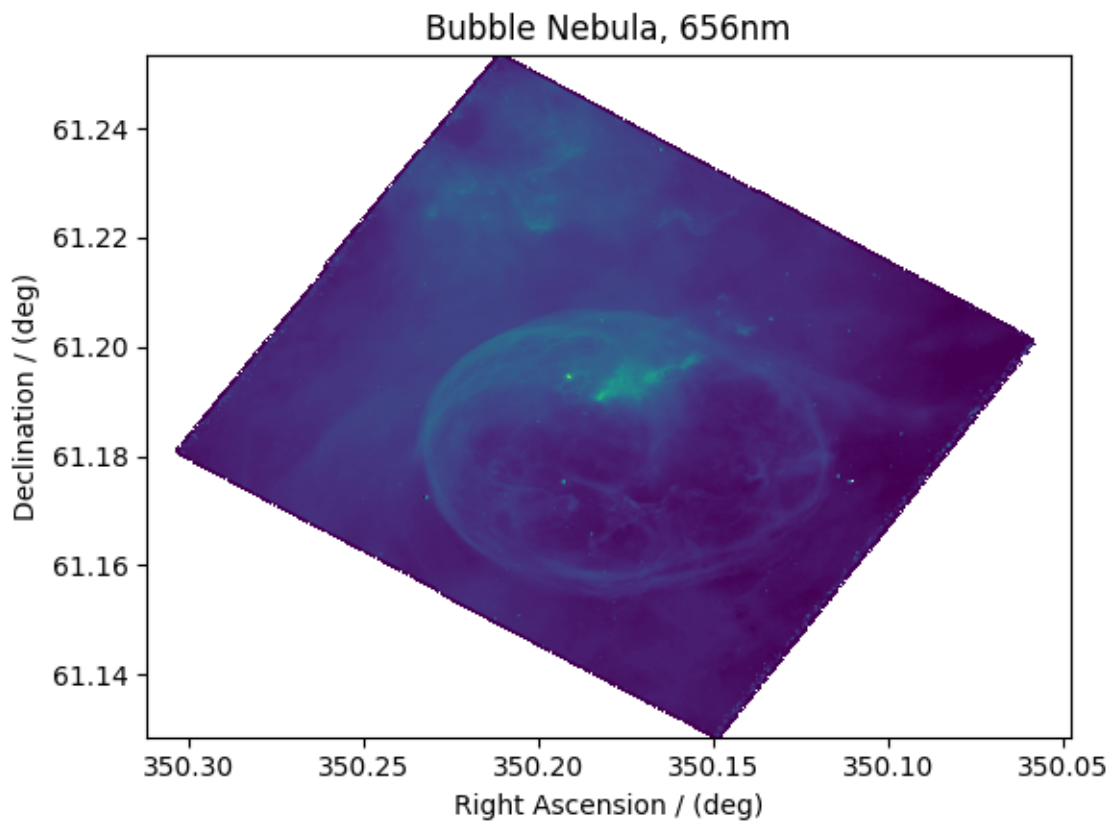
The component of the dependent variable is accessed through the `components` attribute.

```
y00 = y[0].components[0]
```

Visualize the dataset

```
from matplotlib.colors import LogNorm

plt.figure(figsize=(6, 4.5))
ax = plt.subplot(projection="csdm")
ax.imshow(bubble_nebula, norm=LogNorm(vmin=7.5e-3, clip=True), aspect="auto")
plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 0.628 seconds)

4.2.2 Nuclear Magnetic Resonance (NMR) dataset

The following example is a ^{29}Si NMR time-domain saturation recovery measurement of a highly siliceous zeolite ZSM-12. Usually, the spin recovery measurements are acquired over a rectilinear grid where the measurements along one of the dimensions are non-uniform and span several orders of magnitude. In this example, we illustrate the use of *monotonic* dimensions for describing such datasets.

Let's load the file.

```
import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/NMR/satrec/satRec.csd"
NMR_2D_data = cp.load(filename)
print(NMR_2D_data.description)
```

Out:

```
A 29Si NMR magnetization saturation recovery measurement of highly siliceous zeolite_
↪ ZSM-12.
```

The tuples of the dimension and dependent variable instances from the `NMR_2D_data` instance are

```
x = NMR_2D_data.dimensions
y = NMR_2D_data.dependent_variables
```

respectively. There are two dimension instances in this example with respective dimension data structures as

```
print(x[0].data_structure)
```

Out:

```
{
  "type": "linear",
  "count": 1024,
  "increment": "80.0 μs",
  "coordinates_offset": "-41.04 ms",
  "quantity_name": "time",
  "label": "t2",
  "description": "A full echo echo acquisition along the t2 dimension using a Hahn_
↪ echo.",
  "reciprocal": {
    "coordinates_offset": "-8766.0626 Hz",
    "origin_offset": "79578822.26200001 Hz",
    "quantity_name": "frequency",
    "label": "29Si frequency shift"
  }
}
```

and

```
print(x[1].data_structure)
```

Out:

```
{
  "type": "monotonic",
  "coordinates": [
```

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```

    "1 s",
    "5 s",
    "10 s",
    "20 s",
    "40 s",
    "80 s"
  ],
  "quantity_name": "time",
  "label": "t1",
  "reciprocal": {
    "quantity_name": "frequency"
  }
}

```

respectively. The first dimension is uniformly spaced, as indicated by the *linear* subtype, while the second dimension is non-linear and monotonically sampled. The coordinates along the respective dimensions are

```

x0 = x[0].coordinates
print(x0)

```

Out:

```
[-41040. -40960. -40880. ...  40640.  40720.  40800.] us
```

```

x1 = x[1].coordinates
print(x1)

```

Out:

```
[ 1.  5. 10. 20. 40. 80.] s
```

Notice, the unit of `x0` is in microseconds. It might be convenient to convert the unit to milliseconds. To do so, use the `to()` method of the respective *Dimension* instance as follows,

```

x[0].to("ms")
x0 = x[0].coordinates
print(x0)

```

Out:

```
[-41.04 -40.96 -40.88 ...  40.64  40.72  40.8 ] ms
```

As before, the components of the dependent variable are accessed using the *components* attribute.

```
y00 = y[0].components[0]
```

Visualize the dataset

The `plot()` method is a very basic supplementary function for quick visualization of 1D and 2D datasets. You may use this function to plot the data from this example, however, we use the following script to visualize the data with projections onto the respective dimensions.

```

import matplotlib.pyplot as plt
from matplotlib.image import NonUniformImage
import numpy as np

```

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```

# Set the extents of the image.
# To set the independent variable coordinates at the center of each image
# pixel, subtract and add half the sampling interval from the first
# and the last coordinate, respectively, of the linearly sampled
# dimension, i.e., x0.
si = x[0].increment
extent = (
    (x0[0] - 0.5 * si).to("ms").value,
    (x0[-1] + 0.5 * si).to("ms").value,
    x1[0].value,
    x1[-1].value,
)

# Create a 2x2 subplot grid. The subplot at the lower-left corner is for
# the image intensity plot. The subplots at the top-left and bottom-right
# are for the data slice at the horizontal and vertical cross-section,
# respectively. The subplot at the top-right corner is empty.
fig, axi = plt.subplots(
    2, 2, gridspec_kw={"width_ratios": [4, 1], "height_ratios": [1, 4]}
)

# The image subplot quadrant.
# Add an image over a rectilinear grid. Here, only the real part of the
# data values is used.
ax = axi[1, 0]
im = NonUniformImage(ax, interpolation="nearest", extent=extent, cmap="bone_r")
im.set_data(x0, x1, y00.real / y00.real.max())

# Set up the grid lines.
ax.images.append(im)
for i in range(x1.size):
    ax.plot(x0, np.ones(x0.size) * x1[i], "k--", linewidth=0.5)
ax.grid(axis="x", color="k", linestyle="--", linewidth=0.5, which="both")

# Setup the axes, add the axes labels, and the figure title.
ax.set_xlim([extent[0], extent[1]])
ax.set_ylim([extent[2], extent[3]])
ax.set_xlabel(x[0].axis_label)
ax.set_ylabel(x[1].axis_label)
ax.set_title(y[0].name)

# Add the horizontal data slice to the top-left subplot.
ax0 = axi[0, 0]
top = y00[-1].real
ax0.plot(x0, top, "k", linewidth=0.5)
ax0.set_xlim([extent[0], extent[1]])
ax0.set_ylim([top.min(), top.max()])
ax0.axis("off")

# Add the vertical data slice to the bottom-right subplot.
ax1 = axi[1, 1]
right = y00[:, 513].real
ax1.plot(right, x1, "k", linewidth=0.5)
ax1.set_ylim([extent[2], extent[3]])
ax1.set_xlim([right.min(), right.max()])
ax1.axis("off")

```

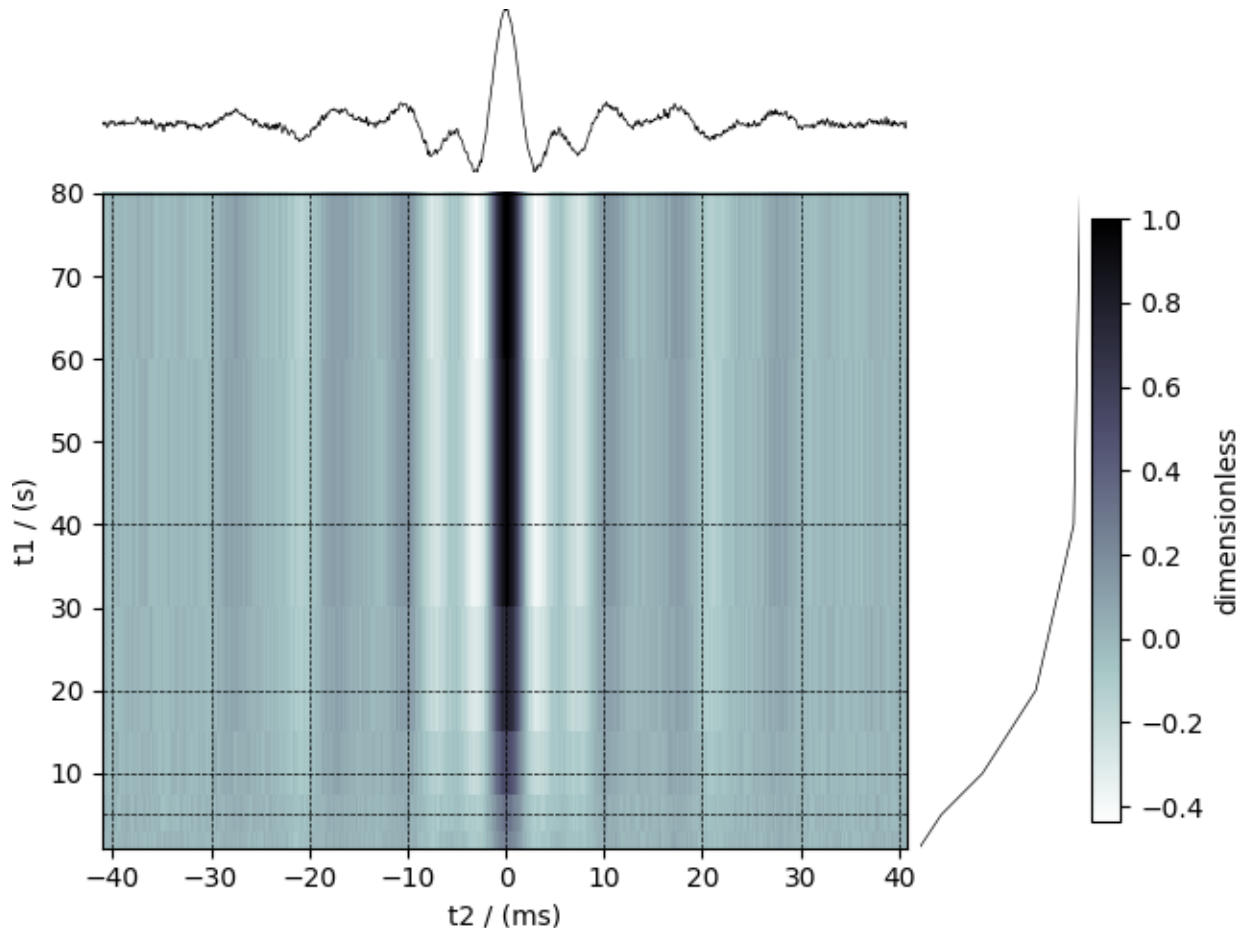
(continues on next page)

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```
# Add the colorbar and the component label.
cbar = fig.colorbar(im, ax=ax1)
cbar.ax.set_ylabel(y[0].axis_label[0])

# Turn off the axis system for the top-right subplot.
axi[0, 1].axis("off")

plt.tight_layout(pad=0.0, w_pad=0.0, h_pad=0.0)
plt.subplots_adjust(wspace=0.025, hspace=0.05)
plt.show()
```



Total running time of the script: (0 minutes 0.439 seconds)

4.2.3 Transmission Electron Microscopy (TEM) dataset

The following [TEM dataset](#) is a section of an early larval brain of *Drosophila melanogaster* used in the analysis of neuronal microcircuitry. The dataset was obtained from the [TrakEM2 tutorial](#) and subsequently converted to the CSD model file-format.

Let's import the CSD model data-file and look at its data structure.

```
import matplotlib.pyplot as plt
```

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```
import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/TEM/TEM.csd"
TEM = cp.load(filename)
print(TEM.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2016-03-12T16:41:00Z",
    "description": "TEM image of the early larval brain of Drosophila melanogaster_↵
↵used in the analysis of neuronal microcircuitry.",
    "dimensions": [
      {
        "type": "linear",
        "count": 512,
        "increment": "4.0 nm",
        "quantity_name": "length",
        "reciprocal": {
          "quantity_name": "wavenumber"
        }
      },
      {
        "type": "linear",
        "count": 512,
        "increment": "4.0 nm",
        "quantity_name": "length",
        "reciprocal": {
          "quantity_name": "wavenumber"
        }
      }
    ],
    "dependent_variables": [
      {
        "type": "internal",
        "numeric_type": "uint8",
        "quantity_type": "scalar",
        "components": [
          [
            "126, 107, ..., 164, 171"
          ]
        ]
      }
    ]
  }
}
```

This dataset consists of two linear dimensions and one single-component dependent variable. The tuple of the dimension and the dependent variable instances from this example are

```
x = TEM.dimensions
y = TEM.dependent_variables
```

and the respective coordinates (viewed only for the first ten coordinates),

```
print(x[0].coordinates[:10])
```

Out:

```
[ 0.  4.  8. 12. 16. 20. 24. 28. 32. 36.] nm
```

```
print(x[1].coordinates[:10])
```

Out:

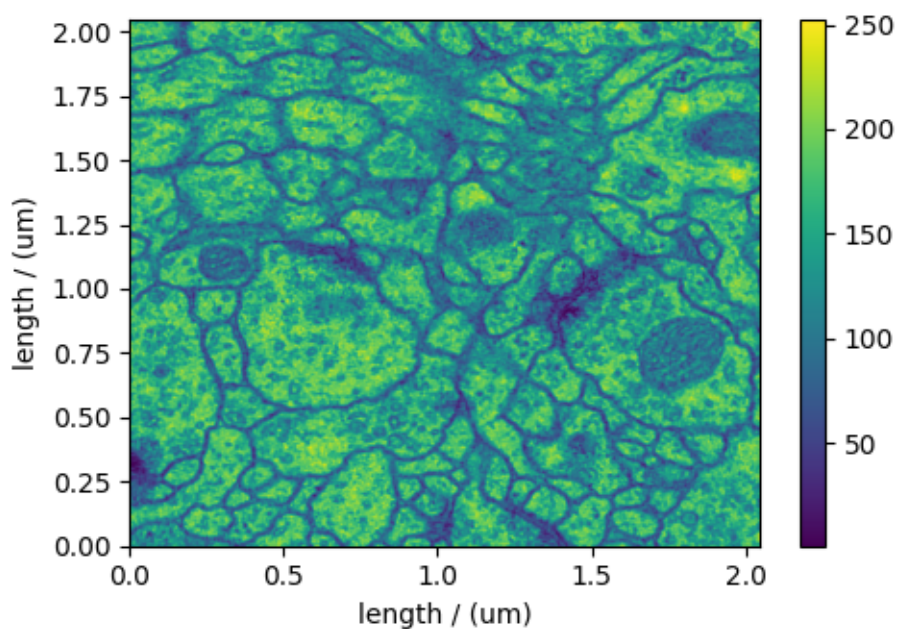
```
[ 0.  4.  8. 12. 16. 20. 24. 28. 32. 36.] nm
```

For convenience, let's convert the coordinates from *nm* to μm using the `to()` method of the respective *Dimension* instance,

```
x[0].to("μm")
x[1].to("μm")
```

and plot the data.

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
cb = ax.imshow(TEM, aspect="auto")
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 0.426 seconds)

4.2.4 Labeled Dataset

The CSD model also supports labeled dimensions. In the following example, we present a mixed *linear* and *labeled* two-dimensional dataset representing the population of the country as a function of time. The dataset is obtained from [The World Bank](#).

Import the *csdmpy* model and load the dataset.

```
import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/labeled/population.csd"
labeled_data = cp.load(filename)
```

The tuple of dimension and dependent variable objects from *labeled_data* instance are

```
x = labeled_data.dimensions
y = labeled_data.dependent_variables
```

Since one of the dimensions is a *labeled* dimension, let's make use of the *type* attribute of the dimension instances to find out which dimension is *labeled*.

```
print(x[0].type)
```

Out:

```
linear
```

```
print(x[1].type)
```

Out:

```
labeled
```

Here, the second dimension is the *labeled* dimension with¹

```
print(x[1].count)
```

Out:

```
263
```

labels, where the first five labels are

```
print(x[1].labels[:5])
```

Out:

```
['Aruba' 'Afghanistan' 'Angola' 'Albania' 'Andorra']
```

Note: For labeled dimensions, the *coordinates* attribute is an alias of the *labels* attribute.

```
print(x[1].coordinates[:5])
```

¹ In the CSD model, the attribute *count* is only valid for the *LinearDimension*. In *csdmpy*, however, the *count* attribute is valid for all dimension objects and returns an integer with the number of grid points along the dimension.

Out:

```
['Aruba' 'Afghanistan' 'Angola' 'Albania' 'Andorra']
```

The coordinates along the first dimension, viewed up to the first ten points, are

```
print(x[0].coordinates[:10])
```

Out:

```
[1960. 1961. 1962. 1963. 1964. 1965. 1966. 1967. 1968. 1969.] yr
```

Plotting the dataset

You may plot this dataset however you like. Here, we use a bar graph to represent the population of countries in the year 2017. The data corresponding to this year is a cross-section of the dependent variable at index 57 along the `x[0]` dimension.

```
print(x[0].coordinates[57])
```

Out:

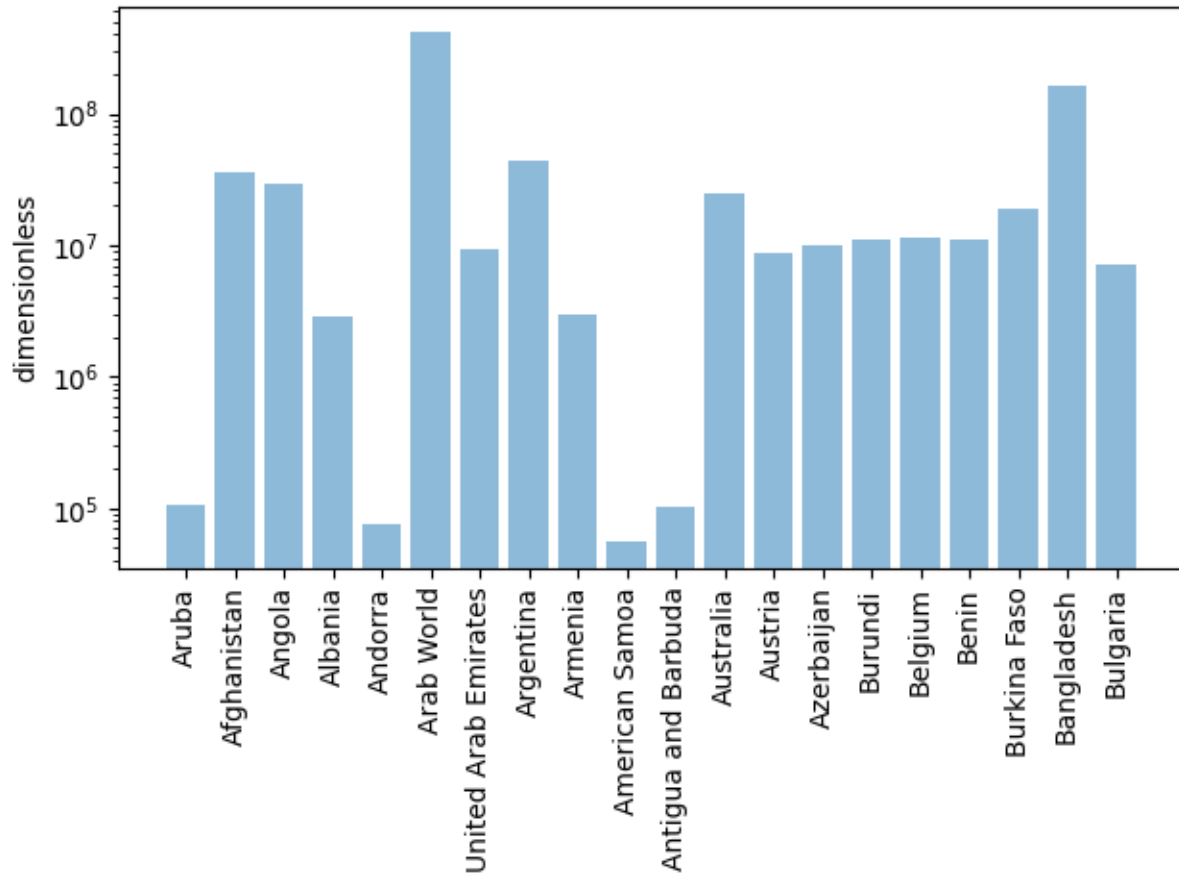
```
2017.0 yr
```

To keep the plot simple, we only plot the first 20 country labels along the `x[1]` dimension.

```
import matplotlib.pyplot as plt
import numpy as np

x_data = x[1].coordinates[:20]
x_pos = np.arange(20)
y_data = y[0].components[0][:20, 57]

plt.bar(x_data, y_data, align="center", alpha=0.5)
plt.xticks(x_pos, x_data, rotation=90)
plt.ylabel(y[0].axis_label[0])
plt.yscale("log")
plt.title(y[0].name)
plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 0.764 seconds)

4.3 Vector datasets

4.3.1 Vector, 1D{2} dataset

The 1D{2} datasets are one-dimensional, $d = 1$, with two-component dependent variable, $p = 2$. Such datasets are more common with the weather forecast, such as the wind velocity predicting at a location as a function of time.

The following is an example of a simulated 1D vector field dataset.

```
import matplotlib.pyplot as plt

import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/vector/1D_vector.csd"
vector_data = cp.load(filename)
print(vector_data.data_structure)
```

Out:

```
{
  "csdm": {
```

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```

"version": "1.0",
"read_only": true,
"timestamp": "2019-02-12T10:00:00Z",
"dimensions": [
  {
    "type": "linear",
    "count": 10,
    "increment": "1.0 m",
    "quantity_name": "length",
    "reciprocal": {
      "quantity_name": "wavenumber"
    }
  }
],
"dependent_variables": [
  {
    "type": "internal",
    "numeric_type": "float32",
    "quantity_type": "vector_2",
    "components": [
      [
        "0.6907923, 0.31292602, ..., 0.40570852, 0.7005596"
      ],
      [
        "0.5603441, 0.06866818, ..., 0.48200375, 0.15077808"
      ]
    ]
  }
]
}

```

The tuple of the dimension and dependent variable instances from this example are

```

x = vector_data.dimensions
y = vector_data.dependent_variables

```

with coordinates

```
print(x[0].coordinates)
```

Out:

```
[0. 1. 2. 3. 4. 5. 6. 7. 8. 9.] m
```

In this example, the components of the dependent variable are vectors as seen from the `quantity_type` attribute of the corresponding dependent variable instance.

```
print(y[0].quantity_type)
```

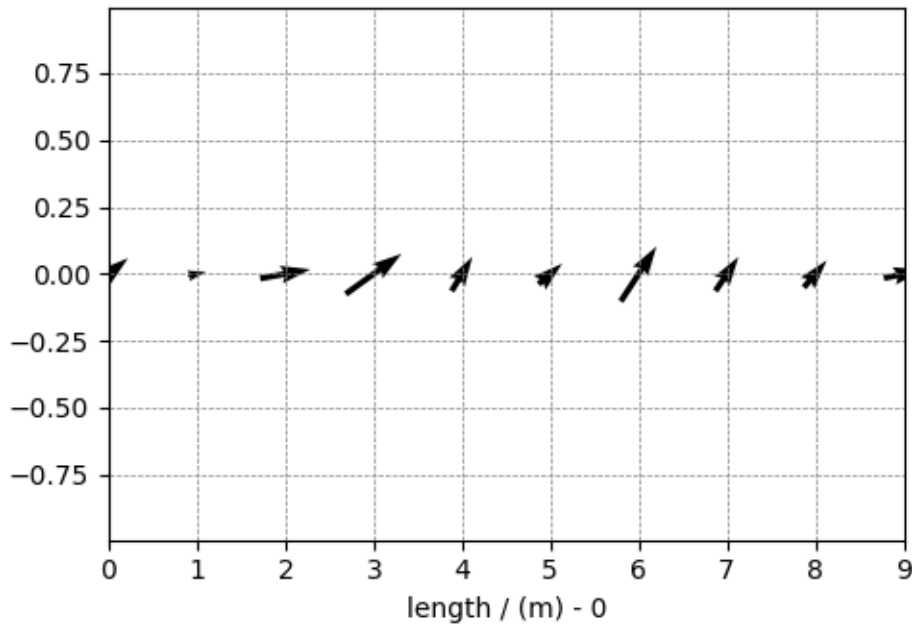
Out:

```
vector_2
```

From the value `vector_2`, `vector` indicates a vector dataset, while 2 indicates the number of vector components.

Visualizing the dataset

```
plt.figure(figsize=(5, 3.5))
cp.plot(vector_data)
plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 0.243 seconds)

4.3.2 Vector, 2D{2} dataset

The 2D{2} datasets are two-dimensional, $d = 2$, with one two-component dependent variable, $p = 2$. The following is an example of a simulated electric field vector dataset of a dipole as a function of two linearly sampled spatial dimensions.

```
import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/vector/electric_field/electric_field_base64.csd"

vector_data = cp.load(filename)
print(vector_data.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2014-09-30T11:16:33Z",
    "description": "A simulated electric field dataset from an electric dipole.",
    "dimensions": [
      {
        "type": "linear",
        "count": 64,
```

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```

        "increment": "0.0625 cm",
        "coordinates_offset": "-2.0 cm",
        "quantity_name": "length",
        "label": "x",
        "reciprocal": {
            "quantity_name": "wavenumber"
        }
    },
    {
        "type": "linear",
        "count": 64,
        "increment": "0.0625 cm",
        "coordinates_offset": "-2.0 cm",
        "quantity_name": "length",
        "label": "y",
        "reciprocal": {
            "quantity_name": "wavenumber"
        }
    }
],
"dependent_variables": [
    {
        "type": "internal",
        "name": "Electric field lines",
        "unit": "C^-1 * N",
        "quantity_name": "electric field strength",
        "numeric_type": "float32",
        "quantity_type": "vector_2",
        "components": [
            [
                "3.7466873e-07, 3.3365018e-07, ..., 3.5343004e-07, 4.0100363e-07"
            ],
            [
                "1.6129676e-06, 1.6765767e-06, ..., 1.846712e-06, 1.7754871e-06"
            ]
        ]
    }
]
}

```

The tuple of the dimension and dependent variable instances from this example are

```

x = vector_data.dimensions
y = vector_data.dependent_variables

```

with the respective coordinates (viewed only up to five values), as

```
print(x[0].coordinates[:5])
```

Out:

```
[-2.      -1.9375 -1.875  -1.8125 -1.75   ] cm
```

```
print(x[1].coordinates[:5])
```

Out:

```
[-2.      -1.9375 -1.875  -1.8125 -1.75   ] cm
```

The components of the dependent variable are vector components as seen from the `quantity_type` attribute of the corresponding dependent variable instance.

```
print(y[0].quantity_type)
```

Out:

```
vector_2
```

Visualizing the dataset

Let's visualize the vector data using the `streamplot` method from the matplotlib package. Before we could visualize, however, there is an initial processing step. We use the Numpy library for processing.

```
import numpy as np

X, Y = np.meshgrid(x[0].coordinates, x[1].coordinates) # (x, y) coordinate pairs
U, V = y[0].components[0], y[0].components[1] # U and V are the components
R = np.sqrt(U**2 + V**2) # The magnitude of the vector
R /= R.min() # Scaled magnitude of the vector
Rlog = np.log10(R) # Scaled magnitude of the vector on a log scale
```

In the above steps, we calculate the X-Y grid points along with a scaled magnitude of the vector dataset. The magnitude is scaled such that the minimum value is one. Next, calculate the log of the scaled magnitude to visualize the intensity on a logarithmic scale.

And now, the streamplot vector plot

```
import matplotlib.pyplot as plt

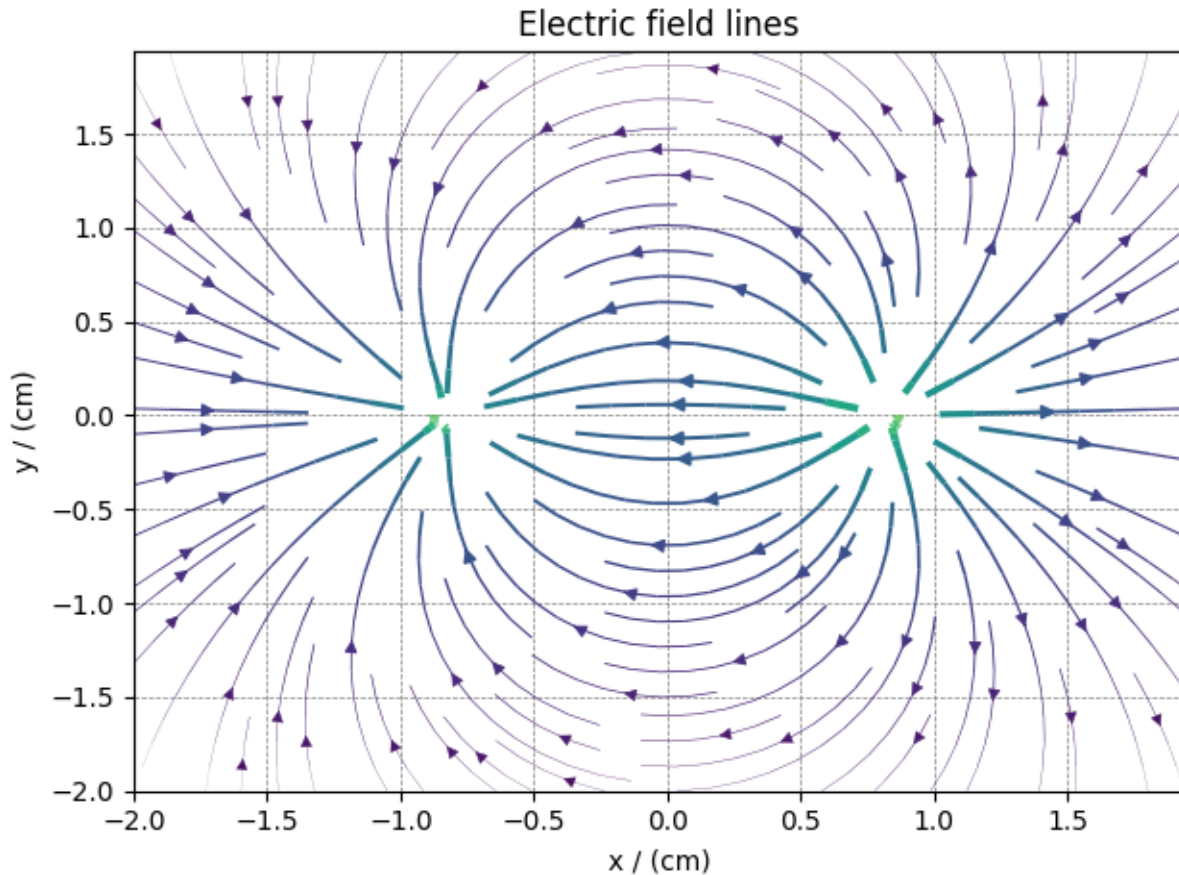
plt.streamplot(
    X.value, Y.value, U, V, density=1, linewidth=Rlog, color=Rlog, cmap="viridis"
)

plt.xlim([x[0].coordinates[0].value, x[0].coordinates[-1].value])
plt.ylim([x[1].coordinates[0].value, x[1].coordinates[-1].value])

# Set axes labels and figure title.
plt.xlabel(x[0].axis_label)
plt.ylabel(x[1].axis_label)
plt.title(y[0].name)

# Set grid lines.
plt.grid(color="gray", linestyle="--", linewidth=0.5)

plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 1.247 seconds)

4.4 Tensor datasets

4.4.1 Diffusion tensor MRI, 3D{6} dataset

The following is an example of a 3D{6} diffusion tensor MRI dataset with three spatial dimensions, $d = 3$, and one, $p = 1$, dependent-variable with six components. For illustration, we have reduced the size of the dataset. The complete diffusion tensor MRI dataset, in the CSDM format, is available [online](https://www.ssnmr.org/sites/default/files/CSDM). The original dataset¹ is also available.

Let's import the CSDM data-file and look at its data structure.

```
import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/tensor/human_brain/brain_MRI_reduced_example.csd"
diff_mri = cp.load(filename)
```

There are three linear dimensions in this dataset, corresponding to the x, y, and z spatial dimensions,

```
x = diff_mri.dimensions
print(x[0].label, x[1].label, x[2].label)
```

¹ Diffusion tensor MRI [data](https://www.ssnmr.org/sites/default/files/CSDM); 2000.

Out:

```
x y z
```

and one six-component dependent variables holding the diffusion tensor components. Because the diffusion tensor is a symmetric second-rank tensor, we only need six tensor components. The components of the tensor are ordered as

```
y = diff_mri.dependent_variables
print(y[0].component_labels)
```

Out:

```
['dxx', 'dxy', 'dxz', 'dyy', 'dyz', 'dzz']
```

The symmetric matrix information is also found with the *quantity_type* attribute,

```
print(y[0].quantity_type)
```

Out:

```
symmetric_matrix_3
```

which implies a 3x3 symmetric matrix.

Visualize the dataset

In the following, we visualize the isotropic diffusion coefficient, that is, the average of the d_{xx} , d_{yy} , and d_{zz} tensor components. Since it's a three-dimensional dataset, we'll visualize the projections onto the three dimensions.

```
# the isotropic diffusion coefficient.
# component at index 0 = dxx
# component at index 3 = dyy
# component at index 5 = dzz
isotropic_diffusion = (y[0].components[0] + y[0].components[3] + y[0].components[5]) /
→ 3
```

In the following, we use certain features of the *csdm* module. Please refer to *Generating CSDM objects* for further details.

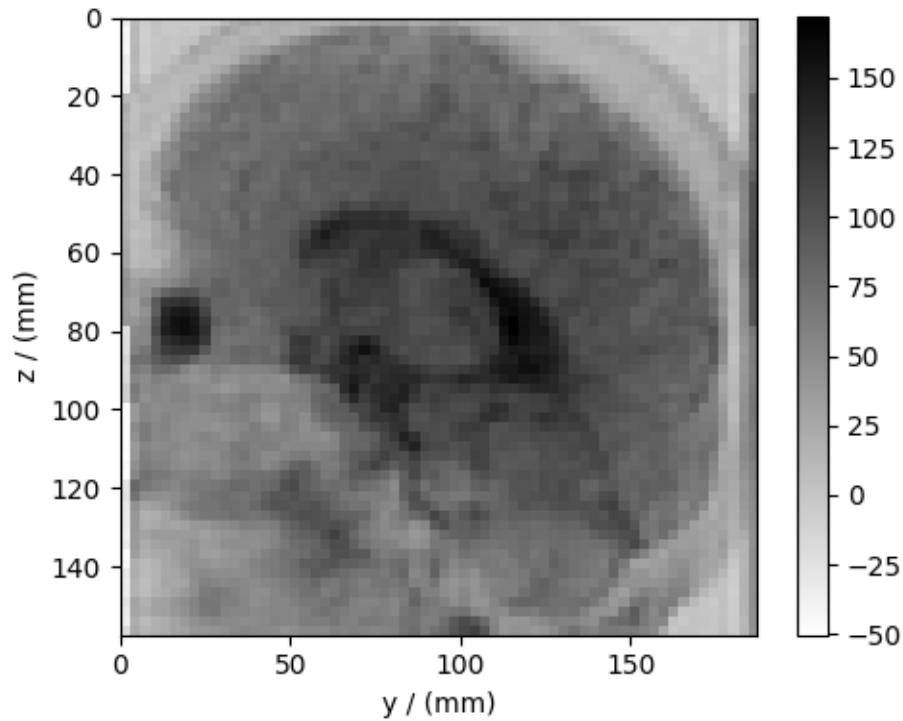
```
# Create a new csdm object from the isotropic diffusion coefficient array.
new_csdm = cp.as_csdm(isotropic_diffusion, quantity_type="scalar")

# Add the dimensions from `diff_mri` object to the `new_csdm` object.
for i, dim in enumerate(x):
    new_csdm.dimensions[i] = dim
```

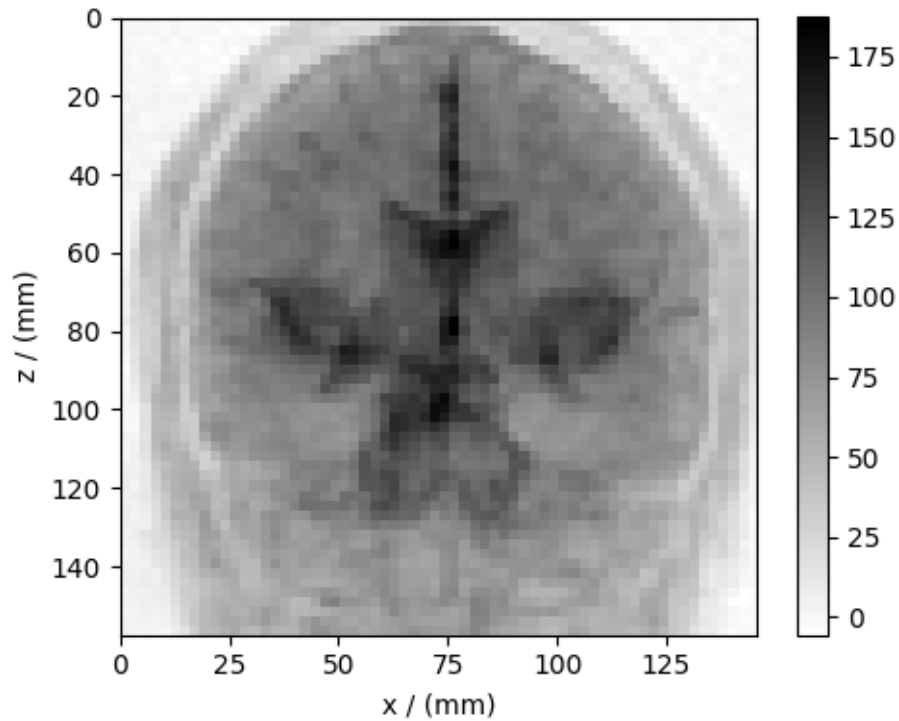
Now, we can plot the projections of the isotropic diffusion coefficients along the respective dimensions as

```
import matplotlib.pyplot as plt

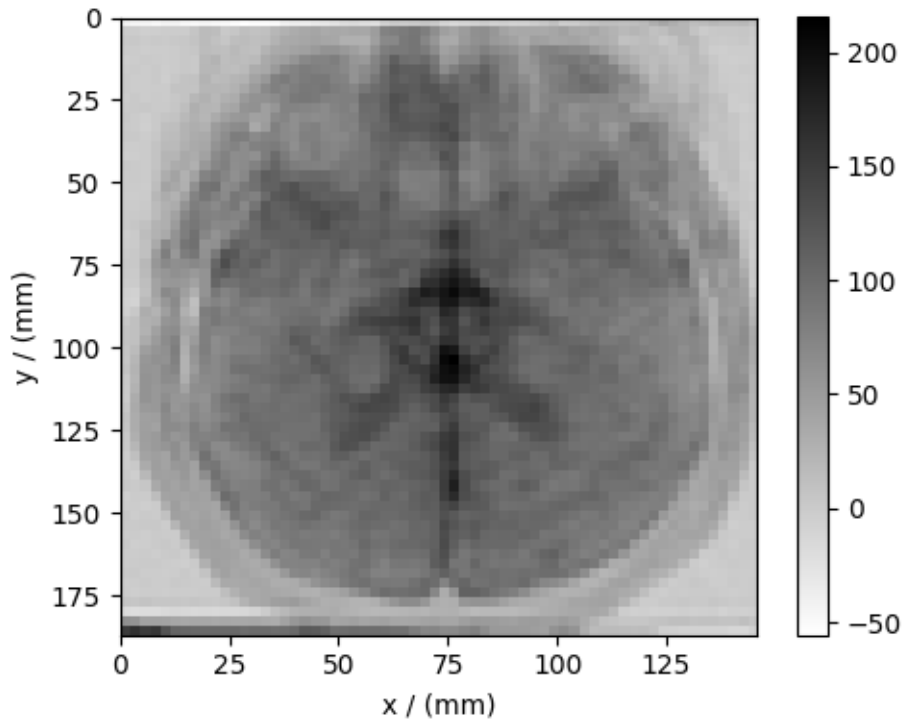
# projection along the x-axis.
plt.figure(figsize=(5, 4))
ax = plt.subplot(projection="csdm")
cb = ax.imshow(new_csdm.sum(axis=0), cmap="gray_r", origin="upper", aspect="auto")
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```

```
# projection along the y-axis.
plt.figure(figsize=(5, 4))
ax = plt.subplot(projection="csdm")
cb = ax.imshow(new_csdm.sum(axis=1), cmap="gray_r", origin="upper", aspect="auto")
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



```
# projection along the z-axis.
plt.figure(figsize=(5, 4))
ax = plt.subplot(projection="csdm")
cb = ax.imshow(new_csdm.sum(axis=2), cmap="gray_r", origin="upper", aspect="auto")
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



Citation

Total running time of the script: (0 minutes 0.990 seconds)

4.5 Pixel datasets

4.5.1 Image, 2D{3} datasets

The 2D{3} dataset is two dimensional, $d = 2$, with a single three-component dependent variable, $p = 3$. A common example from this subset is perhaps the RGB image dataset. An RGB image dataset has two spatial dimensions and one dependent variable with three components corresponding to the red, green, and blue color intensities.

The following is an example of an RGB image dataset.

```
import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/image/raccoon_image.csd"
ImageData = cp.load(filename)
print(ImageData.data_structure)
```

Out:

```
{
  "csdm": {
    "version": "1.0",
    "read_only": true,
    "timestamp": "2016-03-12T16:41:00Z",
```

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```

"tags": [
    "raccoon",
    "image",
    "Judy Weggelaar"
],
"description": "An RGB image of a raccoon face.",
"dimensions": [
    {
        "type": "linear",
        "count": 1024,
        "increment": "1.0",
        "label": "horizontal index"
    },
    {
        "type": "linear",
        "count": 768,
        "increment": "1.0",
        "label": "vertical index"
    }
],
"dependent_variables": [
    {
        "type": "internal",
        "name": "raccoon",
        "numeric_type": "uint8",
        "quantity_type": "pixel_3",
        "component_labels": [
            "red",
            "green",
            "blue"
        ],
        "components": [
            [
                "121, 138, ..., 119, 118"
            ],
            [
                "112, 129, ..., 155, 154"
            ],
            [
                "131, 148, ..., 93, 92"
            ]
        ]
    }
]
}

```

The tuple of the dimension and dependent variable instances from `ImageData` instance are

```

x = ImageData.dimensions
y = ImageData.dependent_variables

```

respectively. There are two dimensions, and the coordinates along each dimension are

```

print("x0 =", x[0].coordinates[:10])

```

Out:

```
x0 = [0. 1. 2. 3. 4. 5. 6. 7. 8. 9.]
```

```
print("x1 =", x[1].coordinates[:10])
```

Out:

```
x1 = [0. 1. 2. 3. 4. 5. 6. 7. 8. 9.]
```

respectively, where only first ten coordinates along each dimension is displayed.

The dependent variable is the image data, as also seen from the *quantity_type* attribute of the corresponding *DependentVariable* instance.

```
print(y[0].quantity_type)
```

Out:

```
pixel_3
```

From the value *pixel_3*, *pixel* indicates a pixel data, while *3* indicates the number of pixel components.

As usual, the components of the dependent variable are accessed through the *components* attribute. To access the individual components, use the appropriate array indexing. For example,

```
print(y[0].components[0])
```

Out:

```
[[121 138 153 ... 119 131 139]
 [ 89 110 130 ... 118 134 146]
 [ 73  94 115 ... 117 133 144]
 ...
 [ 87  94 107 ... 120 119 119]
 [ 85  95 112 ... 121 120 120]
 [ 85  97 111 ... 120 119 118]]
```

will return an array with the first component of all data values. In this case, the components correspond to the red color intensity, also indicated by the corresponding component label. The label corresponding to the component array is accessed through the *component_labels* attribute with appropriate indexing, that is

```
print(y[0].component_labels[0])
```

Out:

```
red
```

To avoid displaying larger output, as an example, we print the shape of each component array (using Numpy array's *shape* attribute) for the three components along with their respective labels.

```
print(y[0].component_labels[0], y[0].components[0].shape)
```

Out:

```
red (768, 1024)
```

```
print(y[0].component_labels[1], y[0].components[1].shape)
```

Out:

```
green (768, 1024)
```

```
print(y[0].component_labels[2], y[0].components[2].shape)
```

Out:

```
blue (768, 1024)
```

The shape (768, 1024) corresponds to the number of points from the each dimension instances.

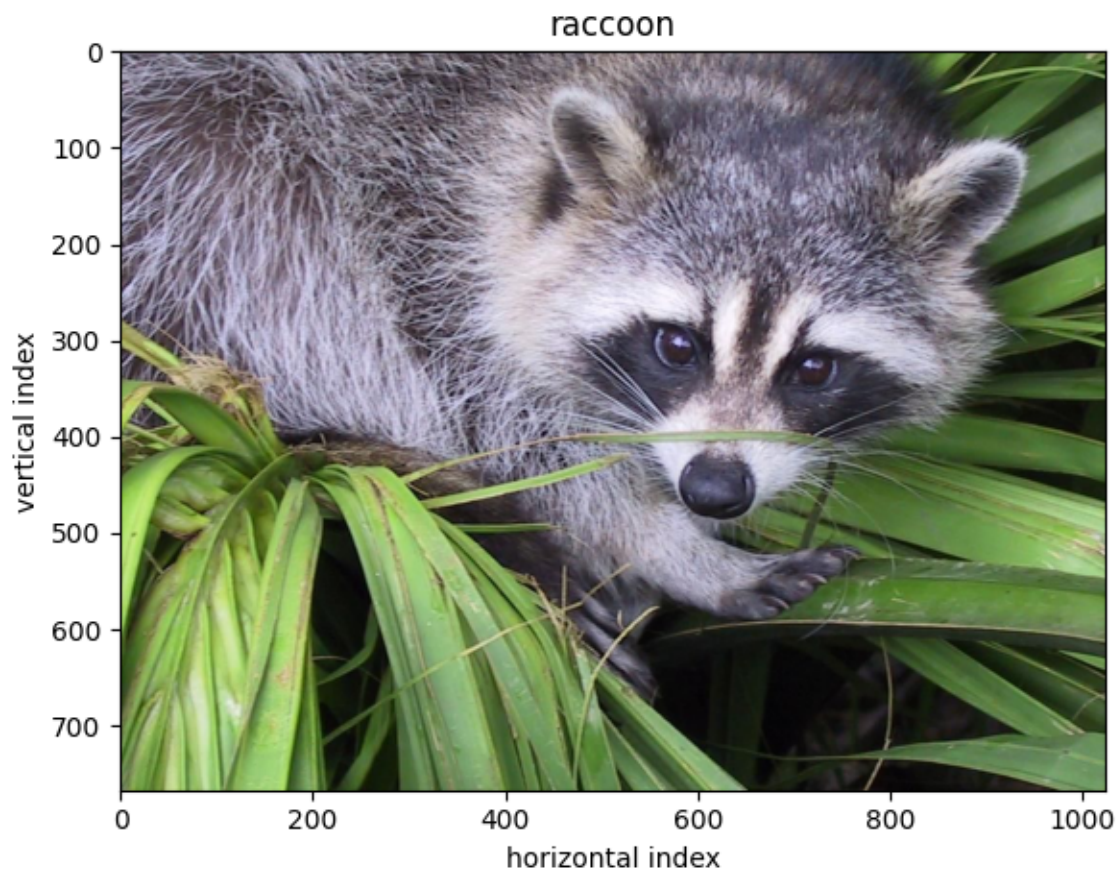
Note: In this example, since there is only one dependent variable, the index of `y` is set to zero, which is `y[0]`. The indices for the `components` and the `component_labels`, on the other hand, spans through the number of components.

Now, to visualize the dataset as an RGB image,

```
import matplotlib.pyplot as plt

ax = plt.subplot(projection="csdm")
ax.imshow(ImageData, origin="upper")
plt.tight_layout()

plt.show()
```



Total running time of the script: (0 minutes 0.578 seconds)

4.6 Correlated datasets

The Core Scientific Dataset Model (CSDM) supports multiple dependent variables that share the same d -dimensional coordinate grid, where $d \geq 0$. We call the dependent variables from these datasets as *correlated datasets*. Following are a few examples of the correlated dataset.

4.6.1 Scatter, 0D{1,1} dataset

We start with a 0D{1,1} correlated dataset, that is, a dataset without a coordinate grid. A 0D{1,1} dataset has no dimensions, $d = 0$, and two single-component dependent variables. In the following example¹, the two *correlated* dependent variables are the ^{29}Si - ^{29}Si nuclear spin couplings, 2J , across a Si-O-Si linkage, and the s -character product on the O and two Si along the Si-O bond across the Si-O-Si linkage.

Let's import the dataset.

```
import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/correlatedDataset/0D_dataset/J_vs_s.csd"
zero_d_dataset = cp.load(filename)
```

Since the dataset has no dimensions, the value of the *dimensions* attribute of the *CSDM* class is an empty tuple,

```
print(zero_d_dataset.dimensions)
```

Out:

```
[]
```

The *dependent_variables* attribute, however, holds two dependent-variable objects. The data structure from the two dependent variables is

```
print(zero_d_dataset.dependent_variables[0].data_structure)
```

Out:

```
{
  "type": "internal",
  "name": "Gaussian computed J-couplings",
  "unit": "Hz",
  "quantity_name": "frequency",
  "numeric_type": "float32",
  "quantity_type": "scalar",
  "component_labels": [
    "J-coupling"
  ],
  "components": [
    [
      "-1.87378, -1.42918, ..., 25.1742, 26.0608"
    ]
  ]
}
```

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¹ Srivastava DJ, Florian P, Baltisberger JH, Grandinetti PJ. Correlating geminal couplings to structure in framework silicates. Phys Chem Chem Phys. 2018;20:562571. DOI:10.1039/C7CP06486A

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```
]
]
}
```

and

```
print(zero_d_dataset.dependent_variables[1].data_structure)
```

Out:

```
{
  "type": "internal",
  "name": "product of s-characters",
  "unit": "%",
  "numeric_type": "float32",
  "quantity_type": "scalar",
  "component_labels": [
    "s-character product"
  ],
  "components": [
    [
      "0.8457453, 0.8534185, ..., 1.5277092, 1.5289451"
    ]
  ]
}
```

respectively.

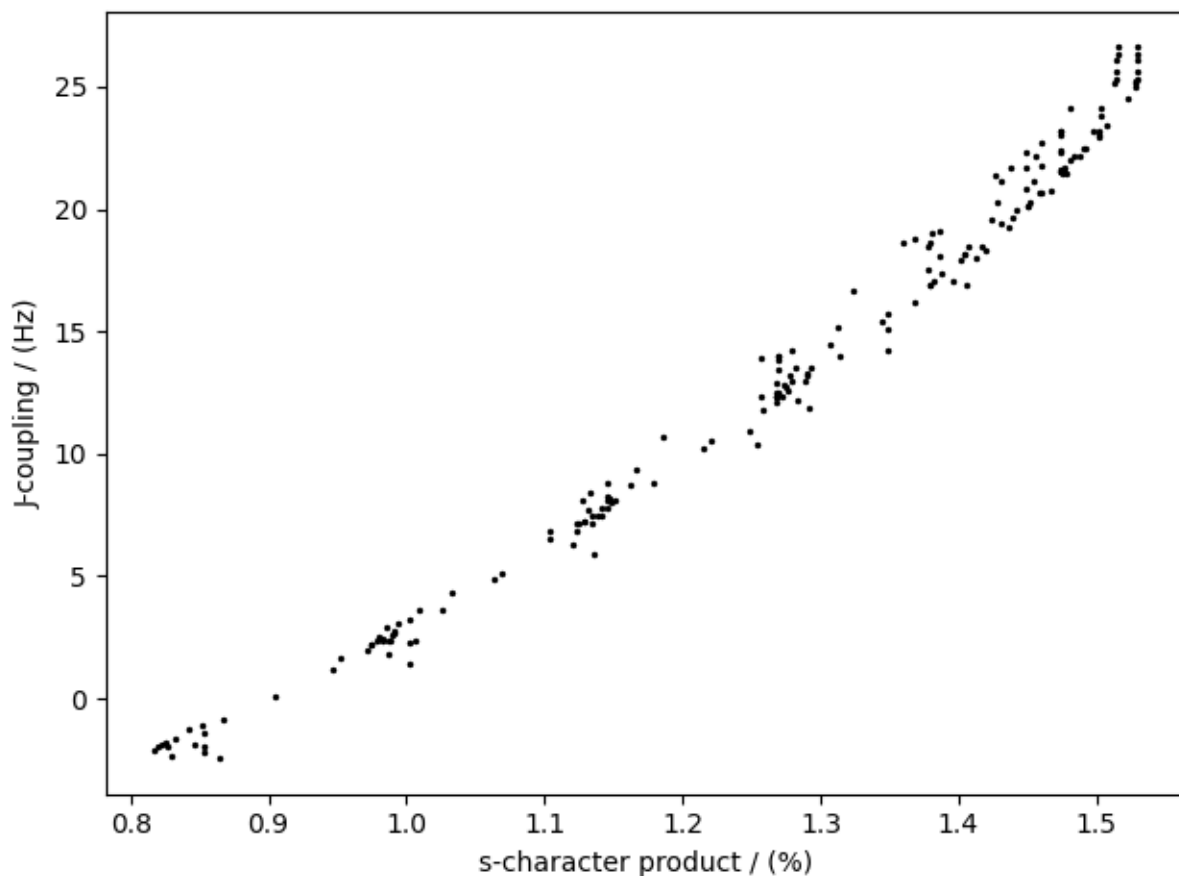
Visualizing the dataset

The correlation plot of the dependent-variables from the dataset is shown below.

```
import matplotlib.pyplot as plt

y0 = zero_d_dataset.dependent_variables[0]
y1 = zero_d_dataset.dependent_variables[1]

plt.scatter(y1.components[0], y0.components[0], s=2, c="k")
plt.xlabel(y1.axis_label[0])
plt.ylabel(y0.axis_label[0])
plt.tight_layout()
plt.show()
```

Citation

Total running time of the script: (0 minutes 0.501 seconds)

4.6.2 Meteorological, 2D{1,1,2,1,1} dataset

The following dataset is obtained from [NOAA/NCEP Global Forecast System \(GFS\) Atmospheric Model](https://www.ssnmr.org/sites/default/files/CSDM) and subsequently converted to the CSD model file-format. The dataset consists of two spatial dimensions describing the geographical coordinates of the earth surface and five dependent variables with 1) surface temperature, 2) air temperature at 2 m, 3) relative humidity, 4) air pressure at sea level as the four *scalar* quantity_type dependent variables, and 5) wind velocity as the two-component *vector*, quantity_type dependent variable.

Let's import the *csdmpy* module and load this dataset.

```
import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"
filename = f"{domain}/correlatedDataset/forecast/NCEI.csd"
multi_dataset = cp.load(filename)
```

The tuple of dimension and dependent variable objects from *multi_dataset* instance are

```
x = multi_dataset.dimensions
y = multi_dataset.dependent_variables
```

The dataset contains two dimension objects representing the *longitude* and *latitude* of the earth's surface. The labels along these respective dimensions are

```
print(x[0].label)
```

Out:

```
longitude
```

```
print(x[1].label)
```

Out:

```
latitude
```

There are a total of five dependent variables stored in this dataset. The first dependent variable is the surface air temperature. The data structure of this dependent variable is

```
print(y[0].data_structure)
```

Out:

```
{
  "type": "internal",
  "description": "The label 'tmpsfc' is the standard attribute name for 'surface air_
→temperature'.",
  "name": "Surface temperature",
  "unit": "K",
  "quantity_name": "temperature",
  "numeric_type": "float64",
  "quantity_type": "scalar",
  "component_labels": [
    "tmpsfc - surface air temperature"
  ],
  "components": [
    [
      "292.8152160644531, 293.0152282714844, ..., 301.8152160644531, 303.8152160644531
→"
    ]
  ]
}
```

If you have followed all previous examples, the above data structure should be self-explanatory.

We will use the following snippet to plot the dependent variables of scalar *quantity_type*.

```
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.axes_grid1 import make_axes_locatable

def plot_scalar(yx):
    fig, ax = plt.subplots(1, 1, figsize=(6, 3))
```

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```

# Set the extents of the image plot.
extent = [
    x[0].coordinates[0].value,
    x[0].coordinates[-1].value,
    x[1].coordinates[0].value,
    x[1].coordinates[-1].value,
]

# Add the image plot.
im = ax.imshow(yx.components[0], origin="lower", extent=extent, cmap="coolwarm")

# Add a colorbar.
divider = make_axes_locatable(ax)
cax = divider.append_axes("right", size="5%", pad=0.05)
cbar = fig.colorbar(im, cax)
cbar.ax.set_ylabel(yx.axis_label[0])

# Set up the axes label and figure title.
ax.set_xlabel(x[0].axis_label)
ax.set_ylabel(x[1].axis_label)
ax.set_title(yx.name)

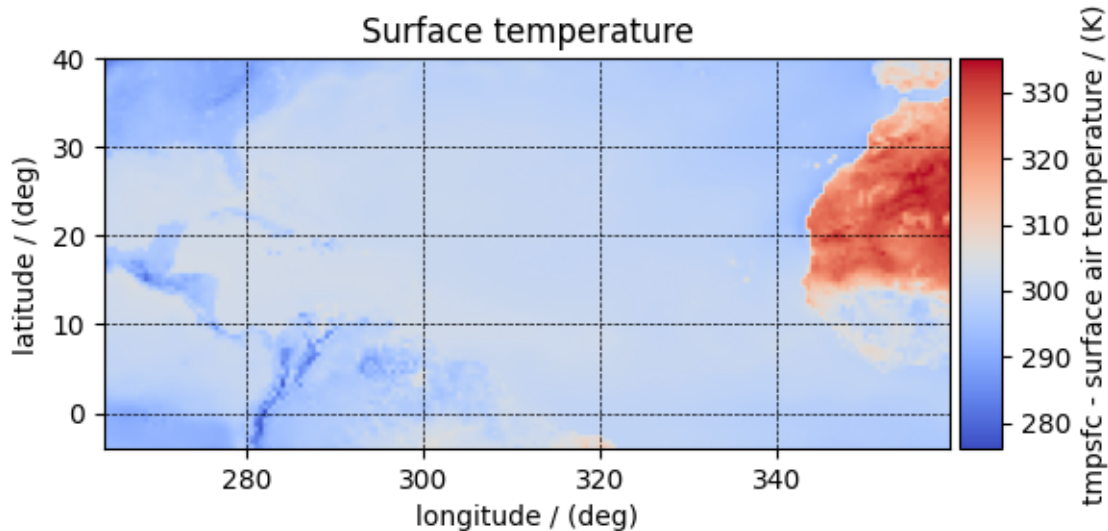
# Set up the grid lines.
ax.grid(color="k", linestyle="--", linewidth=0.5)

plt.tight_layout()
plt.show()

```

Now to plot the data from the dependent variable.

```
plot_scalar(y[0])
```



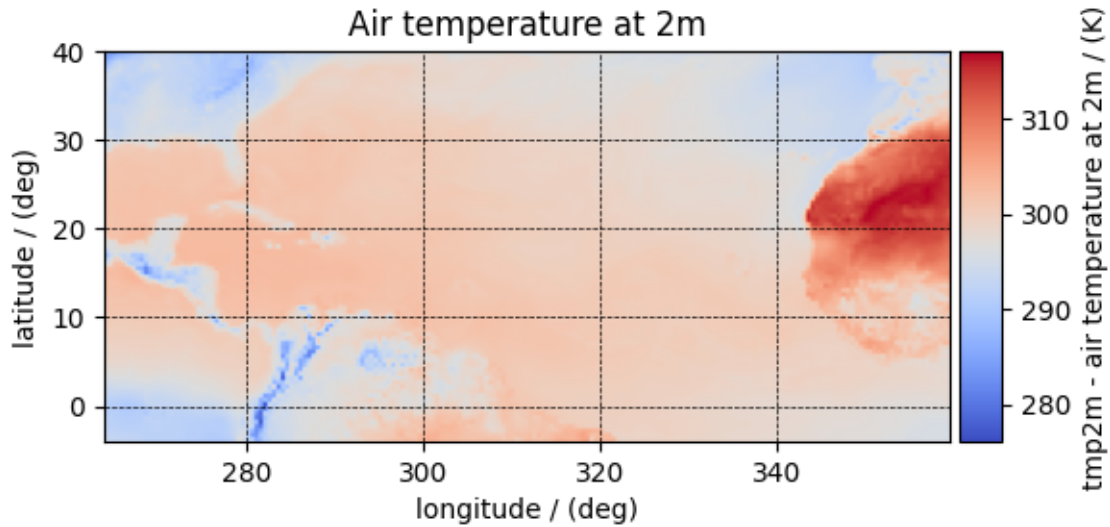
Similarly, other dependent variables with their respective plots are

```
print(y[1].name)
```

Out:

```
Air temperature at 2m
```

```
plot_scalar(y[1])
```

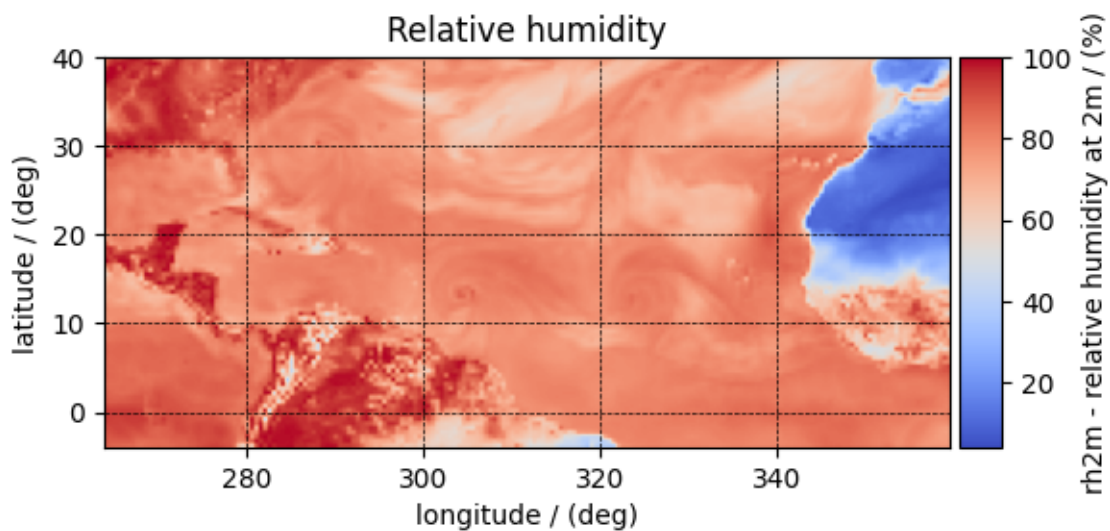


```
print(y[3].name)
```

Out:

```
Relative humidity
```

```
plot_scalar(y[3])
```

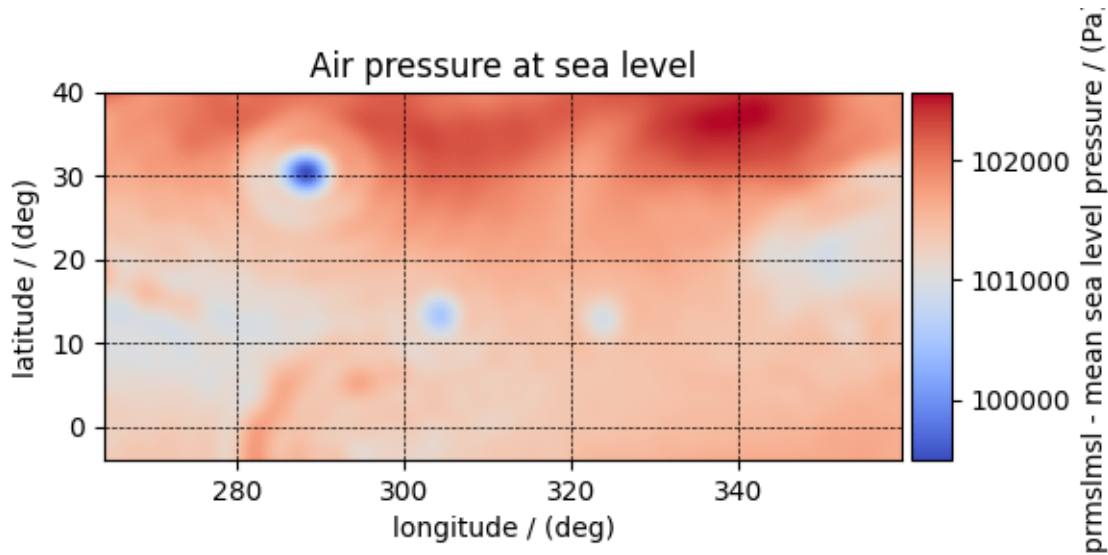


```
print(y[4].name)
```

Out:

```
Air pressure at sea level
```

```
plot_scalar(y[4])
```



Notice, we skipped the dependent variable at index two. The reason is that this particular dependent variable is a vector dataset,

```
print(y[2].quantity_type)
```

Out:

```
vector_2
```

```
print(y[2].name)
```

Out:

```
Wind velocity
```

which represents the wind velocity, and requires a vector visualization routine. To visualize the vector data, we use the matplotlib quiver plot.

```
def plot_vector(yx):
    fig, ax = plt.subplots(1, 1, figsize=(6, 3))
    magnitude = np.sqrt(yx.components[0] ** 2 + yx.components[1] ** 2)

    cf = ax.quiver(
        x[0].coordinates,
        x[1].coordinates,
        yx.components[0],
        yx.components[1],
        magnitude,
        pivot="middle",
        cmap="inferno",
    )
    divider = make_axes_locatable(ax)
```

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```

cax = divider.append_axes("right", size="5%", pad=0.05)
cbar = fig.colorbar(cf, cax)
cbar.ax.set_ylabel(yx.name + " / " + str(yx.unit))

ax.set_xlim([x[0].coordinates[0].value, x[0].coordinates[-1].value])
ax.set_ylim([x[1].coordinates[0].value, x[1].coordinates[-1].value])

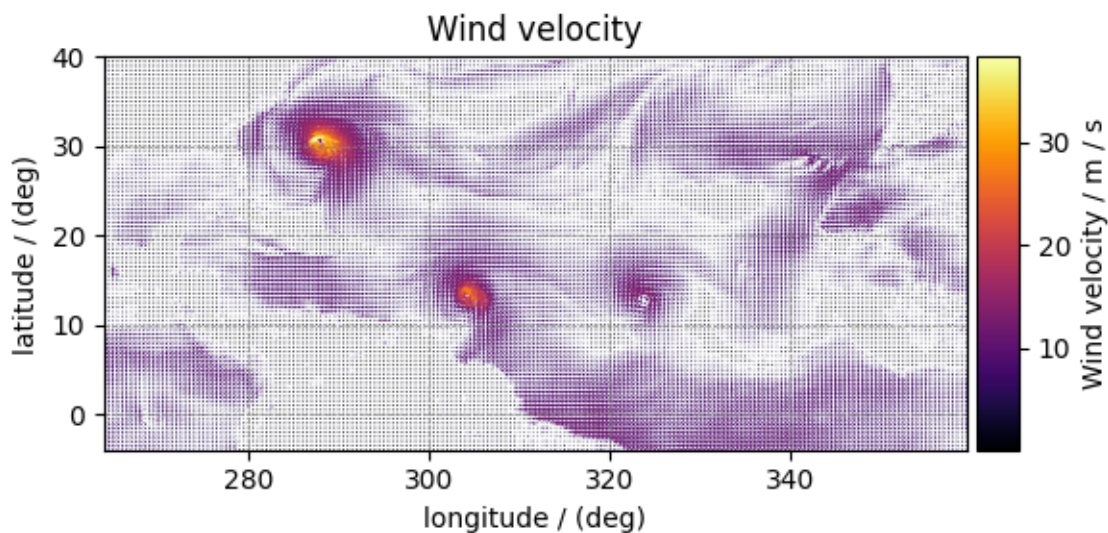
# Set axes labels and figure title.
ax.set_xlabel(x[0].axis_label)
ax.set_ylabel(x[1].axis_label)
ax.set_title(yx.name)

# Set grid lines.
ax.grid(color="gray", linestyle="--", linewidth=0.5)

plt.tight_layout()
plt.show()

```

```
plot_vector(y[2])
```



Total running time of the script: (0 minutes 1.543 seconds)

4.6.3 Astronomy, 2D{1,1,1} dataset (Creating image composition)

More often, the images in astronomy are a composition of datasets measured at different wavelengths over an area of the sky. In this example, we illustrate the use of the CSDM file-format, and *csdmpy* module, beyond just reading a CSDM-compliant file. We'll use these datasets, and compose an image, using Numpy arrays. The following example is the data from the *Eagle Nebula* acquired at three different wavelengths and serialized as a CSDM compliant file.

Import the *csdmpy* model and load the dataset.

```

import csdmpy as cp

domain = "https://www.ssnmr.org/sites/default/files/CSDM"

```

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```
filename = f"{domain}/EagleNebula/eagleNebula_base64.csdf"
eagle_nebula = cp.load(filename)
```

Let's get the tuple of dimension and dependent variable objects from the `eagle_nebula` instance.

```
x = eagle_nebula.dimensions
y = eagle_nebula.dependent_variables
```

Before we compose an image, let's take a look at the individual dependent variables from the dataset. The three dependent variables correspond to signal acquisition at 502 nm, 656 nm, and 673 nm, respectively. This information is also listed in the `name` attribute of the respective dependent variable instances,

```
print(y[0].name)
```

Out:

```
Eagle Nebula acquired @ 502 nm
```

```
print(y[1].name)
```

Out:

```
Eagle Nebula acquired @ 656 nm
```

```
print(y[2].name)
```

Out:

```
Eagle Nebula acquired @ 673 nm
```

Data Visualization

For convince, let's view this CSDM object with three dependent-variables as three CSDM objects, each with a single dependent variable. We use the `split()` method.

```
data0, data1, data2 = eagle_nebula.split()
```

Here, `data0`, `data1`, and `data2` contain the dependent-variable at index 0, 1, 2 of the `eagle_nebula` object. Let's plot the data from these dependent variables.

```
import matplotlib.pyplot as plt

_, ax = plt.subplots(3, 1, figsize=(6, 14), subplot_kw={"projection": "csdm"})

ax[0].imshow(data0 / data0.max(), cmap="bone", vmax=0.1, aspect="auto")
ax[1].imshow(data1 / data1.max(), cmap="bone", vmax=0.1, aspect="auto")
ax[2].imshow(data2 / data2.max(), cmap="bone", vmax=0.1, aspect="auto")

plt.tight_layout()
plt.show()
```

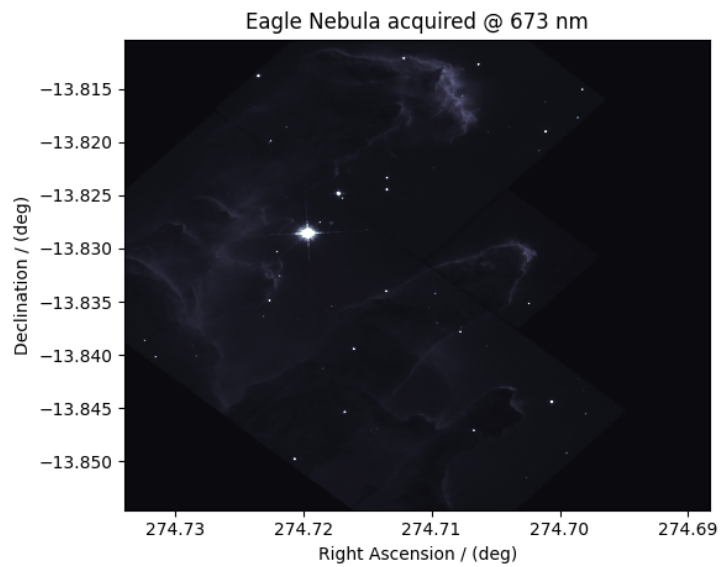
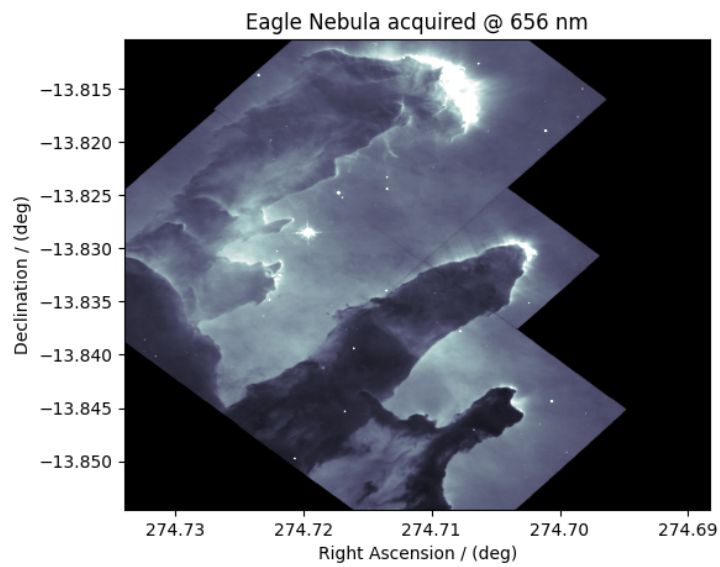
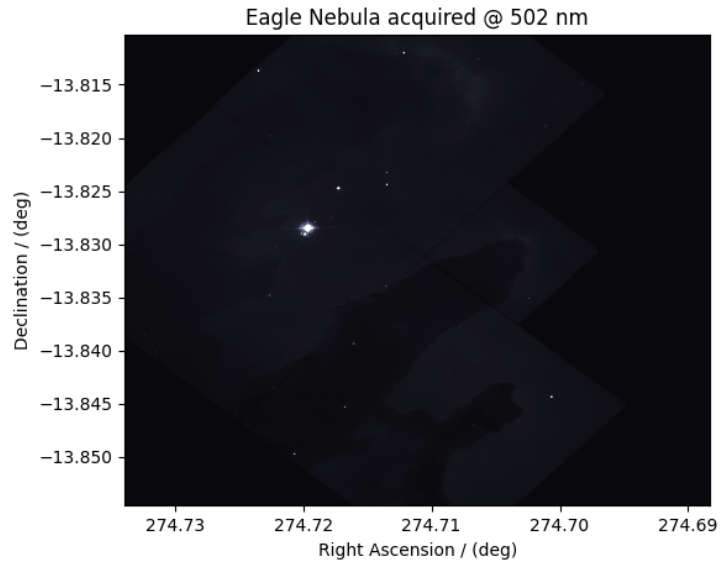


Image composition

```
import numpy as np
```

For the image composition, we assign the dependent variable at index zero as the blue channel, index one as the green channel, and index two as the red channel of an RGB image. Start with creating an empty array to hold the RGB dataset.

```
shape = y[0].components[0].shape + (3,)
image = np.empty(shape, dtype=np.float64)
```

Here, `image` is the variable we use for storing the composition. Add the respective dependent variables to the designated color channel in the `image` array,

```
image[..., 0] = y[2].components[0] / y[2].components[0].max() # red channel
image[..., 1] = y[1].components[0] / y[1].components[0].max() # green channel
image[..., 2] = y[0].components[0] / y[0].components[0].max() # blue channel
```

Following the intensity plot of the individual dependent variables, see the above figures, it is evident that the component intensity from `y[1]` and, therefore, the green channel dominates the other two. If we plot the `image` data, the image will be saturated with green intensity. To attain a color-balanced image, we arbitrarily scale the intensities from the three channels. You may choose any scaling factor. Each scaling factor will produce a different composition. In this example, we use the following,

```
image[..., 0] = np.clip(image[..., 0] * 65.0, 0, 1) # red channel
image[..., 1] = np.clip(image[..., 1] * 7.50, 0, 1) # green channel
image[..., 2] = np.clip(image[..., 2] * 75.0, 0, 1) # blue channel
```

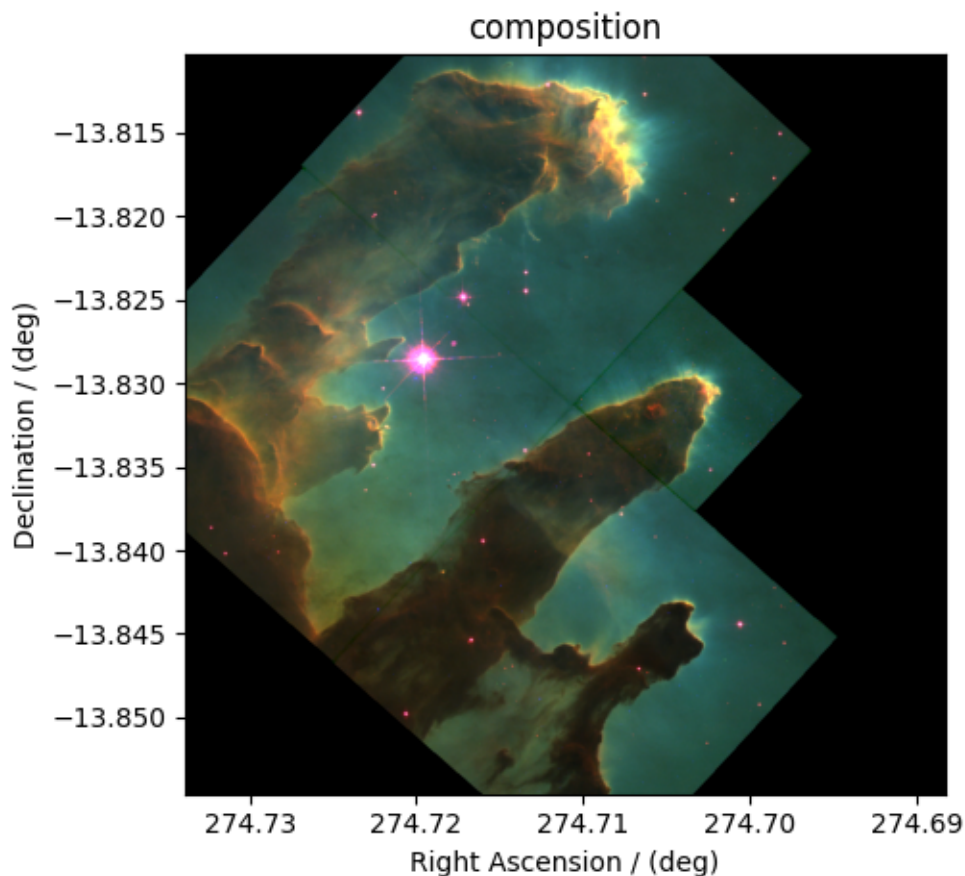
Now to plot this composition.

```
# Set the extents of the image plot.
extent = [
    x[0].coordinates[0].value,
    x[0].coordinates[-1].value,
    x[1].coordinates[0].value,
    x[1].coordinates[-1].value,
]

# add figure
plt.imshow(image, origin="lower", extent=extent)

plt.xlabel(x[0].axis_label)
plt.ylabel(x[1].axis_label)
plt.title("composition")

plt.tight_layout()
plt.show()
```



Total running time of the script: (0 minutes 2.558 seconds)

4.7 Sparse datasets

4.7.1 Sparse along one dimension, 2D{1,1} dataset

The following is an example¹ of a 2D{1,1} sparse dataset with two-dimensions, $d = 2$, and two, $p = 2$, sparse single-component dependent-variables, where the component is sparsely sampled along one dimension. The following is an example of a hypercomplex acquisition of the NMR dataset.

Let's import the CSD model data-file.

```
import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/sparse/iglu_1d.csd"
sparse_1d = cp.load(filename)
```

There are two linear dimensions and two single-component sparse dependent variables. The tuple of the dimension and the dependent variable instances are

¹ Balsgart NM, Vosegaard T., Fast Forward Maximum entropy reconstruction of sparsely sampled data., J Magn Reson. 2012, 223, 164-169. doi: 10.1016/j.jmr.2012.07.002

```
x = sparse_1d.dimensions
y = sparse_1d.dependent_variables
```

The coordinates, viewed only for the first ten coordinates, are

```
print(x[0].coordinates[:10])
```

Out:

```
[ 0.  192.  384.  576.  768.  960. 1152. 1344. 1536. 1728.] us
```

```
print(x[1].coordinates[:10])
```

Out:

```
[ 0.  192.  384.  576.  768.  960. 1152. 1344. 1536. 1728.] us
```

Converting the coordinates to *ms*.

```
x[0].to("ms")
x[1].to("ms")
```

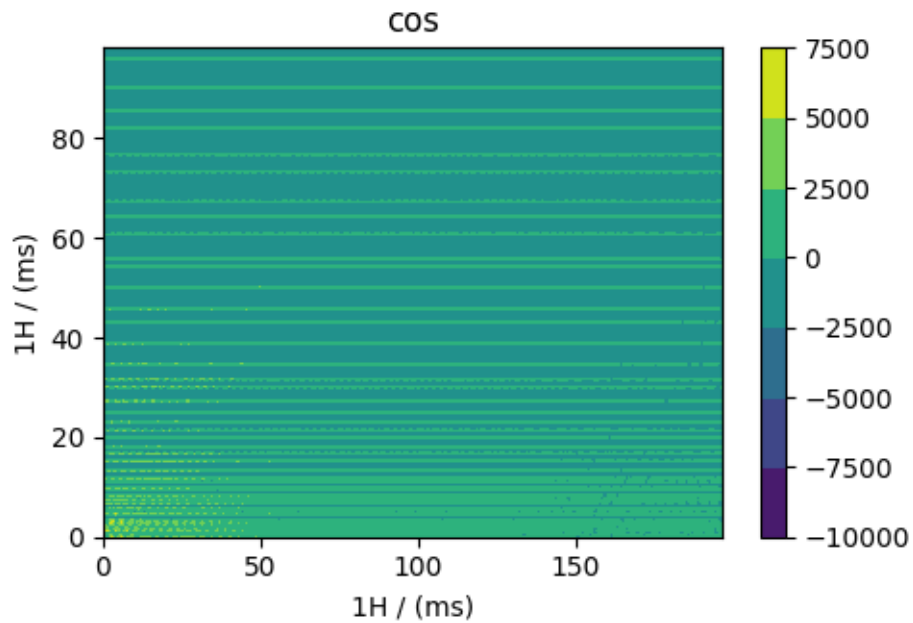
Visualizing the dataset

```
import matplotlib.pyplot as plt

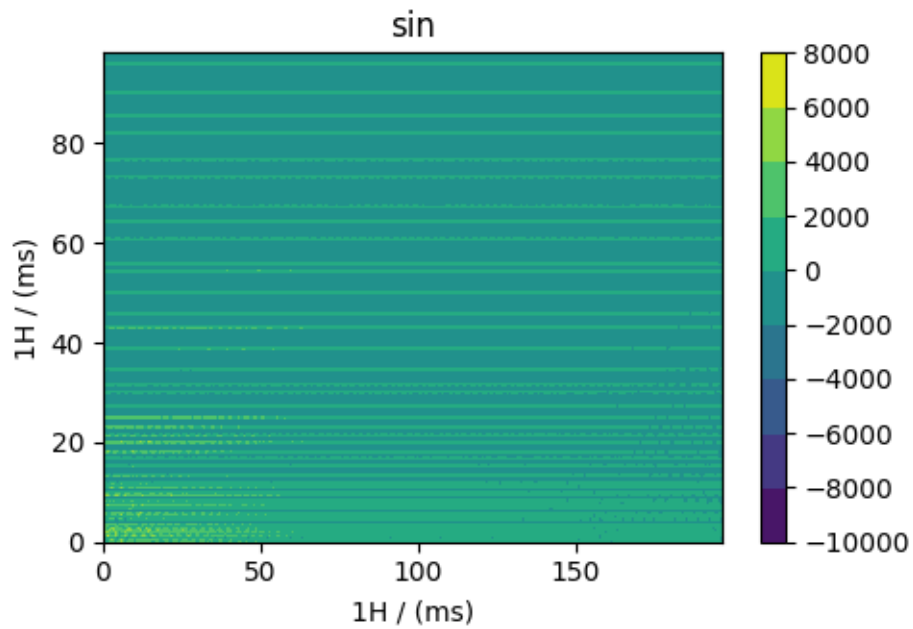
# split the CSDM object with two dependent variables into two CSDM objects with single
# dependent variables.

cos, sin = sparse_1d.split()

# cosine data
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
cb = ax.contourf(cos.real)
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



```
# sine data
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
cb = ax.contourf(sin.real)
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



Citation

Total running time of the script: (0 minutes 1.172 seconds)

4.7.2 Sparse along two dimensions, 2D{1,1} dataset

The following is an example¹ of a 2D{1,1} sparse dataset with two-dimensions, $d = 2$, and two, $p = 2$, sparse single-component dependent-variables, where the component is sparsely sampled along two dimensions. The following is an example of a hypercomplex acquisition of the NMR dataset.

Let's import the CSDM model data-file and look at its data structure.

```
import csdmpy as cp

filename = "https://www.ssnmr.org/sites/default/files/CSDM/sparse/iglu_2d.csd"
sparse_2d = cp.load(filename)
```

There are two linear dimensions and two single-component sparse dependent variables. The tuple of the dimension and the dependent variable instances are

```
x = sparse_2d.dimensions
y = sparse_2d.dependent_variables
```

The coordinates, viewed only for the first ten coordinates, are

```
print(x[0].coordinates[:10])
```

Out:

```
[ 0. 192. 384. 576. 768. 960. 1152. 1344. 1536. 1728.] us
```

```
print(x[1].coordinates[:10])
```

Out:

```
[ 0. 192. 384. 576. 768. 960. 1152. 1344. 1536. 1728.] us
```

Converting the coordinates to *ms*.

```
x[0].to("ms")
x[1].to("ms")
```

Visualize the dataset

```
import matplotlib.pyplot as plt

# split the CSDM object with two dependent variables into two CSDM objects with single
# dependent variables.

cos, sin = sparse_2d.split()

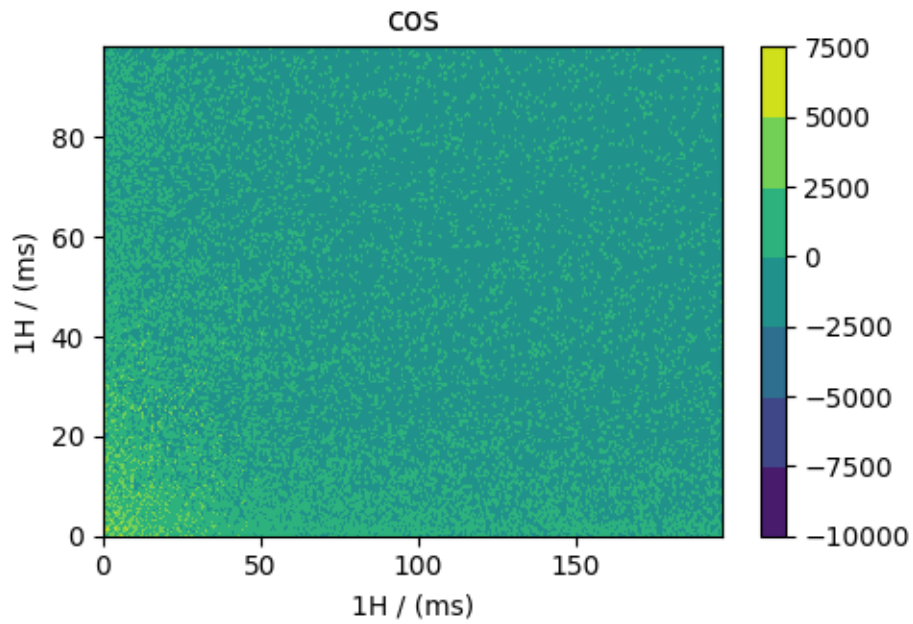
# cosine data
plt.figure(figsize=(5, 3.5))
```

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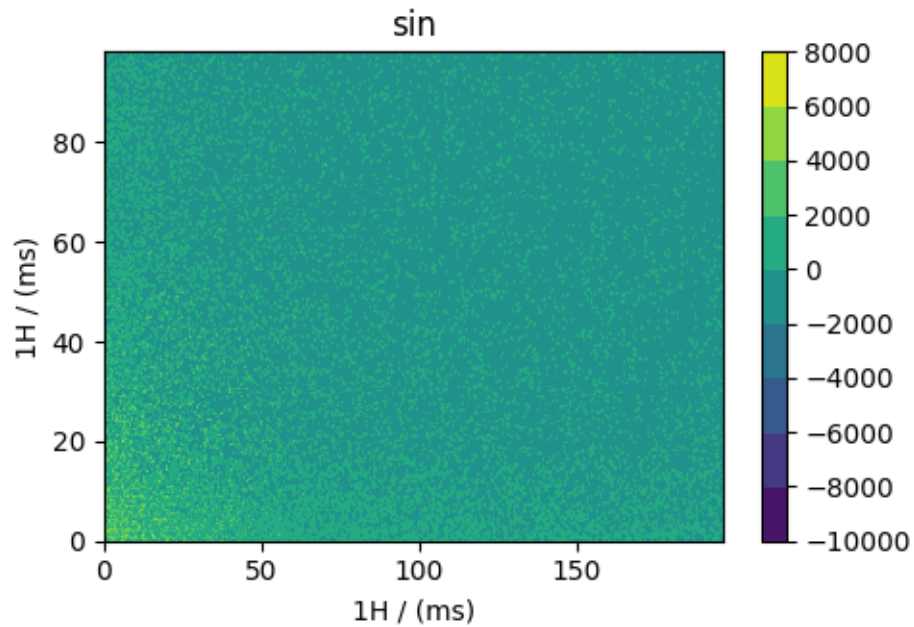
¹ Balsgart NM, Vosegaard T., Fast Forward Maximum entropy reconstruction of sparsely sampled data., J Magn Reson. 2012, 223, 164-169. doi: 10.1016/j.jmr.2012.07.002

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```
ax = plt.subplot(projection="csdm")
cb = ax.contourf(cos.real)
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



```
# sine data
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
cb = ax.contourf(sin.real)
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



Citation

Total running time of the script: (0 minutes 1.097 seconds)

SERIALIZING CSDM OBJECT TO FILE

An instance of a *CSDM* object is serialized as a csdf/csdfc JSON-format file with the `save()` method. When serializing the dependent-variable from the CSDM object to the data-file, the *csdmpy* module uses the value of the dependent variable's *encoding* attribute to determine the encoding type of the serialized data. There are three encoding types for the dependent variables:

- none
- base64
- raw

Note: By default, all instances of *DependentVariable* from a *CSDM* object are serialized as base64 strings.

For the following examples, consider `data` as an instance of the *CSDM* class.

To serialize a dependent variable with a given encoding type, set the value of its *encoding* attribute to the respective encoding. For example,

As “none” encoding

```
>>> data.dependent_variables[0].encoding = "none"
>>> data.save('my_file.csdf')
```

The above code will serialize the dependent variable at index zero to a JSON file, *my_file.csdf*, where each component of the dependent variable is serialized as an array of JSON number.

As “base64” encoding

```
>>> data.dependent_variables[0].encoding = "base64"
>>> data.save('my_file.csdf')
```

The above code will serialize the dependent variable at index zero to a JSON file, *my_file.csdf*, where each component of the dependent variable is serialized as a base64 string.

As “raw” encoding

```
>>> data.dependent_variables[0].encoding = "raw"
>>> data.save('my_file.csdfe')
```

The above code will serialize the metadata from the dependent variable at index zero to a JSON file, *my_file.csdfe*, which includes a link to an external file where the components of the respective dependent variable are serialized as a binary array. The binary file is named, *my_file_0.dat*, where *my_file* is the filename from the argument of the `save` method, and *0* is the index number of the dependent variable from the CSDM object.

Multiple encoding types

In the case of multiple dependent-variables, you may choose to serialize each dependent variables with a different encoding, for example,

```
>>> my_data.dependent_variables[0].encoding = "raw"
>>> my_data.dependent_variables[1].encoding = "base64"
>>> my_data.dependent_variables[2].encoding = "none"
>>> my_data.dependent_variables[3].encoding = "base64"
>>> my_data.save('my_file.csdfe')
```

In the above example, `my_data` is a CSDM object containing four *DependentVariable* objects. Here, we serialize the dependent variable at index two with `none`, the dependent variables at index one and three with `base64`, and the dependent variables at index zero with `raw` encoding, respectively.

Note: Because an instance of the dependent variable, that is, the index zero in the above example, is set to be serialized with an external subtype, the corresponding file should be saved with a `.csdfe` extension.

USING CSDMPY OBJECTS

The *csdmpy* module is not just designed for deserializing and serializing the *.csdf* or *.csdfe* files. It can also be used to create new datasets, a feature that is most useful when converting datasets to CSDM compliant files.

6.1 Generating Dimension objects

6.1.1 LinearDimension

A LinearDimension is where the coordinates are regularly spaced along the dimension. This type of dimension is frequently encountered in many scientific datasets. There are several ways to generate LinearDimension.

Using the *Dimension* class.

```
>>> import csdmpy as cp
>>> x = cp.Dimension(
...     type="linear",
...     count=10,
...     increment="0.1 s",
...     label="time",
...     description="A temporal dimension.",
... )
>>> print(x)
LinearDimension([0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9] s)
```

Using the *LinearDimension* class.

```
>>> import csdmpy as cp
>>> x1 = cp.LinearDimension(
...     count=10, increment="0.1 s", label="time", description="A temporal dimension."
... )
>>> print(x1)
LinearDimension([0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9] s)
```

Using NumPy array

You may also create a LinearDimension object from a one-dimensional NumPy array using the *as_dimension()* method.

```
>>> import numpy as np
>>> array = np.arange(10) * 0.1
>>> x2 = cp.as_dimension(array)
>>> print(x2)
LinearDimension([0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9])
```

Note, the Dimension object `x2` is dimensionless. You can create a physical dimension by either providing an appropriate unit as the argument to the `as_dimension()` method,

```
>>> x3 = cp.as_dimension(array, unit="s")
>>> print(x3)
LinearDimension([0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9] s)
```

or appropriately multiplying the dimension object `x2` with a `ScalarQuantity`.

```
>>> x2 *= cp.ScalarQuantity("s")
>>> print(x2)
LinearDimension([0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9] s)
```

The coordinates of the `x2` `LinearDimension` object are

```
>>> x2.coordinates
<Quantity [0. , 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9] s>
```

where `x2.coordinates` is a `Quantity` array. The value and the unit of the quantity instance are

```
>>> # To access the numpy array
>>> numpy_array = x.coordinates.value
>>> print("numpy array =", numpy_array)
numpy array = [0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9]

>>> # To access the astropy.unit
>>> unit = x.coordinates.unit
>>> print("unit =", unit)
unit = s
```

respectively.

Note: When generating `LinearDimension` objects from NumPy array, the NumPy array must be one-dimensional and regularly spaced.

```
>>> cp.as_dimension(np.arange(20).reshape(2, 10))
ValueError: Cannot convert a 2 dimensional array to a Dimension object.
```

6.1.2 MonotonicDimension

A `MonotonicDimension` is one where the coordinates along the dimension are sampled monotonically, that is, either strictly increasing or decreasing coordinates. Like the `LinearDimension`, there are several ways to generate a `MonotonicDimension`.

Using the `Dimension` class.

```
>>> import csdmpy as cp
>>> x = cp.Dimension(
...     type="monotonic",
...     coordinates=[
...         "10ns",
...         "100ns",
...         "1µs",
...         "10µs",
```

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```

...     "100µs",
...     "1ms",
...     "10ms",
...     "100ms",
...     "1s",
...     "10s",
... ],
... )
>>> print(x)
MonotonicDimension([1.e+01 1.e+02 1.e+03 1.e+04 1.e+05 1.e+06 1.e+07 1.e+08 1.e+09 1.
↪e+10] ns)

```

Using the *MonotonicDimension* class.

```

>>> import numpy as np
>>> array = np.asarray(
...     [
...         -0.28758166,
...         -0.22712233,
...         -0.19913859,
...         -0.17235106,
...         -0.1701172,
...         -0.10372635,
...         -0.01817061,
...         0.05936719,
...         0.18141424,
...         0.34758913,
...     ]
... )
>>> x = cp.MonotonicDimension(coordinates=array) * cp.ScalarQuantity("cm")
>>> print(x)
MonotonicDimension([-0.28758166 -0.22712233 -0.19913859 -0.17235106 -0.1701172 -0.
↪10372635
-0.01817061  0.05936719  0.18141424  0.34758913] cm)

```

In the above example, we generate a dimensionless *MonotonicDimension* from the NumPy array and then scale its dimensionality by multiplying the object with an appropriate *ScalarQuantity*.

From numpy arrays.

Use the *as_dimension()* method to convert a numpy array as a *Dimension* object.

```

>>> numpy_array = 10 ** (np.arange(10) / 10)
>>> x_dim = cp.as_dimension(numpy_array, unit="A")
>>> print(x_dim)
MonotonicDimension([1.          1.25892541 1.58489319 1.99526231 2.51188643 3.16227766
3.98107171 5.01187234 6.30957344 7.94328235] A)

```

When generating *MonotonicDimension* object using the Numpy array, the array must be monotonic, that is, either strictly increasing or decreasing. An exception will be raised otherwise.

```

>>> numpy_array = np.random.rand(10)
>>> x_dim = cp.as_dimension(numpy_array)
Exception: Invalid array for Dimension object.

```

6.1.3 LabeledDimension

A LabeledDimension is one where the coordinates along the dimension are string labels. You can similarly generate a labeled dimension.

Using the *Dimension* class.

```
>>> import csdmpy as cp
>>> x = cp.Dimension(type="labeled", labels=["The", "great", "circle"])
>>> print(x)
LabeledDimension(['The' 'great' 'circle'])
```

Using the *LabeledDimension* class.

```
>>> x = cp.LabeledDimension(labels=["The", "great", "circle"])
>>> print(x)
LabeledDimension(['The' 'great' 'circle'])
```

From numpy arrays or python list.

Use the *as_dimension()* method to convert a numpy array as a Dimension object.

```
>>> array = ["The", "great", "circle"]
>>> x = cp.as_dimension(array)
>>> print(x)
LabeledDimension(['The' 'great' 'circle'])
```

6.2 Generating DependentVariable objects

A DependentVariable is where the responses of the multi-dimensional dataset reside. There are two types of DependentVariable objects, *internal* and *external*. In this section, we show how to generate DependentVariable objects of both types.

6.2.1 InternalDependentVariable

Single component dependent variable

Using the *DependentVariable* class.

```
>>> dv1 = cp.DependentVariable(
...     type="internal",
...     quantity_type="scalar",
...     components=np.arange(10000),
...     unit="J",
...     description="A sample internal dependent variable.",
... )
>>> print(dv1)
DependentVariable(
[[ 0  1  2 ... 9997 9998 9999]] J, quantity_type=scalar, numeric_type=int64)
```

Using NumPy array

Use the *as_dependent_variable()* method to convert a NumPy array into a DependentVariable object. Note, this method returns a view of the NumPy array as the DependentVariable object.

```
>>> dv1 = cp.as_dependent_variable(np.arange(10000).astype(np.complex64), unit="J")
>>> print(dv1)
DependentVariable(
[[0.000e+00+0.j 1.000e+00+0.j 2.000e+00+0.j ... 9.997e+03+0.j
  9.998e+03+0.j 9.999e+03+0.j]] J, quantity_type=scalar, numeric_type=complex64)
```

You may additionally provide the `quantity_type` for the dependent variable,

```
>>> dv2 = cp.as_dependent_variable(
...     np.arange(10000).astype(np.complex64), quantity_type="pixel_1"
... )
>>> print(dv2)
DependentVariable(
[[0.000e+00+0.j 1.000e+00+0.j 2.000e+00+0.j ... 9.997e+03+0.j
  9.998e+03+0.j 9.999e+03+0.j]], quantity_type=pixel_1, numeric_type=complex64)
```

Multi-component dependent variable

To generate a multi-component `DependentVariable` object, add an appropriate `quantity_type` value, see [QuantityType](#) for details.

Using the `DependentVariable` class.

```
>>> dv1 = cp.DependentVariable(
...     type="internal",
...     quantity_type="vector_2",
...     components=np.arange(10000),
...     unit="J",
...     description="A sample internal dependent variable.",
... )
>>> print(dv1)
DependentVariable(
[[ 0  1  2 ... 4997 4998 4999]
 [5000 5001 5002 ... 9997 9998 9999]] J, quantity_type=vector_2, numeric_type=int64)
```

The above example generates a two-component dependent variable.

Using NumPy array

```
>>> dv1 = cp.as_dependent_variable(
...     np.arange(9000).astype(np.complex64), unit="m/s", quantity_type="symmetric_
↪matrix_3"
... )
>>> print(dv1)
DependentVariable(
[[0.000e+00+0.j 1.000e+00+0.j 2.000e+00+0.j ... 1.497e+03+0.j
  1.498e+03+0.j 1.499e+03+0.j]
 [1.500e+03+0.j 1.501e+03+0.j 1.502e+03+0.j ... 2.997e+03+0.j
  2.998e+03+0.j 2.999e+03+0.j]
 [3.000e+03+0.j 3.001e+03+0.j 3.002e+03+0.j ... 4.497e+03+0.j
  4.498e+03+0.j 4.499e+03+0.j]
 [4.500e+03+0.j 4.501e+03+0.j 4.502e+03+0.j ... 5.997e+03+0.j
  5.998e+03+0.j 5.999e+03+0.j]
 [6.000e+03+0.j 6.001e+03+0.j 6.002e+03+0.j ... 7.497e+03+0.j
  7.498e+03+0.j 7.499e+03+0.j]
```

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```
[7.500e+03+0.j 7.501e+03+0.j 7.502e+03+0.j ... 8.997e+03+0.j
 8.998e+03+0.j 8.999e+03+0.j]] m / s, quantity_type=symmetric_matrix_3, numeric_
↪type=complex64)
```

The above example generates a six-component dependent variable.

Note: For multi-component `DependentVariable` objects, the size of the NumPy array must be an integer multiple of the total number of components.

```
>>> d1 = cp.as_dependent_variable(np.arange(127), quantity_type="pixel_2")
ValueError: cannot reshape array of size 127 into shape (2,63)
```

Notice in the above examples, we use a one-dimensional NumPy array to generate a `DependentVariable` object. If a multi-dimensional NumPy array is given as the argument, the array will be raveled (flattened) before returning the `DependentVariable` object. Note, in the core scientific dataset model, the `DependentVariable` objects only contain information about the number of components and not the dimensions. For example, consider the following.

```
>>> d2 = cp.as_dependent_variable(
...     np.arange(6000).reshape(10, 20, 30), quantity_type="vector_2"
... )
>>> print(d2)
DependentVariable(
[[ 0  1  2 ... 2997 2998 2999]
 [3000 3001 3002 ... 5997 5998 5999]], quantity_type=vector_2, numeric_type=int64)
```

Here, a three-dimensional Numpy array is given as the argument with a `quantity_type` of `vector_2`. The `DependentVariable` object generated from this array contains two-components by appropriately flattening the input array.

6.2.2 ExternalDependentVariable

The `ExternalDependentVariable` objects are generated similar to the `InternalDependentVariable` object. The only difference is that the components of the dependent variable are located at a remote and local address.

Using the `DependentVariable` class.

```
>>> dv = cp.DependentVariable(
...     type="external",
...     quantity_type="scalar",
...     unit="J",
...     components_url="address to the binary file.",
...     numeric_type="int64",
...     description="A sample internal dependent variable.",
... )
```

A `DependentVariable` of type `external` is useful for data serialization. When using with `csdmpy`, all instances of the `external` dependent variable objects are set as `internal` after downloading the components from the `components_url`.

6.3 Generating CSDM objects

6.3.1 An empty csdm object

To create a new empty csdm object, import the *csdmpy* module and create a new instance of the CSDM class following,

```
>>> import csdmpy as cp
>>> new_data = cp.new(description="A new test dataset")
```

The *new()* method returns an instance of the CSDM class with zero dimensions and dependent variables. respectively, *i.e.*, a 0D{0} dataset. In the above example, this instance is assigned to the *new_data* variable. Optionally, a description may also be provided as an argument of the *new()* method. The data structure from the above example is

```
>>> print(new_data.data_structure)
{
  "csdm": {
    "version": "1.0",
    "description": "A new test dataset"
  }
}
```

6.3.2 From a NumPy array

Perhaps the easiest way to generate a csdm object is to convert the NumPy array holding the dataset as a csdm object using the *as_csdm()* method, which returns a view of the array as a CSDM object. Here, the NumPy array becomes the dependent variable of the CSDM object of the given *quantity_type*. Unlike the *as_dependent_variable()* method, however, the *as_csdm()* method retains the shape of the Numpy array and uses this information to generate the dimensions of the CSDM object. By default, the dimensions are of a *linear* subtype with unit increment. Consider the following example.

```
>>> array = np.arange(30).reshape(3, 10)
>>> csdm_obj = cp.as_csdm(array)
>>> print(csdm_obj)
CSDM(
  DependentVariable(
    [[[ 0  1  2  3  4  5  6  7  8  9]
      [10 11 12 13 14 15 16 17 18 19]
      [20 21 22 23 24 25 26 27 28 29]]], quantity_type=scalar, numeric_type=int64),
  LinearDimension([0. 1. 2. 3. 4. 5. 6. 7. 8. 9.]),
  LinearDimension([0. 1. 2.])
)
```

Here, a two-dimensional NumPy array of shape (3, 10) is given as the argument of the *as_csdm()* method. The resulting CSDM object, *csdm_obj*, contains a 2D{1} datasets, with two linear dimensions of unit increment and 10 and 3 points, respectively, and a single one-component dependent variable of *quantity_type scalar*.

Note: The order of the dimensions in the CSDM object is the reverse of the order of axes from the corresponding Numpy array. Thus, the dimension at index 0 of the CSDM object is the last axis of the Numpy array.

You may additionally provide a quantity type as the argument of the *as_csdm()* method. When the quantity type requires more than one component, see *QuantityType*, the first axis of the NumPy array must be the number of components. For example,

```
>>> csdm_obj1 = cp.as_csdm(array, quantity_type="pixel_3")
>>> print(csdm_obj1)
CSDM(
DependentVariable(
[[ 0  1  2  3  4  5  6  7  8  9]
 [10 11 12 13 14 15 16 17 18 19]
 [20 21 22 23 24 25 26 27 28 29]], quantity_type=pixel_3, numeric_type=int64),
LinearDimension([0. 1. 2. 3. 4. 5. 6. 7. 8. 9.])
)
```

Here, the `csdm_obj1` object is a 1D{3} datasets, with a single three-component dependent variable. In this case, the length of the NumPy array along axis 0, i.e., 3, is consistent with the number of components required by the quantity type `pixel_3`. The remaining axes of the NumPy array are used in generating the dimensions of the csdm object. In this example, this corresponds to a single dimension of *linear* type with 10 points.

The following example generates a 3D{2} vector dataset. Here, the first axis of the four-dimensional Numpy array is the components of the vector dataset, and the remaining three axes become the respective dimensions.

```
>>> array2 = np.arange(12000).reshape(2, 30, 20, 10)
>>> csdm_obj2 = cp.as_csdm(array2, quantity_type="vector_2")
>>> print(len(csdm_obj2.dimensions), len(csdm_obj2.dependent_variables[0].components))
3 2
```

An exception will be raised if the *quantity_type* and the number of points along the first axis of the NumPy array are inconsistent, for example,

```
>>> csdm_obj_err = cp.as_csdm(array, quantity_type='vector_2')
ValueError: Expecting exactly 2 components for quantity type, `vector_2`, found 3.
Make sure `array.shape[0]` is equal to the number of components supported by vector_2.
```

Note: Only a csdm object with a single dependent variable may be created from a NumPy array. To add more dependent variables to the CSDM object, see [Adding DependentVariable objects to CSDM object](#).

6.4 Adding Dimension objects to CSDM object

There are three subtypes of Dimension objects,

- LinearDimension
- MonotonicDimension
- LabeledDimension

Using an instance of the Dimension class

Please read the topic [Generating Dimension objects](#) for details on how to generate an instance of the Dimension class. Once created, use the dimensions to generate a CSDM object.

```
>>> linear_dim = cp.LinearDimension(count=10, increment="0.1 C/V")
>>> new_data = cp.CSDM(dimensions=[linear_dim])
>>> print(new_data)
CSDM(
LinearDimension([0. 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9] C / V)
)
```

Using Python's dictionary objects

When using python dictionaries, the key-value pairs of the dictionary must be a valid collection for the given Dimension subtype. For example,

```
>>> # dictionary representation of a linear dimension.
>>> d0 = {
...     "type": "linear",
...     "description": "This is a linear dimension",
...     "count": 5,
...     "increment": "0.1 rad",
... }
>>> # dictionary representation of a monotonic dimension.
>>> d1 = {
...     "type": "monotonic",
...     "description": "This is a monotonic dimension",
...     "coordinates": ["1 m/s", "2 cm/s", "4 mm/s"],
... }
>>> # dictionary representation of a labeled dimension.
>>> d2 = {
...     "type": "labeled",
...     "description": "This is a labeled dimension",
...     "labels": ["Cu", "Ag", "Au"],
... }
>>> # add the dictionaries to the CSDM object.
>>> new_data = cp.CSDM(dimensions=[d0, d1, d2])
>>> print(new_data)
CSDM(
LinearDimension([0.  0.1 0.2 0.3 0.4] rad),
MonotonicDimension([1.    0.02 0.004] m / s),
LabeledDimension(['Cu' 'Ag' 'Au'])
)
```

6.5 Adding DependentVariable objects to CSDM object

There are two subtypes of DependentVariable class:

- **InternalDependentVariable:** We refer to an instance of the DependentVariable as *internal* when the components of the dependent variable are listed along with the other metadata specifying the dependent variable.
- **ExternalDependentVariable:** We refer to an instance of the DependentVariable as *external* when the components of the dependent variable are stored in an external file as binary data either locally or at a remote server.

Using an instance of the DependentVariable class

Please read the topic [Generating DependentVariable objects](#) for details on how to generate an instance of the DependentVariable class. Once created, use the dependent variables to generate a CSDM object.

```
>>> dv = cp.as_dependent_variable(np.arange(10))
>>> new_data = cp.CSDM(dependent_variables=[dv])
>>> print(new_data)
CSDM(
DependentVariable(
[[0 1 2 3 4 5 6 7 8 9]], quantity_type=scalar, numeric_type=int64)
)
```

Using Python's dictionary objects

When using python dictionaries, the key-value pairs of the dictionary must be a valid collection for the given Dependent-Variable subtype. For example,

```
>>> dv0 = {
...     "type": "internal",
...     "quantity_type": "scalar",
...     "description": "This is an internal scalar dependent variable",
...     "unit": "cm",
...     "components": np.arange(50),
... }
>>> dv1 = {
...     "type": "internal",
...     "quantity_type": "vector_2",
...     "description": "This is an internal vector dependent variable",
...     "unit": "cm",
...     "components": np.arange(100),
... }
>>> new_data = cp.CSDM(dependent_variables=[dv0, dv1])
>>> print(new_data)
CSDM(
DependentVariable(
[[ 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47
 48 49]] cm, quantity_type=scalar, numeric_type=int64),
DependentVariable(
[[ 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47
 48 49]
[50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73
 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97
 98 99]] cm, quantity_type=vector_2, numeric_type=int64)
)
```

INTERACTING WITH CSDMPY OBJECTS

7.1 Interacting with Dimension objects

7.1.1 LinearDimension

There are several attributes and methods associated with the `LinearDimension`, each controlling the coordinates along the dimension. The following section demonstrates the effect of these attributes and methods on the coordinates of the `LinearDimension`.

```
>>> import csdmpy as cp
>>> x = cp.LinearDimension(
...     count=10, increment="0.1 s", label="time", description="A temporal dimension."
... )
>>> print(x)
LinearDimension([0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9] s)
```

Attributes

type

This attribute returns the type of the instance.

```
>>> print(x.type)
linear
```

The attributes that modify the coordinates

count

The number of points along the dimension

```
>>> print("number of points =", x.count)
number of points = 10
```

To update the number of points, update the value of this attribute,

```
>>> x.count = 12
>>> print("new number of points =", x.count)
new number of points = 12

>>> print("new coordinates =", x.coordinates)
new coordinates = [0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.  1.1] s
```

increment

```
>>> print("old increment =", x.increment)
old increment = 0.1 s

>>> x.increment = "10 s"
>>> print("new increment =", x.increment)
new increment = 10.0 s

>>> print("new coordinates =", x.coordinates)
new coordinates = [ 0. 10. 20. 30. 40. 50. 60. 70. 80. 90. 100. 110.] s
```

coordinates_offset

```
>>> print("old reference offset =", x.coordinates_offset)
old reference offset = 0.0 s

>>> x.coordinates_offset = "1 s"
>>> print("new reference offset =", x.coordinates_offset)
new reference offset = 1.0 s

>>> print("new coordinates =", x.coordinates)
new coordinates = [ 1. 11. 21. 31. 41. 51. 61. 71. 81. 91. 101. 111.] s
```

origin_offset

```
>>> print("old origin offset =", x.origin_offset)
old origin offset = 0.0 s

>>> x.origin_offset = "1 day"
>>> print("new origin offset =", x.origin_offset)
new origin offset = 1.0 d

>>> print("new coordinates =", x.coordinates)
new coordinates = [ 1. 11. 21. 31. 41. 51. 61. 71. 81. 91. 101. 111.] s
```

The last operation updates the value of the origin offset, however, the coordinates remain unaffected. This is because the *coordinates* attribute refers to the reference coordinates. You may access the absolute coordinates through the *absolute_coordinates* attribute.

```
>>> print("absolute coordinates =", x.absolute_coordinates)
absolute coordinates = [86401. 86411. 86421. 86431. 86441. 86451. 86461. 86471. 86481. 86491. 86501. 86511.] s
```

The attributes that modify the order of coordinates

complex_fft

If true, orders the coordinates along the dimension according to the output of a complex Fast Fourier Transform (FFT) routine.

```
>>> print("old coordinates =", x.coordinates)
old coordinates = [ 1. 11. 21. 31. 41. 51. 61. 71. 81. 91. 101. 111.] s

>>> x.complex_fft = True
>>> print("new coordinates =", x.coordinates)
new coordinates = [-59. -49. -39. -29. -19. -9. 1. 11. 21. 31. 41. 51.] s
```

Other attributes

period

The period of the dimension.

```
>>> print("old period =", x.period)
old period = inf s

>>> x.period = "10 s"
>>> print("new period =", x.period)
new period = 10.0 s
```

quantity_name

Returns the quantity name.

```
>>> print("quantity name is", x.quantity_name)
quantity name is time
```

label

```
>>> x.label
'time'

>>> x.label = "t1"
>>> x.label
't1'
```

axis_label

Returns a formatted string for labeling axis.

```
>>> x.label
't1'
>>> x.axis_label
't1 / (s)'
```

Methods

to(): This method is used for unit conversions.

```
>>> print("old unit =", x.coordinates.unit)
old unit = s

>>> print("old coordinates =", x.coordinates)
old coordinates = [-59. -49. -39. -29. -19.  -9.   1.  11.  21.  31.  41.  51.] s

>>> ## unit conversion
>>> x.to("min")

>>> print("new coordinates =", x.coordinates)
new coordinates = [-0.98333333 -0.81666667 -0.65          -0.48333333 -0.31666667 -0.15
 0.01666667  0.18333333  0.35          0.51666667  0.68333333  0.85          ] min
```

Note: In the above examples, the coordinates are ordered according to the FFT output order, based on the previous set of operations.

The argument of this method is a string containing the unit, in this case, *min*, whose dimensionality is be consistent with the dimensionality of the coordinates. An exception will be raised otherwise.

```
>>> x.to("km/s")
Exception: The unit 'km / s' (speed) is inconsistent with the unit 'min' (time).
```

Changing the dimensionality

You may scale the dimension object by multiplying the object with the appropriate `ScalarQuantity`, as follows,

```
>>> print(x)
LinearDimension([-0.98333333 -0.81666667 -0.65          -0.48333333 -0.31666667 -0.15
 0.01666667  0.18333333  0.35          0.51666667  0.68333333  0.85          ] min)
>>> x *= cp.ScalarQuantity("m/s")
>>> print(x)
LinearDimension([-59. -49. -39. -29. -19.  -9.   1.  11.  21.  31.  41.  51.] m)
```

7.1.2 MonotonicDimension

There are several attributes and methods associated with a `MonotonicDimension`, controlling the coordinates along the dimension. The following section demonstrates the effect of these attributes and methods on the coordinates.

```
>>> import numpy as np
>>> array = np.asarray(
...     [
...         -0.28758166,
...         -0.22712233,
...         -0.19913859,
...         -0.17235106,
...         -0.1701172,
...         -0.10372635,
...         -0.01817061,
...         0.05936719,
...         0.18141424,
...         0.34758913,
...     ]
... )
>>> x = cp.MonotonicDimension(coordinates=array) * cp.ScalarQuantity("cm")
```

Attributes

The following are the attributes of the `MonotonicDimension` instance.

type

This attribute returns the type of the instance.

```
>>> print(x.type)
monotonic
```

The attributes that modify the coordinates

count

The number of points along the dimension

```
>>> print("number of points =", x.count)
number of points = 10
```


You may update the number of points with this attribute, however, you can only lower the number of points.

```
>>> x.count = 6
>>> print("new number of points =", x.count)
new number of points = 6
>>> print(x.coordinates)
[-0.28758166 -0.22712233 -0.19913859 -0.17235106 -0.1701172  -0.10372635] cm
```

origin_offset

```
>>> print("old origin offset =", x.origin_offset)
old origin offset = 0.0 cm

>>> x.origin_offset = "1 km"
>>> print("new origin offset =", x.origin_offset)
new origin offset = 1.0 km

>>> print(x.coordinates)
[-0.28758166 -0.22712233 -0.19913859 -0.17235106 -0.1701172  -0.10372635] cm
```

The last operation updates the value of the origin offset, however, the value of the `coordinates` attribute remains unchanged. This is because the `coordinates` refer to the reference coordinates. The absolute coordinates are accessed through the `absolute_coordinates` attribute.

```
>>> print("absolute coordinates =", x.absolute_coordinates)
absolute coordinates = [99999.71241834 99999.77287767 99999.80086141 99999.
↪82764894
99999.8298828 99999.89627365] cm
```

Other attributes

label

```
>>> x.label = "t1"
>>> print("new label =", x.label)
new label = t1
```

period

```
>>> print("old period =", x.period)
old period = inf cm

>>> x.period = "10 m"
>>> print("new period =", x.period)
new period = 10.0 m
```

quantity_name

Returns the quantity name.

```
>>> print("quantity is", x.quantity_name)
quantity is length
```

Methods

`to()`

The method is used for unit conversions. It follows,

```
>>> print("old unit =", x.coordinates.unit)
old unit = cm
>>> print("old coordinates =", x.coordinates)
old coordinates = [-0.28758166 -0.22712233 -0.19913859 -0.17235106 -0.1701172  -0.
↪10372635] cm

>>> ## unit conversion
>>> x.to("mm")

>>> print("new coordinates =", x.coordinates)
new coordinates = [-2.8758166 -2.2712233 -1.9913859 -1.7235106 -1.701172  -1.0372635] ↪
↪mm
```

The argument of this method is a unit, in this case, 'mm', whose dimensionality must be consistent with the dimensionality of the coordinates. An exception will be raised otherwise,

```
>>> x.to("km/s")
Exception("Validation Failed: The unit 'km / s' (speed) is inconsistent with the unit
↪ 'mm' (length).")
```

Changing the dimensionality

You may scale the dimension object by multiplying the object with the appropriate `ScalarQuantity`, as follows,

```
>>> print(x)
MonotonicDimension([-2.8758166 -2.2712233 -1.9913859 -1.7235106 -1.701172  -1.
↪0372635] mm)
>>> x *= cp.ScalarQuantity("2 s/mm")
>>> print(x)
MonotonicDimension([-0.57516332 -0.45424466 -0.39827718 -0.34470212 -0.3402344  -0.
↪2074527 ] cm s / mm)
```

7.2 Interacting with CSDM objects

7.2.1 Basic math operations

The `csdm` object supports basic mathematical operations such as additive and multiplicative operations.

Note: All operations applied to or involving the `csdm` objects apply only to the components of the dependent variables within the `csdm` object. These operations do not apply to the dimensions within the `csdm` object.

Consider the following `csdm` data object.

```
>>> arr1 = np.arange(6, dtype=np.float32).reshape(2, 3)
>>> csdm_obj1 = cp.as_csdm(arr1)
>>> # converting the dimension to proper physical dimensions.
```

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```

>>> csdm_obj1.dimensions[0] *= cp.ScalarQuantity("2.64 m")
>>> csdm_obj1.dimensions[0].coordinates_offset = "1 km"
>>> # converting the dimension to proper physical dimensions.
>>> csdm_obj1.dimensions[1] *= cp.ScalarQuantity("10 μs")
>>> csdm_obj1.dimensions[1].coordinates_offset = "-0.5 ms"
>>> print(csdm_obj1)
CSDM(
DependentVariable(
[[[0. 1. 2.]
  [3. 4. 5.]]], quantity_type=scalar, numeric_type=float32),
LinearDimension([1000. 1002.64 1005.28] m),
LinearDimension([-500. -490.] us)
)

```

Additive operations involving a scalar

Example 1

```

>>> csdm_obj1 += np.pi
>>> print(csdm_obj1)
CSDM(
DependentVariable(
[[[3.1415927 4.141593 5.141593 ]
  [6.141593 7.141593 8.141593 ]]], quantity_type=scalar, numeric_type=float32),
LinearDimension([1000. 1002.64 1005.28] m),
LinearDimension([-500. -490.] us)
)

```

Example 2

```

>>> csdm_obj2 = csdm_obj1 + (2 - 4j)
>>> print(csdm_obj2)
CSDM(
DependentVariable(
[[[ 5.141593-4.j 6.141593-4.j 7.141593-4.j]
  [ 8.141593-4.j 9.141593-4.j 10.141593-4.j]]], quantity_type=scalar, numeric_
↪type=complex64),
LinearDimension([1000. 1002.64 1005.28] m),
LinearDimension([-500. -490.] us)
)

```

Multiplicative operations involving scalar / ScalarQuantity

Example 3

```

>>> csdm_obj1 = cp.as_csdm(np.ones(6).reshape(2, 3))
>>> csdm_obj2 = csdm_obj1 * 4.693
>>> print(csdm_obj2)
CSDM(
DependentVariable(
[[[4.693 4.693 4.693]
  [4.693 4.693 4.693]]], quantity_type=scalar, numeric_type=float64),
LinearDimension([0. 1. 2.]),

```

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```
LinearDimension([0. 1.])
)
```

Example 4

```
>>> csdm_obj2 = csdm_obj1 * 3j / 2.4
>>> print(csdm_obj2)
CSDM(
  DependentVariable(
    [[[0.+1.25j 0.+1.25j 0.+1.25j]
      [0.+1.25j 0.+1.25j 0.+1.25j]]], quantity_type=scalar, numeric_type=complex128),
  LinearDimension([0. 1. 2.]),
  LinearDimension([0. 1.])
)
```

You may change the dimensionality of the dependent variables by multiplying the csdm object with the appropriate scalar quantity, for example,

Example 5

```
>>> csdm_obj1 *= cp.ScalarQuantity("3.23 m")
>>> print(csdm_obj1)
CSDM(
  DependentVariable(
    [[[3.23 3.23 3.23]
      [3.23 3.23 3.23]]] m, quantity_type=scalar, numeric_type=float64),
  LinearDimension([0. 1. 2.]),
  LinearDimension([0. 1.])
)
```

Example 6

```
>>> csdm_obj1 /= cp.ScalarQuantity("3.23 m")
>>> print(csdm_obj1)
CSDM(
  DependentVariable(
    [[[1. 1. 1.]
      [1. 1. 1.]]], quantity_type=scalar, numeric_type=float64),
  LinearDimension([0. 1. 2.]),
  LinearDimension([0. 1.])
)
```

Additive operations involving two csdm objects

The additive operations are supported between two csdm objects only when the two objects have identical sets of Dimension objects and DependentVariable objects with the same dimensionality. For examples,

Example 7

```
>>> csdm1 = cp.as_csdm(np.ones((2, 3)), unit="m/s")
>>> csdm2 = cp.as_csdm(np.ones((2, 3)), unit="cm/s")
>>> csdm_obj = csdm1 + csdm2
>>> print(csdm_obj)
CSDM(
  DependentVariable(
```

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```
[[[1.01 1.01 1.01]
  [1.01 1.01 1.01]]] m / s, quantity_type=scalar, numeric_type=float64),
LinearDimension([0. 1. 2.]),
LinearDimension([0. 1.])
)
```

An exception will be raised if the `DependentVariable` objects of the two `csdm` objects have different dimensionality.

Example 8

```
>>> csdm1 = cp.as_csdm(np.ones((2, 3)), unit="m/s")
>>> csdm2 = cp.as_csdm(np.ones((2, 3)))
>>> csdm_obj = csdm1 + csdm2
Exception: Cannot operate on dependent variables with physical types: speed and_
↳ dimensionless.
```

Similarly, an exception will be raised if the dimension objects of the two `csdm` objects are different.

Example 9

```
>>> csdm1 = cp.as_csdm(np.ones((2, 3)), unit="m/s")
>>> csdm1.dimensions[1] = cp.MonotonicDimension(coordinates=["1 ms", "1 s"])
>>> csdm2 = cp.as_csdm(np.ones((2, 3)), unit="cm/s")
>>> csdm_obj = csdm1 + csdm2
Exception: Cannot operate on CSDM objects with different dimensions.
```

7.2.2 Basic Slicing and Indexing

The CSDM objects support NumPy basic slicing and indexing and follow the same rules as the NumPy array. Consider the following 3D{1} `csdm` object.

```
>>> csdm1 = cp.as_csdm(np.zeros((5, 10, 20)), unit="s")
>>> csdm1.dimensions[0] = cp.as_dimension(np.arange(20) * 0.5 + 4.3, unit="kg")
>>> csdm1.dimensions[1] = cp.as_dimension([1, 2, 3, 5, 7, 11, 13, 17, 19, 23], unit=
↳ "mm")
>>> csdm1.dimensions[2] = cp.LabeledDimension(labels=list("abcde"))
>>> print(csdm1.shape)
(20, 10, 5)
>>> print(csdm1.dimensions)
[LinearDimension(count=20, increment=0.5 kg, coordinates_offset=4.3 kg, quantity_
↳ name=mass),
MonotonicDimension(coordinates=[ 1.  2.  3.  5.  7. 11. 13. 17. 19. 23.] mm, quantity_
↳ name=length, reciprocal={'quantity_name': 'wavenumber'}),
LabeledDimension(labels=['a', 'b', 'c', 'd', 'e'])]
```

The above object `csdm1` has three dimensions, each with different dimensionality and dimension type. To retrieve a sub-grid of this 3D{1} dataset, use the NumPy indexing scheme.

Example 10

```
>>> sub_csdm = csdm1[0]
>>> print(sub_csdm.shape)
(10, 5)
>>> print(sub_csdm.dimensions)
```

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```
[MonotonicDimension(coordinates=[ 1.  2.  3.  5.  7. 11. 13. 17. 19. 23.] mm, ↵
↵quantity_name=length, reciprocal={'quantity_name': 'wavenumber'}),
LabeledDimension(labels=['a', 'b', 'c', 'd', 'e'])]
```

The above example returns a 2D{1} cross-section of the 3D{1} datasets corresponding to the index 0 along the first dimension of the `csdm1` object as a `sub_csdm` `csdm` object. The two dimensions in `sub_csdm` are the `MonotonicDimension` and `LabeledDimension`.

Example 11

```
>>> sub_csdm = csdm1[::5, 2::2, :]
>>> print(sub_csdm.shape)
(4, 4, 5)
>>> print(sub_csdm.dimensions)
[LinearDimension(count=4, increment=2.5 kg, coordinates_offset=4.3 kg, quantity_
↵name=mass),
MonotonicDimension(coordinates=[ 3.  7. 13. 19.] mm, quantity_name=length, reciprocal=
↵{'quantity_name': 'wavenumber'}),
LabeledDimension(labels=['a', 'b', 'c', 'd', 'e'])]
```

The above example returns a 3D{1} dataset, `sub_csdm`, which contains a sub-grid of the 3D{1} datasets from `csdm1`. In `sub_csdm`, the first dimension is a sub-grid of the first dimension from the `csdm1` object, where only every fifth grid point is selected. Similarly, the second dimension of the `sub_csdm` object is sampled from the second dimension of the `csdm1` object, where every second grid point is selected, starting with the entry at the grid index two. The third dimension of the `sub_csdm` object is the same as the third object of the `csdm1` object. The values of the corresponding linear, monotonic, and labeled dimensions are adjusted accordingly. For example, notice the value of the *count* and *increment* attributes of the linear dimension in `sub_csdm` object.

Example 12

```
>>> sub_csdm = csdm1[::5, 2::2, -3::-1]
>>> print(sub_csdm.shape)
(4, 4, 3)
>>> print(sub_csdm.dimensions)
[LinearDimension(count=4, increment=2.5 kg, coordinates_offset=4.3 kg, quantity_
↵name=mass),
MonotonicDimension(coordinates=[ 3.  7. 13. 19.] mm, quantity_name=length, reciprocal=
↵{'quantity_name': 'wavenumber'}),
LabeledDimension(labels=['c', 'b', 'a'])]
```

The above example is similar to the previous examples, except the third dimension indexed in reversed starting at the third index from the end.

See also:

[Basic Slicing and Indexing](#)

7.2.3 Support for Numpy methods

In most cases, the csdm object may be used as if it were a NumPy array. See the list of all supported *Supported NumPy functions*.

Method that only operate on dimensionless dependent variables

Example 13

```
>>> csdm_obj1 = cp.as_csdm(10 ** (np.arange(10) / 10))
>>> new_csdm1 = np.log10(csdm_obj1)
>>> print(new_csdm1)
CSDM(
DependentVariable(
[[0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9]], quantity_type=scalar, numeric_
↪type=float64),
LinearDimension([0. 1. 2. 3. 4. 5. 6. 7. 8. 9.])
)
```

Example 14

```
>>> new_csdm2 = np.cos(2 * np.pi * new_csdm1)
>>> print(new_csdm2)
CSDM(
DependentVariable(
[[ 1.          0.80901699  0.30901699 -0.30901699 -0.80901699 -1.
 -0.80901699 -0.30901699  0.30901699  0.80901699]], quantity_type=scalar, numeric_
↪type=float64),
LinearDimension([0. 1. 2. 3. 4. 5. 6. 7. 8. 9.])
)
```

Example 15

```
>>> new_csdm2 = np.exp(new_csdm1 * cp.ScalarQuantity("K"))
ValueError: Cannot apply `exp` to quantity with physical type `temperature`.
```

An exception is raised for csdm object with non-dimensionless dependent variables.

Method that are independent of the dependent variable dimensionality

Example 16

```
>>> new_csdm2 = np.square(new_csdm1 * cp.ScalarQuantity("K"))
>>> print(new_csdm2)
CSDM(
DependentVariable(
[[0.  0.01 0.04 0.09 0.16 0.25 0.36 0.49 0.64 0.81]] K2, quantity_type=scalar, ↪
↪numeric_type=float64),
LinearDimension([0. 1. 2. 3. 4. 5. 6. 7. 8. 9.])
)
```

Example 17

```
>>> new_csdm1 = np.sqrt(new_csdm2)
>>> print(new_csdm1)
CSDM(
DependentVariable(
[[0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9]] K, quantity_type=scalar, numeric_
↪type=float64),
LinearDimension([0. 1. 2. 3. 4. 5. 6. 7. 8. 9.])
)
```

Dimension reduction methods

Example 18

```
>>> csdm1 = cp.as_csdm(np.ones((10, 20, 30)), unit="μG")
>>> csdm1.shape
(30, 20, 10)
>>> new = np.sum(csdm1, axis=1)
>>> new.shape
(30, 10)
>>> print(new.dimensions)
[LinearDimension(count=30, increment=1.0),
LinearDimension(count=10, increment=1.0)]
```

Example 19

```
>>> csdm1 = cp.as_csdm(np.ones((10, 20, 30)), unit="μG")
>>> csdm1.shape
(30, 20, 10)
>>> new = np.sum(csdm1, axis=(1, 2))
>>> new.shape
(30,)
>>> print(new.dimensions)
[LinearDimension(count=30, increment=1.0)]
```

Example 20

```
>>> minimum = np.min(new_csdm1)
>>> print(minimum)
0.0 K
>>> np.min(new_csdm1) == new_csdm1.min()
True
```

Note: See the list of all supported *Supported NumPy functions*.

PLOTTING CSDM OBJECT WITH MATPLOTLIB

As you may have noticed by now, a CSDM object holds basic metadata such as the label, unit, and physical quantity of the dimensions and dependent-variables, which is enough to visualize the CSDM datasets on proper coordinate axes. In the following section, we illustrate how you may use the CSDM object with the matplotlib plotting library.

When plotting CSDM objects with matplotlib, we make use of the CSDM object's metadata to produce a [matplotlib Axes](#) object with basic formattings, such as the coordinate axes label, dependent variable labels, and legends. You may still additionally customize your figures. Please refer to the [matplotlib documentation](#) for further details.

To enable plotting CSDM objects with matplotlib, add a `projection="csdm"` to the matplotlib's Axes instance, as follows,

```
ax = plt.subplot(projection="csdm")
# now add the matplotlib plotting functions to this axes.
# ax.plot(csdm_object) or
# ax.imshow(csdm_object) ... etc
```

See the following examples.

8.1 1D CSDM objects with `plot()` | `scatter()`

8.1.1 1D{1} datasets

```
import matplotlib.pyplot as plt
import numpy as np

import csdmpy as cp

# Create a test 1D{1} dataset. =====

# Step-1: Create dimension objects.
x = cp.as_dimension(np.arange(10) * 0.1 + 15, unit="s", label="t1")

# Step-2: Create dependent variable objects.
y = cp.as_dependent_variable(np.random.rand(10), unit="cm", name="test-0")

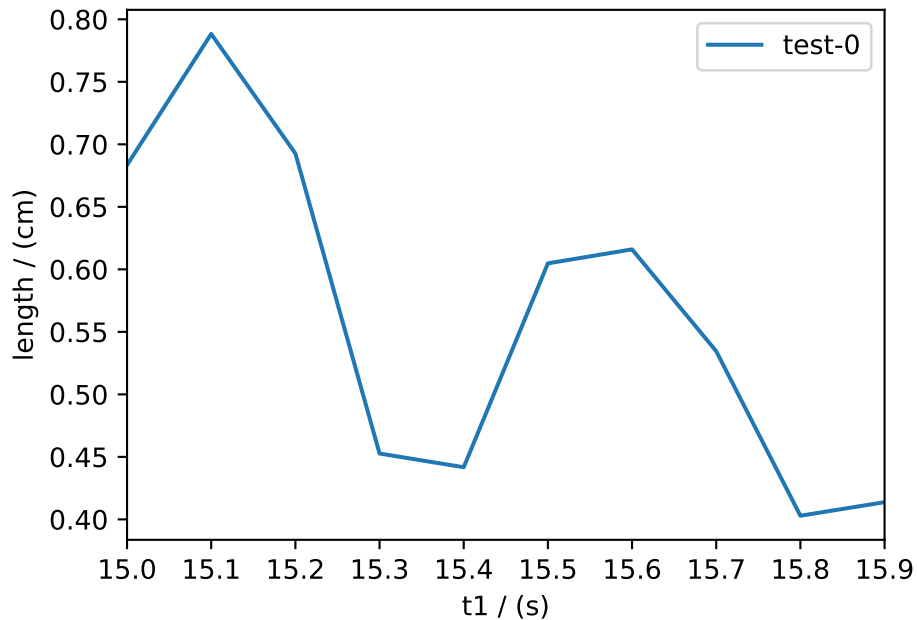
# Step-3: Create the CSDM object with Dimension and Dependent variable objects.
csdm = cp.CSDM(dimensions=[x], dependent_variables=[y])

# Plot =====
plt.figure(figsize=(5, 3.5))
```

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```
# create the axes with `projection="csdm"`
ax = plt.subplot(projection="csdm")
# use matplotlib plot function with csdm object.
ax.plot(csdm)
plt.tight_layout()
plt.show()
```

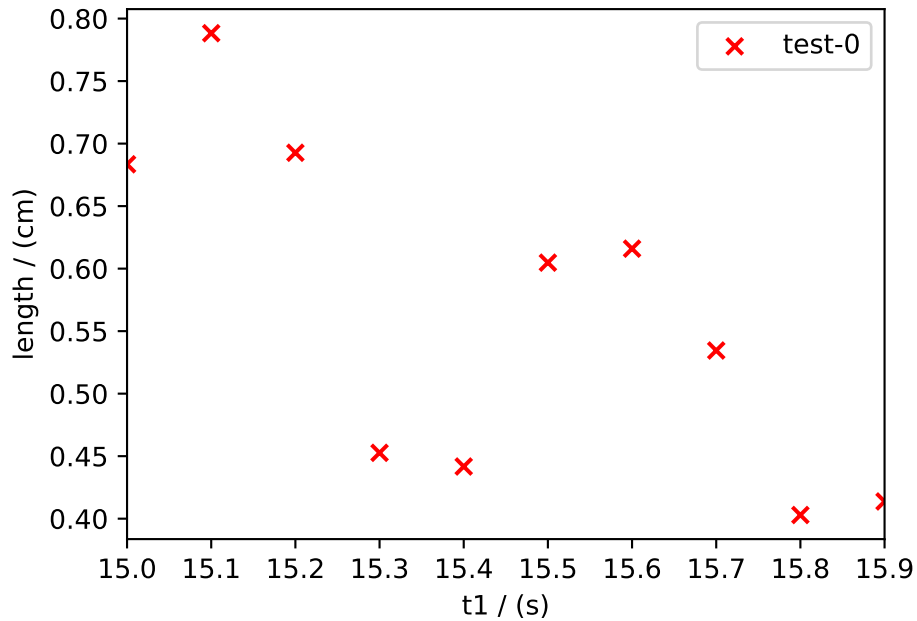


```
# Scatter =====
plt.figure(figsize=(5, 3.5))
# create the axes with `projection="csdm"`
ax = plt.subplot(projection="csdm")
# use matplotlib plot function with csdm object.
ax.scatter(csdm, marker="x", color="red")
plt.tight_layout()
plt.show()
```

8.1.2 1D{1, 1, ...} datasets

Plotting on the same Axes

When multiple single-component dependent variables are present within the CSDM object, the data from all dependent-variables is plotted on the same axes. The name of each dependent variable is displayed within the legend.



Plotting on separate Axes

To plot the data from individual dependent variables onto separate axes, use the `split()` method to first split the CSDM object with n dependent variables into n CSDM objects with single dependent variables, and then plot them separately.

```
import matplotlib.pyplot as plt
import numpy as np

import csdmpy as cp

# Create a test 1D{1, 1, 1, 1, 1} dataset. =====

# Step-1: Create dimension objects.
x = cp.as_dimension(np.arange(40) * 0.5 - 10, unit="μm", label="x")

# Step-2: Create dependent variable objects.
units = ["cm", "s", "m/s", ""]
y = [
    cp.as_dependent_variable(np.random.rand(40) + 10, unit=units[i], name=f"test-{i}")
    for i in range(4)
]

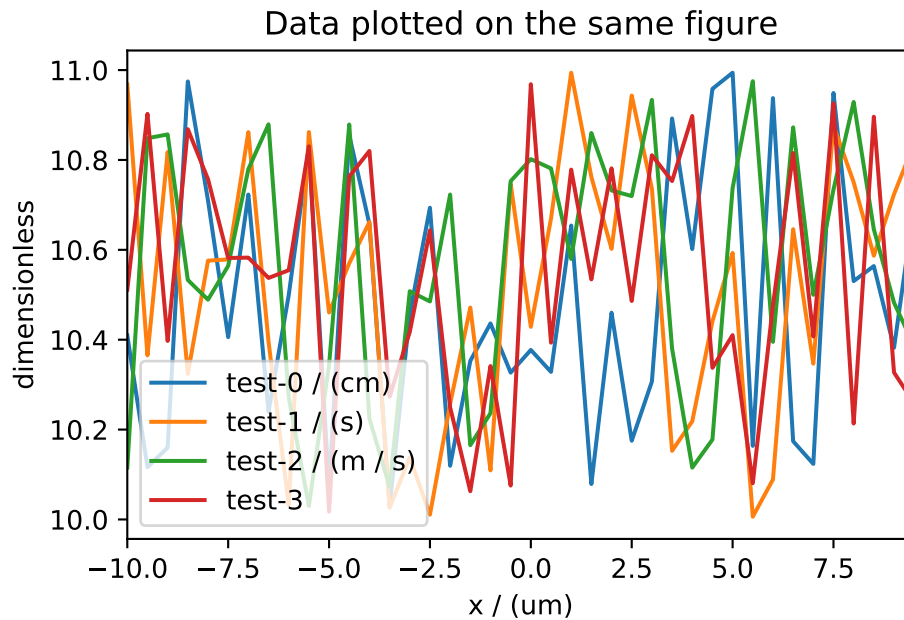
# Step-3: Create the CSDM object with Dimension and Dependent variable objects.
csdm = cp.CSDM(dimensions=[x], dependent_variables=y)

# Plot =====
plt.figure(figsize=(5, 3.5))
# create the axes with `projection="csdm"`
ax = plt.subplot(projection="csdm")
# use matplotlib plot function with csdm object.
ax.plot(csdm)
plt.title("Data plotted on the same figure")
```

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```
plt.tight_layout()
plt.show()
```



```
# The plot on separate axes =====

# Split the CSDM object into multiple single dependent-variable CSDM objects.
sub_type = csdm.split()

# create the axes with `projection="csdm"`
_, ax = plt.subplots(2, 2, figsize=(8, 6), subplot_kw={"projection": "csdm"})
# now use matplotlib plot function with csdm object.
ax[0, 0].plot(sub_type[0])
ax[0, 1].plot(sub_type[1])
ax[1, 0].plot(sub_type[2])
ax[1, 1].plot(sub_type[3])
plt.title("Data plotted separately")
plt.tight_layout()
plt.show()
```

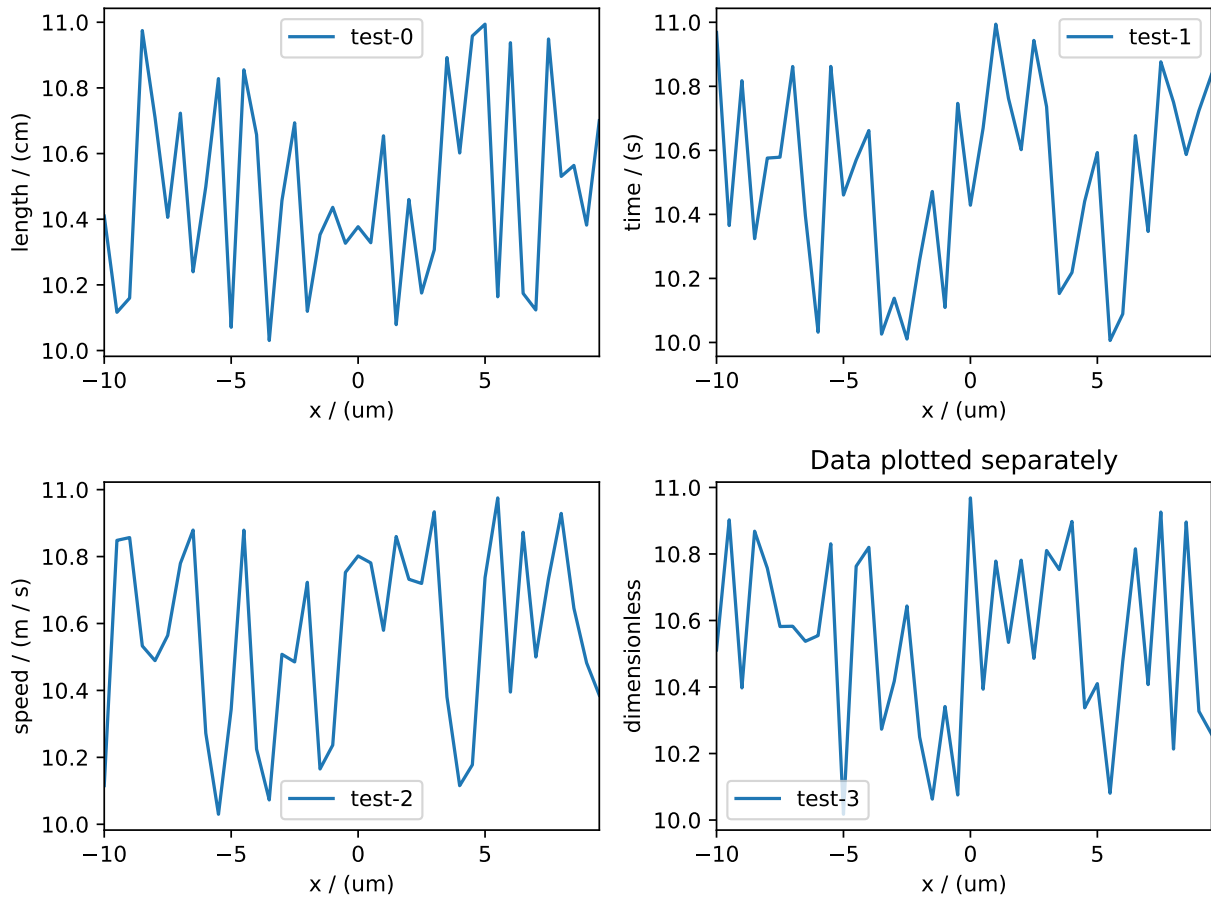
8.2 2D CSDM objects with `imshow()` | `contour()` | `contourf()`

8.2.1 2D{1} datasets

```
import matplotlib.pyplot as plt
import numpy as np

import csdmpy as cp
```

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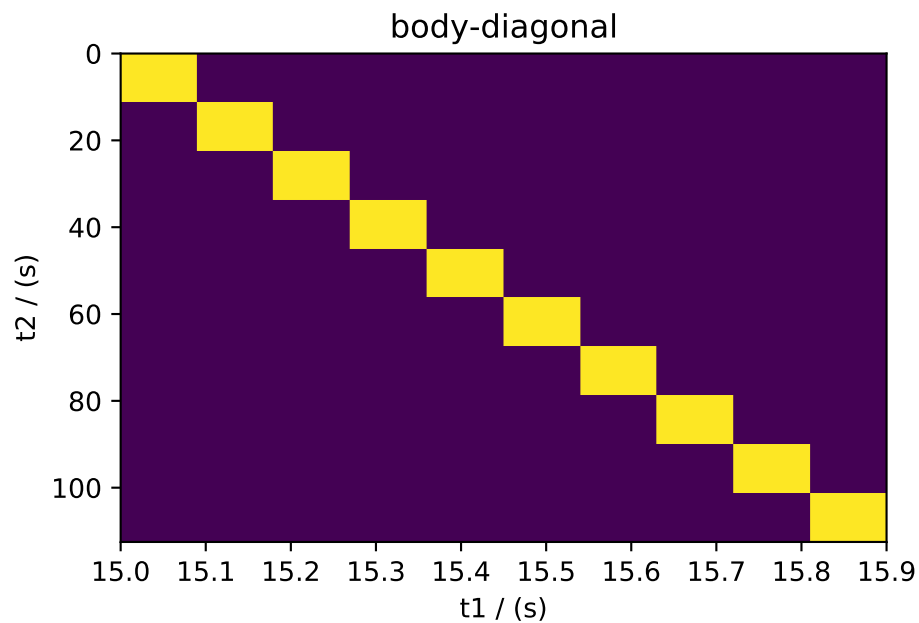
```
# Create a test 2D{1} dataset. =====

# Step-1: Create dimension objects.
x1 = cp.as_dimension(np.arange(10) * 0.1 + 15, unit="s", label="t1")
x2 = cp.as_dimension(np.arange(10) * 12.5, unit="s", label="t2")

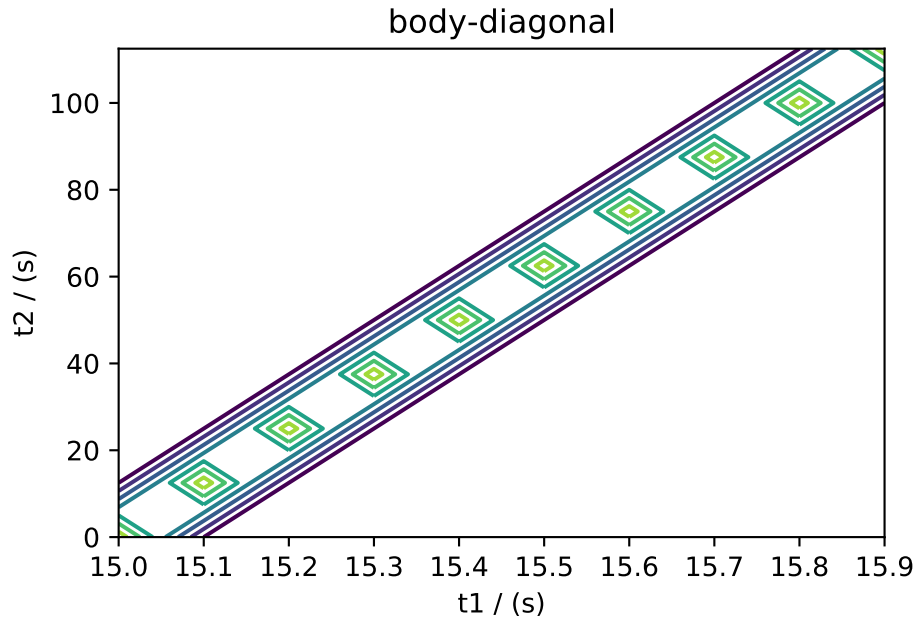
# Step-2: Create dependent variable objects.
y = cp.as_dependent_variable(np.diag(np.ones(10)), name="body-diagonal")

# Step-3: Create the CSDM object with Dimension and Dependent variable objects.
csdm = cp.CSDM(dimensions=[x1, x2], dependent_variables=[y])

# Plot imshow =====
plt.figure(figsize=(5, 3.5))
# create the axes with `projection="csdm"`
ax = plt.subplot(projection="csdm")
# use matplotlib imshow function with csdm object.
ax.imshow(csdm, origin="upper", aspect="auto")
plt.tight_layout()
plt.show()
```



```
# Plot contour =====
plt.figure(figsize=(5, 3.5))
# create the axes with `projection="csdm"`
ax = plt.subplot(projection="csdm")
# use matplotlib contour function with csdm object.
ax.contour(csdm)
plt.tight_layout()
plt.show()
```



8.2.2 2D{1, 1, ..} datasets

Plotting on the same Axes

When multiple single-component dependent variables are present within the CSDM object, the data from all dependent-variables is plotted on the same axes. The name of each dependent variable is displayed along the color bar.

```
import matplotlib.pyplot as plt
import numpy as np

import csdmpy as cp

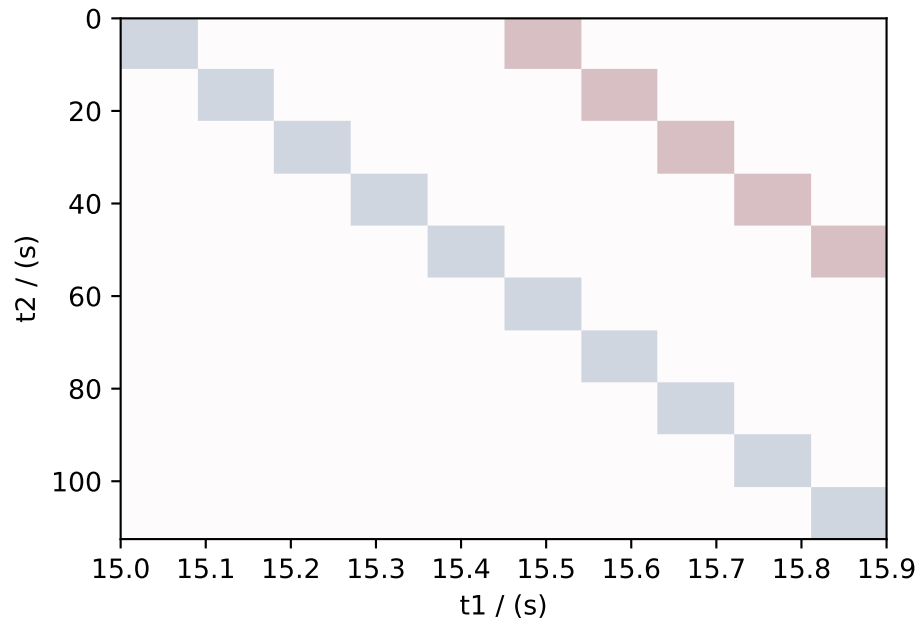
# Create a test 2D{1} dataset. =====

# Step-1: Create dimension objects.
x1 = cp.as_dimension(np.arange(10) * 0.1 + 15, unit="s", label="t1")
x2 = cp.as_dimension(np.arange(10) * 12.5, unit="s", label="t2")

# Step-2: Create dependent variable objects.
y1 = cp.as_dependent_variable(np.diag(np.ones(10)), name="body-diagonal")
y2 = cp.as_dependent_variable(np.diag(np.ones(5), 5), name="off-body-diagonal")

# Step-3: Create the CSDM object with Dimension and Dependent variable objects.
csdm = cp.CSDM(dimensions=[x1, x2], dependent_variables=[y1, y2])

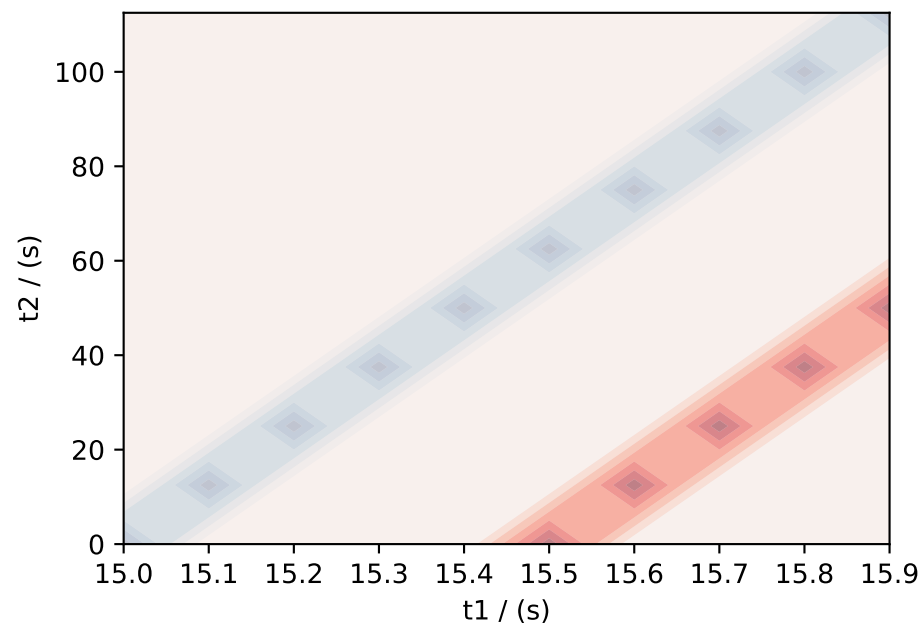
# Plot imshow =====
plt.figure(figsize=(5, 3.5))
# create the axes with `projection="csdm"`
ax = plt.subplot(projection="csdm")
# use matplotlib imshow function with csdm object.
ax.imshow(csdm, origin="upper", aspect="auto", cmaps=["Blues", "Reds"], alpha=0.5)
plt.tight_layout()
plt.show()
```



```
# Plot contourf =====
plt.figure(figsize=(5, 3.5))
# create the axes with `projection="csdm"`
ax = plt.subplot(projection="csdm")
# use matplotlib contourf function with csdm object.
ax.contourf(csdm, cmaps=["Blues", "Reds"], alpha=0.5)
plt.tight_layout()
plt.show()
```

Plotting on separate Axes

To plot the data from individual dependent variables onto separate axes, use the `split()` method to first split the CSDM object with n dependent variables into n CSDM objects with single dependent variables, and then plot them separately.



TUTORIAL EXAMPLES ON GENERATING CSDM DATASETS

9.1 1D Datasets

9.1.1 1D{1} datasets

In the following example, we illustrate how one can convert a Numpy array into a CSDM object. Start by importing the Numpy and csdmpy libraries.

```
import matplotlib.pyplot as plt
import numpy as np

import csdmpy as cp
```

Let's generate a 1D NumPy array of as our dataset.

```
test_data = np.zeros(500)
test_data[250] = 1
```

Create a DependentVariable object from the numpy object

```
dv = cp.as_dependent_variable(test_data, unit="%")
```

Create the corresponding dimensions object. Here, we create a LinearDimension object

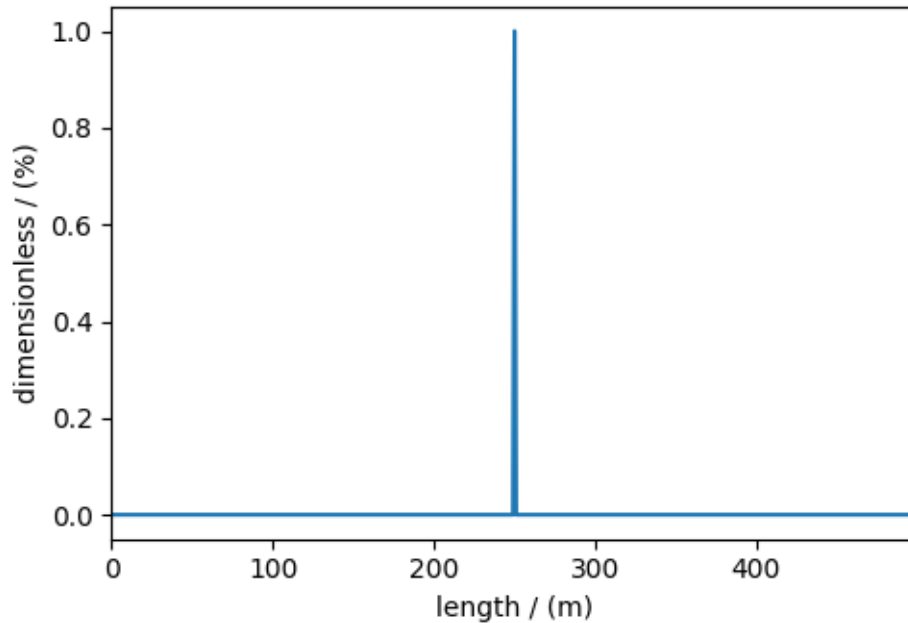
```
dim = cp.LinearDimension(count=500, increment="1 m")
```

Creating the CSDM object.

```
csdm_object = cp.CSDM(dependent_variables=[dv], dimensions=[dim])
```

Plot of the dataset.

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(csdm_object)
plt.tight_layout()
plt.show()
```



To serialize the file, use the save method.

```
csdm_object.save("1D_1_dataset.csdf")
```

Total running time of the script: (0 minutes 0.116 seconds)

9.1.2 1D{1,1} datasets

In the following example, we illustrate how one can convert a Numpy array into a CSDM object. Start by importing the Numpy and csdmpy libraries.

```
import matplotlib.pyplot as plt
import numpy as np

import csdmpy as cp
```

Let's generate two 1D NumPy arrays as the dependent variables of our dataset.

```
test_data1 = np.zeros(500)
test_data1[250] = 1

test_data2 = np.zeros(500)
test_data2[150] = 1
```

Create the two `DependentVariable` objects from the numpy objects.

```
dv1 = cp.as_dependent_variable(test_data1, unit="%")
dv2 = cp.as_dependent_variable(test_data2, unit="J")
```

Create the corresponding dimension object. Here, we create a `LinearDimension` object.

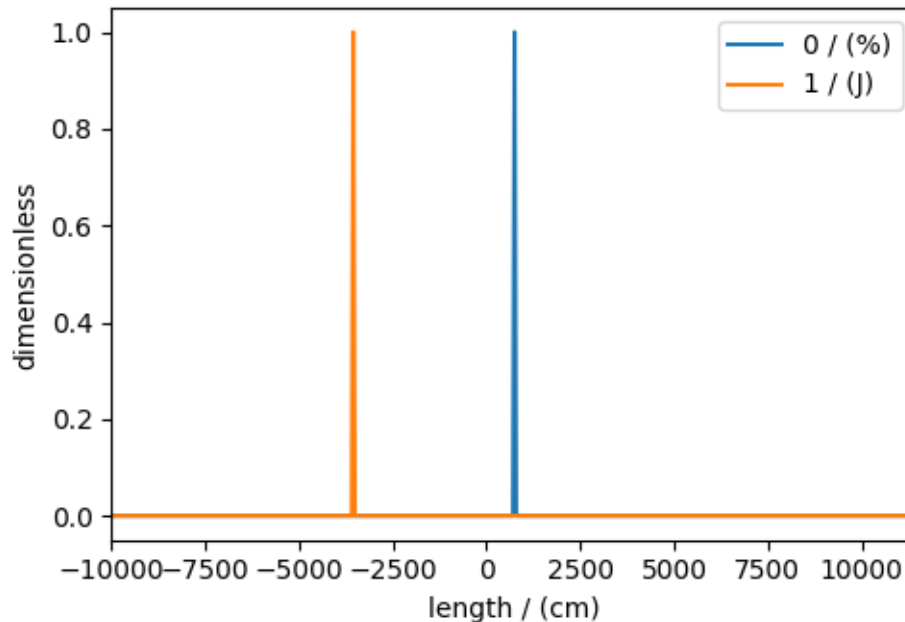
```
dim = cp.LinearDimension(count=500, increment="43 cm", coordinates_offset="-0.1 km")
```

Creating the CSDM object.

```
csdm_object = cp.CSDM(dependent_variables=[dv1, dv2], dimensions=[dim])
```

Plot of the dataset.

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="csdm")
ax.plot(csdm_object)
plt.tight_layout()
plt.show()
```



To serialize the file, use the save method.

```
csdm_object.save("1D_11_dataset.csdf")
```

Total running time of the script: (0 minutes 0.153 seconds)

9.2 2D Datasets

9.2.1 2D{1} dataset with two linear dimensions

In the following example, we illustrate how one can convert a Numpy array into a CSDM object. Start by importing the Numpy and csdmpy libraries.

```
import matplotlib.pyplot as plt
import numpy as np
import csdmpy as cp
```

Let's generate a 2D NumPy array of random numbers as our dataset.

```
data = np.random.rand(65536).reshape(256, 256)
```

Create the `DependentVariable` object from the numpy object.

```
dv = cp.as_dependent_variable(data, unit="Pa")
```

Create the two `Dimension` objects

```
d0 = cp.LinearDimension(
    count=256, increment="15.23 μs", coordinates_offset="-1.95 ms", label="t1"
)

d1 = cp.LinearDimension(
    count=256, increment="10 cm", coordinates_offset="-5 m", label="x2"
)
```

Here, `d0` and `d1` are `LinearDimension` objects with 256 points and 15.23 μs and 10 cm as increment.

Creating the `CSDM` object.

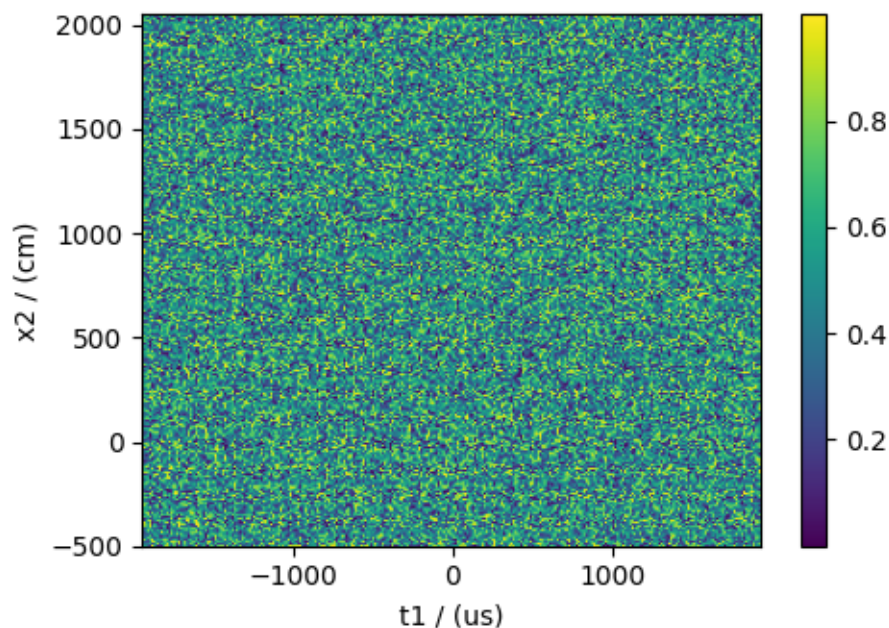
```
cscdm_object = cp.CSDM(dependent_variables=[dv], dimensions=[d0, d1])
print(cscdm_object.dimensions)
```

Out:

```
[LinearDimension(count=256, increment=15.23 μs, coordinates_offset=-1.95 ms, quantity_
↪name=time, label=t1, reciprocal={'quantity_name': 'frequency'}),
LinearDimension(count=256, increment=10.0 cm, coordinates_offset=-5.0 m, quantity_
↪name=length, label=x2, reciprocal={'quantity_name': 'wavenumber'})]
```

Plot of the dataset.

```
plt.figure(figsize=(5, 3.5))
ax = plt.subplot(projection="cscdm")
cb = ax.imshow(cscdm_object, aspect="auto")
plt.colorbar(cb, ax=ax)
plt.tight_layout()
plt.show()
```



To serialize the file, use the save method.

```
csdm_object.save("2D_1_dataset.csdf")
```

Total running time of the script: (0 minutes 0.211 seconds)

9.2.2 2D{1} dataset with linear and monotonic dimensions

In the following example, we illustrate how one can convert a Numpy array into a CSDM object. Start by importing the Numpy and csdmpy libraries.

```
import matplotlib.pyplot as plt
import numpy as np

import csdmpy as cp
```

Let's generate a 2D NumPy array of random numbers as our dataset.

```
data = np.random.rand(8192).reshape(32, 256)
```

Create the DependentVariable object from the numpy object.

```
dv = cp.as_dependent_variable(data, unit="J/(mol K)")
```

Create the two Dimension objects.

```
d0 = cp.LinearDimension(
    count=256, increment="15.23 μs", coordinates_offset="-1.95 ms", label="t1"
)
```

Here, d0 is a LinearDimension with 256 points and 15.23 μs increment. You may similarly set the second dimension as a LinearDimension, however, in this example, let's set it as a MonotonicDimension.

```
array = 10 ** (np.arange(32) / 8)
d1 = cp.as_dimension(array, unit="μs", label="t2")
```

The variable `array` is a NumPy array that is uniformly sampled on a log scale. To convert this array into a Dimension object, we use the `as_dimension()` method.

Creating the CSDM object.

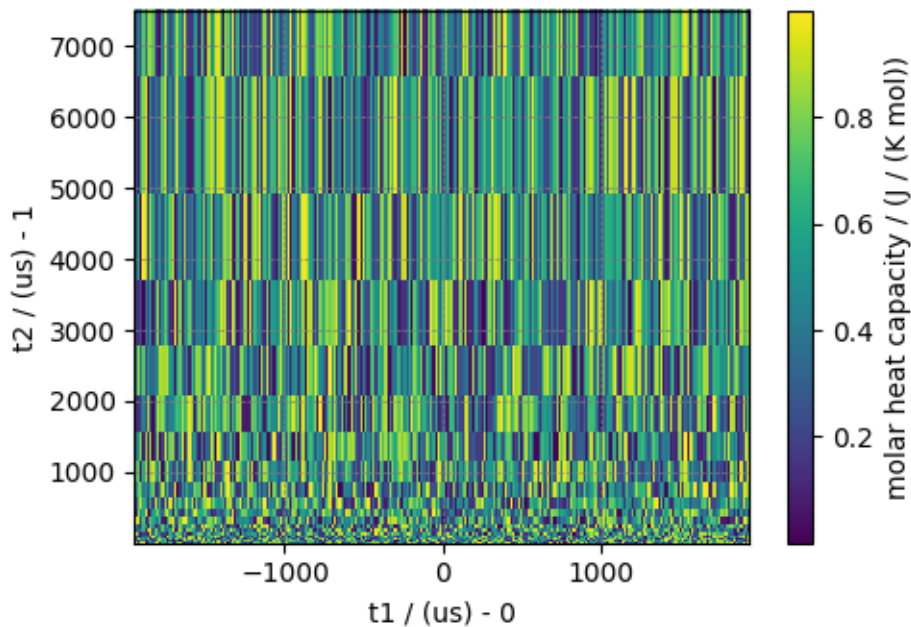
```
cscdm_object = cp.CSDM(dependent_variables=[dv], dimensions=[d0, d1])
print(cscdm_object.dimensions)
```

Out:

```
[LinearDimension(count=256, increment=15.23 μs, coordinates_offset=-1.95 ms, quantity_
↪name=time, label=t1, reciprocal={'quantity_name': 'frequency'}),
MonotonicDimension(coordinates=[1.00000000e+00 1.33352143e+00 1.77827941e+00 2.
↪37137371e+00
3.16227766e+00 4.21696503e+00 5.62341325e+00 7.49894209e+00
1.00000000e+01 1.33352143e+01 1.77827941e+01 2.37137371e+01
3.16227766e+01 4.21696503e+01 5.62341325e+01 7.49894209e+01
1.00000000e+02 1.33352143e+02 1.77827941e+02 2.37137371e+02
3.16227766e+02 4.21696503e+02 5.62341325e+02 7.49894209e+02
1.00000000e+03 1.33352143e+03 1.77827941e+03 2.37137371e+03
3.16227766e+03 4.21696503e+03 5.62341325e+03 7.49894209e+03] us, quantity_name=time,
↪label=t2, reciprocal={'quantity_name': 'frequency'})]
```

Plot of the dataset.

```
plt.figure(figsize=(5, 3.5))
cp.plot(cscdm_object)
plt.tight_layout()
plt.show()
```



To serialize the file, use the save method.


```
csdm_object.save("2D_1_dataset.csdf")
```

Total running time of the script: (0 minutes 0.185 seconds)

AN EMOJI 🍌 EXAMPLE

Let's make use of what we learned so far and create a simple 1D{1} dataset. To make it interesting, let's create an emoji dataset.

Start by importing the *csdmpy* package.

```
>>> import csdmpy as cp
```

Create a labeled dimension. Here, we make use of python dictionary.

```
>>> x = dict(type="labeled", labels=["🍌", "🍌", "🍌", "🍌", "🍌", "🍌"])
```

The above python dictionary contains two keys. The *type* key identifies the dimension as a labeled dimension while the *labels* key holds an array of labels. In this example, the labels are emojis. Add this dictionary to the list of dimensions.

Next, create a dependent variable. Similarly, set up a python dictionary corresponding to the dependent variable object.

```
>>> y = dict(
...     type="internal",
...     numeric_type="float32",
...     quantity_type="scalar",
...     components=[[0.5, 0.25, 1, 2, 1, 0.25]],
... )
```

Here, the python dictionary contains *type*, *numeric_type*, and *components* key. The value of the *components* key holds an array of data values corresponding to the labels from the labeled dimension.

Create a csdm object from the dimensions and dependent variables and we have a 🍌 dataset...

```
>>> fun_data = cp.CSDM(
...     dimensions=[x], dependent_variables=[y], description="An emoji dataset"
... )
>>> print(fun_data.data_structure)
{
  "csdm": {
    "version": "1.0",
    "description": "An emoji dataset",
    "dimensions": [
      {
        "type": "labeled",
        "labels": [
          "🍌",
          "🍌",
          "🍌",
          "🍌",
          "🍌",
          "🍌",
        ]
      }
    ]
  }
}
```

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```
        "👩"
    ]
}
],
"dependent_variables": [
    {
        "type": "internal",
        "numeric_type": "float32",
        "quantity_type": "scalar",
        "components": [
            [
                "0.5, 0.25, ..., 1.0, 0.25"
            ]
        ]
    }
]
}
```

To serialize this file, use the `save()` method of the `fun_data` instance as

```
>>> fun_data.dependent_variables[0].encoding = "base64"
>>> fun_data.save("my_file.csdf")
```

In the above code, the components from the `dependent_variables` attribute at index zero, are encoded as `base64` strings before serializing to the `my_file.csdf` file.

You may also save the components as a binary file, in which case, the file is serialized with a `.csdfe` file extension.

```
>>> fun_data.dependent_variables[0].encoding = "raw"
>>> fun_data.save("my_file_raw.csdfe")
```

API-REFERENCE

11.1 csdmpy

The *csdmpy* is a python package for importing and exporting files serialized with the core scientific dataset model file-format. The package supports a p -component dependent variable, $\mathbf{U} \equiv \{\mathbf{U}_0, \dots, \mathbf{U}_q, \dots, \mathbf{U}_{p-1}\}$, which is discretely sampled at M unique points in a d -dimensional space $(\mathbf{X}_0, \dots \mathbf{X}_k, \dots \mathbf{X}_{d-1})$. Besides, the package also supports multiple dependent variables, \mathbf{U}_i , sharing the same d -dimensional space.

Here, every dataset is an instance of the *CSDM* class, which holds a list of dimensions and dependent variables. Every dimension, \mathbf{X}_k , is an instance of the *Dimension* class, while every dependent variable, \mathbf{U}_i , is an instance of the *DependentVariable* class.

11.1.1 Methods

Methods Summary

<code>parse_dict</code>	Parse a CSDM compliant python dictionary and return a CSDM object.
<code>load</code>	Loads a .csdf/.csdfe file and returns an instance of the <i>CSDM</i> class.
<code>loads</code>	Loads a JSON serialized string as a CSDM object.
<code>new</code>	Creates a new instance of the <i>CSDM</i> class containing a 0D{0} dataset.
<code>as_dimension</code>	Generate and return a Dimension object from a 1D numpy array.
<code>as_dependent_variable</code>	Generate and return a DependentVariable object from a 1D or 2D numpy array.
<code>as_csdm</code>	Generate and return a view of the nD numpy array as a csdm object.
<code>plot</code>	A supplementary function for plotting basic 1D and 2D datasets only.

Method Documentation

`csdmpy.parse_dict(dictionary)`

Parse a CSDM compliant python dictionary and return a CSDM object.

Parameters

dictionary – A CSDM compliant python dictionary.

`csdmpy.load(filename=None, application=False, verbose=False)`

Loads a .csdf/.csdfe file and returns an instance of the *CSDM* class.

The file must be a JSON serialization of the CSD Model.

Example

```
>>> data1 = cp.load('local_address/file.csdf')
>>> data2 = cp.load('url_address/file.csdf')
```

Parameters

- **filename** (*str*) – A local or a remote address to the *.csdf* or *.csdfe* file.
- **application** (*bool*) – If true, the application metadata from application that last serialized the file will be imported. Default is False.
- **verbose** (*bool*) – If the filename is a URL, this option will show the progress bar for the file download status, when True.

Returns

A CSDM instance.

`csdmpy.loads(string)`

Loads a JSON serialized string as a CSDM object.

Parameters

string – A JSON serialized CSDM string.

Returns

A CSDM object.

Example

```
>>> object_from_string = cp.loads(cp.new('A test dump').dumps())
>>> print(object_from_string.data_structure)
{
  "csdm": {
    "version": "1.0",
    "timestamp": "2019-10-21T20:33:17Z",
    "description": "A test dump",
    "dimensions": [],
    "dependent_variables": []
  }
}
```

`csdmpy.new(description="")`

Creates a new instance of the *CSDM* class containing a 0D{0} dataset.

Parameters

description (*str*) – A string describing the csdm object. This is optional.

Example

```
>>> import csdmpy as cp
>>> empty_data = cp.new(description='Testing Testing 1 2 3')
>>> print(empty_data.data_structure)
{
  "csdm": {
    "version": "1.0",
    "description": "Testing Testing 1 2 3"
  }
}
```

Returns

A CSDM instance.

`csdmpy.as_csdm(array, unit="", quantity_type='scalar')`

Generate and return a view of the nD numpy array as a csdm object. The nD array is the dependent variable of the csdm object of the given quantity type. The shape of the nD array is used to generate Dimension object of *linear* subtype.

Parameters

- **array** – The nD numpy array.
- **unit** – The unit for the dependent variable. The default is empty string.
- **quantity_type** – The quantity type of the dependent variable.

Example

```
>>> array = np.arange(30).reshape(3, 10)
>>> csdm_obj = cp.as_csdm(array)
>>> print(csdm_obj)
CSDM(
  DependentVariable(
    [[[ 0  1  2  3  4  5  6  7  8  9]
      [10 11 12 13 14 15 16 17 18 19]
      [20 21 22 23 24 25 26 27 28 29]]], quantity_type=scalar, numeric_type=int64),
  LinearDimension([0. 1. 2. 3. 4. 5. 6. 7. 8. 9.]),
  LinearDimension([0. 1. 2.])
)
```

`csdmpy.as_dimension(array, unit="", type=None, **kwargs)`

Generate and return a Dimension object from a 1D numpy array.

Parameters

- **array** – A 1D numpy array.
- **unit** – The unit of the coordinates along the dimension.

- **type** – The dimension type. Valid values are linear, monotonic, labeled, or None. If the value is None, let us decide. The default value is None.
- **kwargs** – Additional keyword arguments from the Dimension class.

Example

```
>>> array = np.arange(15)*0.5
>>> dim_object = cp.as_dimension(array)
>>> print(dim_object)
LinearDimension([0.  0.5 1.  1.5 2.  2.5 3.  3.5 4.  4.5 5.  5.5 6.  6.5 7. ])
```

```
>>> array = ['The', 'great', 'circle']
>>> dim_object = cp.as_dimension(array, label='in the sky')
>>> print(dim_object)
LabeledDimension(['The' 'great' 'circle'])
```

`csdmpy.as_dependent_variable(array, **kwargs)`

Generate and return a DependentVariable object from a 1D or 2D numpy array.

Parameters

- **array** – A 1D or 2D numpy array.
- **kwargs** – Additional keyword arguments from the DependentVariable class.

Example

```
>>> array = np.arange(1e4).astype(np.complex128)
>>> dim_object = cp.as_dependent_variable(array)
>>> print(dim_object)
DependentVariable(
[[0.000e+00+0.j 1.000e+00+0.j 2.000e+00+0.j ... 9.997e+03+0.j
 9.998e+03+0.j 9.999e+03+0.j]], quantity_type=scalar, numeric_type=complex128)
```

`csdmpy.plot(csdm_object, reverse_axis=None, range=None, **kwargs)`

A supplementary function for plotting basic 1D and 2D datasets only.

Parameters

- **csdm_object** – The CSDM object.
- **reverse_axis** – An ordered array of boolean specifying which dimensions will be displayed on a reverse axis.
- **range** – A list of minimum and maximum coordinates along the dimensions. The range along each dimension is given as [min, max]
- **kwargs** – Additional keyword arguments are used in matplotlib plotting functions. We implement the following matplotlib methods for the one and two-dimensional datasets.
 - The 1D{1} scalar dataset use the `plt.plot()` method.
 - The 1D{2} vector dataset use the `plt.quiver()` method.
 - The 2D{1} scalar dataset use the `plt.imshow()` method if the two dimensions have a *linear* subtype. If any one of the dimension is *monotonic*, `plt.NonUniformImage()` method is used instead.

- The 2D{2} vector dataset use the `plt.quiver()` method.
- The 2D{3} pixel dataset use the `plt.imshow()`, assuming the pixel dataset as an RGB image.

Returns

A matplotlib figure instance.

Example

```
>>> cp.plot(data_object)
```

11.2 CSDM

class `csdmpy.CSDM` (*filename=""*, *version=None*, *description=""*, ***kwargs*)

Bases: `object`

Create an instance of a CSDM class.

This class is based on the root CSDM object of the core scientific dataset (CSD) model. The class is a composition of the *DependentVariable* and *Dimension* instances, where an instance of the *DependentVariable* class describes a p -component dependent variable, and an instance of the *Dimension* class describes a dimension of a d -dimensional space. Additional attributes of this class are listed below.

Attributes Summary

<i>version</i>	Version number of the CSD model on file.
<i>description</i>	Description of the dataset.
<i>read_only</i>	If True, the data-file is serialized as read only, otherwise, False.
<i>tags</i>	List of tags attached to the dataset.
<i>timestamp</i>	Timestamp from when the file was last serialized.
<i>geographic_coordinate</i>	Geographic coordinate, if present, from where the file was last serialized.
<i>dimensions</i>	Tuple of the <i>Dimension</i> instances.
<i>x</i>	Alias for the dimensions attribute.
<i>dependent_variables</i>	Tuple of the <i>DependentVariable</i> instances.
<i>y</i>	Alias for the dependent_variables attribute.
<i>application</i>	Application metadata dictionary of the CSDM object.
<i>data_structure</i>	Json serialized string describing the CSDM class instance.
<i>filename</i>	Local file address of the current file.

Methods summary

<i>dict</i>	Serialize the <i>CSDM</i> instance as a python dictionary.
<i>to_dict</i>	Alias to the <i>dict()</i> method of the class.
<i>dumps</i>	Serialize the <i>CSDM</i> instance as a JSON data-exchange string.
<i>astype</i>	Return a copy of the CSDM object by converting the numeric type of each dependent variables components to the given value.
<i>save</i>	Serialize the <i>CSDM</i> instance as a JSON data-exchange file.
<i>copy</i>	Create a copy of the current CSDM instance.
<i>split</i>	View of the dependent-variables as individual csdm objects.

Numpy compatible attributes summary

<i>real</i>	Return a csdm object with only the real part of the dependent variable components.
<i>imag</i>	Return a csdm object with only the imaginary part of the dependent variable components.
<i>shape</i>	Return the count along each dimension of the csdm object.
<i>size</i>	Return the size of the dependent_variable components.
<i>T</i>	Return a csdm object with a transpose of the dataset.

Numpy compatible method summary

<i>max</i>	Return a csdm object of maximum dependent variable along a given axis.s
<i>min</i>	Return a csdm object of minimum dependent variable component along a given axis.
<i>clip</i>	Clip the dependent variable components between the <i>min</i> and <i>max</i> values.
<i>conj</i>	Return a complex conjugate of the csdm object.
<i>round</i>	Rounds a csdm object to the given <i>decimals</i> .
<i>sum</i>	Return a csdm object sum over a given axis.
<i>mean</i>	Return a csdm object mean over a given axis.
<i>var</i>	Return a csdm object variance over a given axis.
<i>std</i>	Return a csdm object standard deviation over a given axis.
<i>prod</i>	Return a csdm object product over a given axis.

Attributes documentation

version

Version number of the CSD model on file.

description

Description of the dataset. The default value is an empty string.

Example

```
>>> print(data.description)
A simulated sine curve.
```

Returns

A string of UTF-8 allows characters describing the dataset.

Raises

TypeError – When the assigned value is not a string.

read_only

If True, the data-file is serialized as read only, otherwise, False.

By default, the *CSDM* object loads a copy of the .csdf(e) file, irrespective of the value of the *read_only* attribute. The value of this attribute may be toggled at any time after the file import. When serializing the .csdf(e) file, if the value of the *read_only* attribute is found True, the file will be serialized as read only.

tags

List of tags attached to the dataset.

timestamp

Timestamp from when the file was last serialized. Attribute is read only.

The timestamp stamp is a string representation of the Coordinated Universal Time (UTC) formatted according to the iso-8601 standard.

Raises

AttributeError – When the attribute is modified.

geographic_coordinate

Geographic coordinate, if present, from where the file was last serialized. This attribute is read-only.

The geographic coordinates correspond to the location where the file was last serialized. If present, the geographic coordinates are described with three attributes, the required latitude and longitude, and an optional altitude.

Raises

AttributeError – When the attribute is modified.

dimensions

Tuple of the *Dimension* instances.

x

Alias for the dimensions attribute.

dependent_variables

Tuple of the *DependentVariable* instances.

y

Alias for the `dependent_variables` attribute.

application

Application metadata dictionary of the CSDM object.

```
>>> print(data.application)
None
```

By default, the application attribute is an empty object, that is, the application metadata stored by the previous application is ignored upon file import.

The application metadata may, however, be retained with a request via the `load()` method. This feature may be useful to related applications where application metadata might contain additional information. The attribute may be updated with a python dictionary.

The application attribute is where an application can place its own metadata as a python dictionary object containing application specific metadata, using a reverse domain name notation string as the attribute key, for example,

Example

```
>>> data.application = {
...     "com.example.myApp" : {
...         "myApp_key": "myApp_metadata"
...     }
... }
>>> print(data.application)
{'com.example.myApp': {'myApp_key': 'myApp_metadata'}}
```

Returns

Python dictionary object with the application metadata.

data_structure

Json serialized string describing the CSDM class instance.

The `data_structure` attribute is only intended for a quick preview of the dataset. This JSON serialized string from this attribute avoids displaying large datasets. Do not use the value of this attribute to save the data to a file, instead use the `save()` methods of the instance.

Raises

AttributeError – When modified.

filename

Local file address of the current file.

Numpy compatible attributes documentation

real

Return a csdm object with only the real part of the dependent variable components.

imag

Return a csdm object with only the imaginary part of the dependent variable components.

shape

Return the count along each dimension of the csdm object.

size

Return the size of the dependent_variable components.

T

Return a csdm object with a transpose of the dataset.

Methods documentation

dict (*update_timestamp=False, read_only=False*)

Serialize the *CSDM* instance as a python dictionary.

Parameters

- **update_timestamp** (*bool*) – If True, timestamp is updated to current time.
- **read_only** (*bool*) – If true, the read_only flag is set true.

Example

```
>>> data.dict()['csdm']['version']
'1.0'
```

to_dict (*update_timestamp=False, read_only=False*)

Alias to the *dict()* method of the class.

dumps (*update_timestamp=False, read_only=False, **kwargs*)

Serialize the *CSDM* instance as a JSON data-exchange string.

Parameters

- **update_timestamp** (*bool*) – If True, timestamp is updated to current time.
- **read_only** (*bool*) – If true, the file is serialized as read_only.

Example

```
>>> data.dumps()[ :63] # first 63 characters
'{"csdm": {"version": "1.0", "timestamp": "1994-11-05T13:15:30Z"'
```

save (*filename*="", *read_only*=False, *output_device*=None, *indent*=0)

Serialize the *CSDM* instance as a JSON data-exchange file.

There are two types of file serialization extensions, *.csdf* and *.csdfe*. In the CSD model, when every instance of the *DependentVariable* objects from a CSDM class has an *internal* subtype, the corresponding CSDM instance is serialized with a *.csdf* file extension. If any single *DependentVariable* instance has an *external* subtype, the CSDM instance is serialized with a *.csdfe* file extension. The two different file extensions are used to alert the end-user of the possible deserialization error associated with the *.csdfe* file extensions had the external data file becomes inaccessible.

In *csdmpy*, however, irrespective of the dependent variable subtypes from the serialized JSON file, by default, all instances of *DependentVariable* class are treated an *internal* after import. Therefore, when serialized, the CSDM object should be stored as a *.csdf* file.

To store a file as a *.csdfe* file, the user much set the value of the *encoding* attribute from the dependent variables to *raw*. In which case, a binary file named *filename_i.dat* will be generated where *i* is the *i*th dependent variable. The parameter *filename* is an argument of this method.

Note: Only dependent variables with *encoding*="raw" will be serialized to a binary file.

Parameters

- **filename** (*str*) – The filename of the serialized file.
- **read_only** (*bool*) – If true, the file is serialized as *read_only*.
- **output_device** (*object*) – Object where the data is written. If provided, the argument *filename* become irrelevant.

Example

```
>>> data.save('my_file.csdf')
```

to_list ()

Return the dimension coordinates and dependent variable components as a list of numpy arrays. For multiple dependent variables, the components of each dependent variable is appended in the order of the dependent variables.

For example,

- A 2D{1} will be packed as $[x_0, x_1, y_{0,0}]$
- A 2D{3} will be packed as $[x_0, x_1, y_{0,0}, y_{0,1}, y_{0,2}]$
- A 1D{1,2} will be packed as $[x_0, y_{0,0}, y_{1,0}, y_{1,1}]$

where x_i represents the *i*th dimension and $y_{i,j}$ represents the *j*th component of the *i*th dependent variable.

astype (*numeric_type*)

Return a copy of the CSDM object by converting the numeric type of each dependent variables components to the given value.

Parameters

- **numeric_type** – A numpy dtype or a string with a valid numeric type

Example

```
>>> data_32 = data_64.astype('float32')
```

copy()

Create a copy of the current CSDM instance.

Returns

A CSDM instance.

Example

```
>>> data2 = data.copy()
```

split()

View of the dependent-variables as individual csdm objects.

Returns

A list of CSDM objects, each with one dependent variable. The objects are returned as a view.

Example

```
>>> # data contains two dependent variables
>>> d1, d2 = data.split()
```

transpose()

Return a transpose of the CSDM object.

fft (axis=0)

Perform a FFT along the given *dimension=axis*, for linear dimension, assuming Nyquist-Shannon relation.

Parameters

axis – dimension index along which the FFT is performed.

The FFT method uses the `complex_fft` attribute of the Dimension object to decide whether a forward or inverse Fourier transform is performed. If the value of the `complex_fft` is True, an inverse FFT is performed, otherwise a forward FFT.

For FFT process, this function is equivalent to performing

```
phase = np.exp(-2j * np.pi * coordinates_offset * reciprocal_coordinates)
x_fft = np.fft.fftshift(np.fft.fft(x)) * phase
```

over all components for every dependent variable.

Similarly, for inverse FFT process, this function is equivalent to performing

```
phase = np.exp(2j * np.pi * reciprocal_coordinates_offset * coordinates)
x = np.fft.ifft(np.fft.ifftshift(x_fft * phase))
```

over all components for every dependent variable.

Returns

A CSDM object with the Fourier Transform data.

Numpy compatible method documentation

max (*axis=None*)

Return a csdm object of maximum dependent variable along a given axis.

Parameters

axis – An integer or None or a tuple of m integers corresponding to the dimension index/indices along which the operation is performed. If None, the output is over all dimensions per dependent variable.

Returns

A CSDM object with m dimensions removed, or a numpy array when dimension is None.

Example

```
>>> data.max()
<Quantity 0.95105654>
```

min (*axis=None*)

Return a csdm object of minimum dependent variable component along a given axis.

Parameters

axis – An integer or None or a tuple of m integers corresponding to the dimension index/indices along which the operation is performed. If None, the output is over all dimensions per dependent variable.

Returns

A CSDM object with m dimensions removed, or a list when *axis* is None.

clip (*min=None, max=None*)

Clip the dependent variable components between the *min* and *max* values.

Parameters

- **min** – The minimum clip value.
- **max** – The maximum clip value.

Returns

A CSDM object with values clipped between min and max.

conj ()

Return a complex conjugate of the csdm object.

round (*decimals=0*)

Rounds a csdm object to the given *decimals*.

sum (*axis=None*)

Return a csdm object sum over a given axis.

Parameters

axis – An integer or None or a tuple of m integers corresponding to the dimension index/indices along which the operation is performed. If None, the output is over all dimensions per dependent variable.

Returns

A CSDM object with m dimensions removed, or a list when *axis* is None.

mean (*axis=None*)

Return a csdm object mean over a given axis.

Parameters

axis – An integer or None or a tuple of m integers corresponding to the dimension index/indices along which the operation is performed. If None, the output is over all dimensions per dependent variable.

Returns

A CSDM object with m dimensions removed, or a list when *axis* is None.

var (*axis=None*)

Return a csdm object variance over a given axis.

Parameters

axis – An integer or None or a tuple of m integers corresponding to the dimension index/indices along which the operation is performed. If None, the output is over all dimensions per dependent variable.

Returns

A CSDM object with m dimensions removed, or a list when *axis* is None.

std (*axis=None*)

Return a csdm object standard deviation over a given axis.

Parameters

axis – An integer or None or a tuple of m integers corresponding to the dimensions index/indices along which the operation is performed. If None, the output is over all dimensions per dependent variable.

Returns

A CSDM object with m dimensions removed, or a list when *axis* is None.

prod (*axis=None*)

Return a csdm object product over a given axis.

Parameters

axis – An integer or None or a tuple of m integers corresponding to the dimension index/indices along which the operation is performed. If None, the output is over all dimensions per dependent variable.

Returns

A CSDM object with m dimensions removed, or a list when *axis* is None.

11.3 Dimension

11.3.1 LinearDimension

class `csdmpy.LinearDimension` (*count, increment, complex_fft=False, **kwargs*)

Bases: `BaseQuantitativeDimension`

LinearDimension class.

Generates an object representing a physical dimension whose coordinates are uniformly sampled along a grid dimension. See [LinearDimension](#) for details.

property complex_fft

If True, orders the coordinates according to FFT output order.

property coordinates

Return the coordinates along the dimensions.

property count

Total number of points along the linear dimension.

dict()

Return the LinearDimension as a python dictionary.

get_nmr_reference_offset()

Calculate reference offset for NMR datasets.

property increment

Increment along the linear dimension.

reciprocal_coordinates()

Return reciprocal coordinates assuming Nyquist-Shannon theorem.

reciprocal_increment()

Return reciprocal increment assuming Nyquist-Shannon theorem.

property type

Return the type of the dimension.

11.3.2 MonotonicDimension

```
class csdmpy.MonotonicDimension(coordinates, **kwargs)
```

Bases: BaseQuantitativeDimension

Monotonic grid dimension.

Generates an object representing a physical dimension whose coordinates are monotonically sampled along a grid dimension. See [MonotonicDimension](#) for details.

property coordinates

Return the coordinates along the dimensions.

property coordinates_offset

Value at index zero, c_k , along the dimension.

property count

Total number of points along the monotonic dimension.

dict()

Return the MonotonicDimension as a python dictionary.

property type

Return the type of the dimension.

11.3.3 LabeledDimension

class csdmpy.LabeledDimension (labels, label="", description="", application=None, **kwargs)

Bases: BaseDimension

A labeled dimension.

Generates an object representing a non-physical dimension whose coordinates are labels. See [LabeledDimension](#) for details.

property coordinates

Return the coordinates along the dimensions. This is an alias for labels.

property count

Total number of labels along the dimension.

dict ()

Return the LabeledDimension as a python dictionary.

is_quantitative ()

Return *True*, if the dimension is quantitative, otherwise *False*. :returns: A Boolean.

property labels

Return a list of labels along the dimension.

property type

Return the type of the dimension.

class csdmpy.Dimension (*args, **kwargs)

Bases: object

Dimension class.

An instance of this class describes a dimension of a multi-dimensional system. In version 1.0 of the CSD model, there are three subtypes of the Dimension class:

- [LinearDimension](#),
- [MonotonicDimension](#), and
- [LabeledDimension](#).

Creating an instance of a dimension object

There are two ways of creating a new instance of a Dimension class.

From a python dictionary containing valid keywords.

```
>>> from csdmpy import Dimension
>>> dimension_dictionary = {
...     "type": "linear",
...     "description": "test",
...     "increment": "5 G",
...     "count": 10,
...     "coordinates_offset": "10 mT",
...     "origin_offset": "10 T",
... }
>>> x = Dimension(dimension_dictionary)
```

Here, *dimension_dictionary* is the python dictionary.

From valid keyword arguments.

```

>>> x = Dimension(
...     type="linear",
...     description="test",
...     increment="5 G",
...     count=10,
...     coordinates_offset="10 mT",
...     origin_offset="10 T",
... )

```

Attributes Summary

<i>type</i>	The dimension subtype.
<i>description</i>	Brief description of the dimension object.
<i>application</i>	Application metadata dictionary of the dimension object.
<i>coordinates</i>	Coordinates, \mathbf{X}_k , along the dimension.
<i>coords</i>	Alias for the <i>coordinates</i> attribute.
<i>absolute_coordinates</i>	Absolute coordinates, $\mathbf{X}_k^{\text{abs}}$, along the dimension.
<i>count</i>	Number of coordinates, $N_k \geq 1$, along the dimension.
<i>increment</i>	Increment along a <i>linear</i> dimension.
<i>coordinates_offset</i>	Offset corresponding to the zero of the indexes array, \mathbf{J}_k .
<i>origin_offset</i>	Origin offset, o_k , along the dimension.
<i>complex_fft</i>	If true, the coordinates are the ordered as the output of a complex fft.
<i>quantity_name</i>	Quantity name associated with the physical quantities specifying dimension.
<i>label</i>	Label associated with the dimension.
<i>labels</i>	Ordered list of labels along the <i>Labeled</i> dimension.
<i>period</i>	Period of the dimension.
<i>axis_label</i>	Formatted string for displaying label along the dimension axis.
<i>data_structure</i>	JSON serialized string describing the Dimension class instance.

Methods Summary

<i>to</i>	Convert the coordinates along the dimension to the unit, <i>unit</i> .
<i>dict</i>	Return Dimension object as a python dictionary.
<i>to_dict</i>	Alias to the <i>dict()</i> method of the class.
<i>is_quantitative</i>	Return True if the dependent variable is quantitative.
<i>copy</i>	Return a copy of the Dimension object.
<i>reciprocal_coordinates</i>	Return reciprocal coordinates assuming Nyquist-Shannon theorem.
<i>reciprocal_increment</i>	Return reciprocal increment assuming Nyquist-Shannon theorem.

Attributes Documentation

type

The dimension subtype.

There are three *valid* subtypes of Dimension class. The valid literals are given by the *DimObjectSubtype* enumeration.

```
>>> print(x.type)
linear
```

Returns

A string with a valid dimension subtype.

Raises

AttributeError – When the attribute is modified.

description

Brief description of the dimension object.

The default value is an empty string, ''. The attribute may be modified, for example,

```
>>> print(x.description)
This is a test

>>> x.description = "This is a test dimension."
```

Returns

A string of UTF-8 allows characters describing the dimension.

Raises

TypeError – When the assigned value is not a string.

application

Application metadata dictionary of the dimension object.

```
>>> print(x.application)
None
```

The application attribute is where an application can place its metadata as a python dictionary object using a reverse domain name notation string as the attribute key, for example,

```
>>> x.application = {"com.example.myApp": {"myApp_key": "myApp_metadata"}}
>>> print(x.application)
{'com.example.myApp': {'myApp_key': 'myApp_metadata'}}
```

Returns

A python dictionary containing dimension application metadata.

coordinates

Coordinates, \mathbf{X}_k , along the dimension.

Example

```
>>> print(x.coordinates)
[100. 105. 110. 115. 120. 125. 130. 135. 140. 145.] G
```

For *linear* dimensions, the order of the *coordinates* also depend on the value of the *complex_fft* attributes. For examples, when the value of the *complex_fft* attribute is True, the coordinates are

```
>>> x.complex_fft = True
>>> print(x.coordinates)
[ 75.  80.  85.  90.  95. 100. 105. 110. 115. 120.] G
```

Returns

A Quantity array of coordinates for quantitative dimensions, *i.e.* *linear* and *monotonic*.

Returns

A Numpy array for labeled dimensions.

Raises

AttributeError – For dimensions with subtype *linear*.

coords

Alias for the *coordinates* attribute.

absolute_coordinates

Absolute coordinates, $\mathbf{X}_k^{\text{abs}}$, along the dimension.

This attribute is only *valid* for quantitative dimensions, that is, *linear* and *monotonic* dimensions. The absolute coordinates are given as

$$\mathbf{X}_k^{\text{abs}} = \mathbf{X}_k + o_k \mathbf{1} \quad (11.1)$$

where \mathbf{X}_k are the coordinates along the dimension and o_k is the *origin_offset*. For example, consider

```
>>> print(x.origin_offset)
10.0 T
>>> print(x.coordinates[:5])
[100. 105. 110. 115. 120.] G
```

then the absolute coordinates are

```
>>> print(x.absolute_coordinates[:5])
[100100. 100105. 100110. 100115. 100120.] G
```

For *linear* dimensions, the order of the *absolute_coordinates* further depend on the value of the *complex_fft* attributes. For examples, when the value of the *complex_fft* attribute is True, the absolute coordinates are

```
>>> x.complex_fft = True
>>> print(x.absolute_coordinates[:5])
[100075. 100080. 100085. 100090. 100095.] G
```

Returns

A Quantity array of absolute coordinates for quantitative dimensions, *i.e.* *linear* and *monotonic*.

Raises

AttributeError – For labeled dimensions.

count

Number of coordinates, $N_k \geq 1$, along the dimension.

Example

```
>>> print(x.count)
10
>>> x.count = 5
```

Returns

An Integer specifying the number of coordinates along the dimension.

Raises

TypeError – When the assigned value is not an integer.

increment

Increment along a *linear* dimension.

The attribute is only *valid* for Dimension instances with the subtype *linear*. When assigning a value, the dimensionality of the value must be consistent with the dimensionality of other members specifying the dimension.

Example

```
>>> print(x.increment)
5.0 G
>>> x.increment = "0.1 G"
>>> print(x.coordinates)
[100.  100.1 100.2 100.3 100.4 100.5 100.6 100.7 100.8 100.9] G
```

Returns

A Quantity instance with the increment along the dimension.

Raises

- **AttributeError** – For dimension with subtypes other than *linear*.
- **TypeError** – When the assigned value is not a string containing a quantity or a Quantity object.

coordinates_offset

Offset corresponding to the zero of the indexes array, \mathbf{J}_k .

When assigning a value, the dimensionality of the value must be consistent with the dimensionality of the other members specifying the dimension.

Example

```
>>> print(x.coordinates_offset)
10.0 mT
>>> x.coordinates_offset = "0 T"
>>> print(x.coordinates)
[ 0.  5. 10. 15. 20. 25. 30. 35. 40. 45.] G
```

The attribute is *invalid* for *labeled* dimensions.

Returns

A Quantity instance with the coordinates offset.

Raises

- **AttributeError** – For *labeled* dimensions.
- **TypeError** – When the assigned value is not a string containing a quantity or a Quantity object.

origin_offset

Origin offset, o_k , along the dimension.

When assigning a value, the dimensionality of the value must be consistent with the dimensionality of other members specifying the dimension.

Example

```
>>> print(x.origin_offset)
10.0 T
>>> x.origin_offset = "1e5 G"
```

The origin offset only affect the absolute_coordinates along the dimension. This attribute is *invalid* for *labeled* dimensions.

Returns

A Quantity instance with the origin offset.

Raises

- **AttributeError** – For *labeled* dimensions.
- **TypeError** – When the assigned value is not a string containing a quantity or a Quantity object.

complex_fft

If true, the coordinates are the ordered as the output of a complex fft.

This attribute is only *valid* for the Dimension instances with *linear* subtype. The value of this attribute is a boolean specifying if the coordinates along the dimension are evaluated as the output of a complex fast Fourier transform (FFT) routine. For example, consider the following Dimension object,

```
>>> test = Dimension(type="linear", increment="1", count=10)
>>> test.complex_fft
False
>>> print(test.coordinates)
[0. 1. 2. 3. 4. 5. 6. 7. 8. 9.]

>>> test.complex_fft = True
```

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```
>>> print(test.coordinates)
[-5. -4. -3. -2. -1.  0.  1.  2.  3.  4.]
```

Returns

A Boolean.

Raises

TypeError – When the assigned value is not a boolean.

quantity_name

Quantity name associated with the physical quantities specifying dimension.

The attribute is *invalid* for the labeled dimension.

```
>>> print(x.quantity_name)
magnetic flux density
```

Returns

A string with the *quantity name*.

Raises

- **AttributeError** – For *labeled* dimensions.
- **NotImplementedError** – When assigning a value.

label

Label associated with the dimension.

Example

```
>>> print(x.label)
field strength
>>> x.label = 'magnetic field strength'
```

Returns

A string containing the label.

Raises

TypeError – When the assigned value is not a string.

labels

Ordered list of labels along the *Labeled* dimension.

Consider the following labeled dimension,

```
>>> x2 = Dimension(type="labeled", labels=["Cu", "Ag", "Au"])
```

then the labels along the labeled dimension are

```
>>> print(x2.labels)
['Cu' 'Ag' 'Au']
```

Note: For Labeled dimension, the `coordinates` attribute is an alias of `labels` attribute. For example,

```
>>> np.all(x2.coordinates == x2.labels)
True
```

In the above example, `x2` is an instance of the `Dimension` class with `labeled` subtype.

Returns

A Numpy array with labels along the dimension.

Raises

AttributeError – For dimensions with subtype other than `labeled`.

`period`

Period of the dimension.

The default value of the period is infinity, i.e., the dimension is non-periodic.

Example

```
>>> print(x.period)
inf G
>>> x.period = '1 T'
```

To assign a dimension as non-periodic, one of the following may be used,

```
>>> x.period = "1/0 T"
>>> x.period = "infinity μT"
>>> x.period = "∞ G"
```

Attention: The physical quantity of the period must be consistent with other physical quantities specifying the dimension.

Returns

A Quantity instance with the period of the dimension.

Raises

- **AttributeError** – For `labeled` dimensions.
- **TypeError** – When the assigned value is not a string containing a quantity or a Quantity object.

`axis_label`

Formatted string for displaying label along the dimension axis.

This attribute is not a part of the original core scientific dataset model, however, it is a convenient supplementary attribute that provides a formatted string ready for labeling dimension axes. For quantitative dimensions, this attribute returns a string, `label / unit`, if the `label` is a non-empty string, otherwise, `quantity_name / unit`. Here `quantity_name` and `label` are the attributes of the `Dimension` instances, and `unit` is the unit associated with the coordinates along the dimension. For examples,

```
>>> x.label
'field strength'
>>> x.axis_label
'field strength / (G)'
```

For *labeled* dimensions, this attribute returns *label*.

Returns

A formatted string of label.

Raises

AttributeError – When assigned a value.

data_structure

JSON serialized string describing the Dimension class instance.

This supplementary attribute is useful for a quick preview of the dimension object. The attribute cannot be modified.

```
>>> print(x.data_structure)
{
  "type": "linear",
  "count": 10,
  "increment": "5.0 G",
  "coordinates_offset": "10.0 mT",
  "origin_offset": "10.0 T",
  "quantity_name": "magnetic flux density",
  "label": "field strength",
  "description": "This is a test",
  "reciprocal": {
    "quantity_name": "electrical mobility"
  }
}
```

Returns

A json serialized string of the dimension object.

Raises

AttributeError – When modified.

Method Documentation

to (*unit*=, *equivalencies*=None)

Convert the coordinates along the dimension to the unit, *unit*.

This method is a wrapper of the *to* method from the [Quantity](#) class and is only *valid* for physical dimensions.

Example

```
>>> print(x.coordinates)
[100. 105. 110. 115. 120. 125. 130. 135. 140. 145.] G
>>> x.to('mT')
>>> print(x.coordinates)
[10.  10.5 11.  11.5 12.  12.5 13.  13.5 14.  14.5] mT
```

Parameters

unit – A string containing a unit with the same dimensionality as the coordinates along the dimension.

Raises

AttributeError – For *labeled* dimensions.

dict()

Return Dimension object as a python dictionary.

Example

```
>>> x.dict()
{'type': 'linear', 'description': 'This is a test', 'count': 10,
 'increment': '5.0 G', 'coordinates_offset': '10.0 mT',
 'origin_offset': '10.0 T', 'quantity_name': 'magnetic flux density',
 'label': 'field strength'}
```

to_dict()

Alias to the *dict()* method of the class.

is_quantitative()

Return True if the dependent variable is quantitative.

Example

```
>>> x.is_quantitative()
True
```

copy()

Return a copy of the Dimension object.

reciprocal_coordinates()

Return reciprocal coordinates assuming Nyquist-Shannon theorem.

reciprocal_increment()

Return reciprocal increment assuming Nyquist-Shannon theorem.

11.4 DependentVariable

class csdmpy.DependentVariable (*args, **kwargs)

Bases: object

Create an instance of the DependentVariable class.

The instance of this class represents a dependent variable, **U**. A dependent variable holds p -component data values, where $p > 0$ is an integer. For example, a scalar is single-component ($p = 1$), a vector may have up to n -components ($p = n$), while a second rank symmetric tensor have six unique component ($p = 6$).

Creating a new dependent variable.

There are two ways of creating a new instance of a DependentVariable class.

From a python dictionary containing valid keywords.

```
>>> from csdmpy import DependentVariable
>>> import numpy as np
>>> numpy_array = np.arange(30).reshape(3, 10).astype(np.float32)

>>> dependent_variable_dictionary = {
...     "type": "internal",
...     "components": numpy_array,
...     "name": "star",
...     "unit": "W s",
...     "quantity_name": "energy",
...     "quantity_type": "pixel_3",
... }
>>> y = DependentVariable(dependent_variable_dictionary)
```

Here, *dependent_variable_dictionary* is the python dictionary.

From valid keyword arguments.

```
>>> y = DependentVariable(
...     type="internal",
...     name="star",
...     unit="W s",
...     quantity_type="pixel_3",
...     components=numpy_array,
... )
```

Attributes Summary

<code>type</code>	The dependent variable subtype.
<code>description</code>	Brief description of the dependent variables.
<code>application</code>	Application metadata of the DependentVariable object.
<code>name</code>	Name of the dependent variable.
<code>unit</code>	Unit associated with the dependent variable.
<code>quantity_name</code>	Quantity name of physical quantities associated with the dependent variable.
<code>encoding</code>	The encoding method used in representing the dependent variable.
<code>numeric_type</code>	The numeric type of the component values from the dependent variable.
<code>quantity_type</code>	Quantity type of the dependent variable.
<code>component_labels</code>	List of labels corresponding to the components of the dependent variable.
<code>components</code>	Component array of the dependent variable.
<code>components_url</code>	URL where the data components of the dependent variable are stored.
<code>axis_label</code>	List of formatted string labels for each component of the dependent variable.
<code>data_structure</code>	Json serialized string describing the DependentVariable class instance.

Methods Summary

<code>to</code>	Convert the unit of the dependent variable to the <i>unit</i> .
<code>dict</code>	Return DependentVariable object as a python dictionary.
<code>to_dict</code>	Alias to the <code>dict()</code> method of the class.
<code>copy</code>	Return a copy of the DependentVariable object.

Attributes Documentation

type

The dependent variable subtype.

There are two *valid* subtypes of DependentVariable class with the following enumeration literals,

```
internal
external
```

corresponding to Internal and External sub class. By default, all instances of the DependentVariable class are assigned as *internal* upon import. The user may update the value of this attribute, at any time, with a string containing a valid *type* literal, for example,

```
>>> print(y.type)
internal

>>> y.type = "external"
```

When *type* is external, the data values from the corresponding dependent variable are serialized to an external file within the same directory as the *.csdfe* file.

Returns

A string with a *valid* dependent variable subtype.

Raises

ValueError – When an invalid value is assigned.

description

Brief description of the dependent variables.

The default value is an empty string, "".

```
>>> print(y.description)
A test image
>>> y.description = "A test pixel_3 image"
>>> print(y.description)
A test pixel_3 image
```

Returns

A string of UTF-8 allowed characters describing the dependent variable.

Raises

TypeError – When the assigned value is not a string.

application

Application metadata of the DependentVariable object.

```
>>> print(y.application)
None
```

The application attribute is where an application can place its own metadata as a python dictionary object containing the application specific metadata, using a reverse domain name notation string as the attribute key, for example,

```
>>> y.application = {"com.example.myApp": {"myApp_key": "myApp_metadata"}}
>>> print(y.application)
{'com.example.myApp': {'myApp_key': 'myApp_metadata'}}
```

Please refer to the Core Scientific Dataset Model article for details.

Returns

A python dictionary containing dependent variable application metadata.

name

Name of the dependent variable.

```
>>> y.name
'star'
>>> y.name = "rock star"
```

Returns

A string containing the name of the dependent variable.

Raises

TypeError – When the assigned value is not a string.

unit

Unit associated with the dependent variable.

Note: The attribute cannot be modified. To convert the unit, use the `to()` method of the class instance.

```
>>> y.unit
Unit("s W")
```

Returns

A *Unit* object from `astropy.unit` package.

Raises

AttributeError – When assigned a value.

quantity_name

Quantity name of physical quantities associated with the dependent variable.

```
>>> y.quantity_name
'energy'
```

Returns

A string with the quantity name associated with the dependent variable physical quantities .

Raises

NotImplementedError – When assigning a value.

encoding

The encoding method used in representing the dependent variable.

The value of this attribute determines the method used when serializing or deserializing the data values to and from the file. Currently, there are three *valid* encoding methods:

```
raw
base64
none
```

A value, *raw*, means that the data values are serialized as binary data. The value, *base64*, implies that the data values are serialized as base64 strings, while, the value *none* refers to text-based serialization.

By default, the encoding attribute of all dependent variable object are set to *base64* after import. The user may update this attribute, at any time, with a string containing a *valid* encoding literal, for example,

```
>>> y.encoding = "base64"
```

The value of this attribute will be used in serializing the data to the file, when using the `save()` method.

Returns

A string with a *valid* encoding type.

Raises

ValueError – If an invalid encoding value is assigned.

numeric_type

The numeric type of the component values from the dependent variable.

There are currently twelve *valid* numeric types in core scientific dataset model.

uint8	int8	float32	complex64
uint16	int16	float64	complex128
uint32	int32		
uint64	int64		

Besides, csdmpy also accepts any valid *type* object, such as int, float, np.complex64, as long as the type is consistent with the above twelve entries.

When assigning a valid value, this attribute updates the *dtype* of the Numpy array from the corresponding *components* attribute.

```
>>> y.numeric_type
'float32'

>>> print(y.components)
[[ 0.  1.  2.  3.  4.  5.  6.  7.  8.  9.]
 [10. 11. 12. 13. 14. 15. 16. 17. 18. 19.]
 [20. 21. 22. 23. 24. 25. 26. 27. 28. 29.]]

>>> y.numeric_type = "complex64"
>>> print(y.components[:, :5])
[[ 0.+0.j  1.+0.j  2.+0.j  3.+0.j  4.+0.j]
 [10.+0.j 11.+0.j 12.+0.j 13.+0.j 14.+0.j]
 [20.+0.j 21.+0.j 22.+0.j 23.+0.j 24.+0.j]]

>>> y.numeric_type = float # python type object
>>> print(y.components[:, :5])
[[ 0.  1.  2.  3.  4.]
 [10. 11. 12. 13. 14.]
 [20. 21. 22. 23. 24.]]
```

Returns

A string with a *valid* numeric type.

Raises

ValueError – If an invalid numeric type value is assigned.

quantity_type

Quantity type of the dependent variable.

There are currently six *valid* quantity types,

```
scalar
vector_n
pixel_n
```

```
matrix_n_m
symmetric_matrix_n
```

where n and m are integers. The value of the attribute is modified with a string containing a *valid* quantity type.

```
>>> y.quantity_type
'pixel_3'
>>> y.quantity_type = "vector_3"
```

Returns

A string with a *valid* quantity type.

Raises

ValueError – If an invalid value is assigned.

component_labels

List of labels corresponding to the components of the dependent variable.

```
>>> y.component_labels
['', '', '']
```

To update the *component_labels*, assign an array of strings with same number of elements as the number of components.

```
>>> y.component_labels = ["channel 0", "channel 1", "channel 2"]
```

The individual labels are accessed with proper indexing, for example,

```
>>> y.component_labels[2]
'channel 2'
```

Returns

A list of component label strings.

Raises

TypeError – When the assigned value is not an array of strings.

components

Component array of the dependent variable.

The value of this attribute, \mathbb{U} , is a Numpy array of shape $(p \times N_{d-1} \times \dots N_1 \times N_0)$ where p is the number of components, and N_k is the number of points from the k^{th} *Dimension* object.

Note: The shape of the components Numpy array, $(p \times N_{d-1} \times \dots N_1 \times N_0)$, is reverse the shape of the components array, $(N_0 \times N_1 \times \dots N_{d-1} \times p)$, from the CSD model. This is because CSD model utilizes a column-major order to shape the components array relative to the order of the dimension while Numpy utilizes a row-major order.

The dimensionality of this Numpy array is $d + 1$ where d is the number of dimension objects. The zeroth axis with p points is the number of components.

This attribute can only be updated when the shape of the new array is the same as the shape of the components array.

For example,

```
>>> print(y.components.shape)
(3, 10)
>>> y.numeric_type
'float32'
```

is a three-component dependent variable with ten data values per component. The numeric type of the data values, in this example, is *float32*. To update the components array, assign an array of shape (3, 10) to the *components* attribute. In the following example, we assign a Numpy array,

```
>>> y.components = np.linspace(0, 256, 30, dtype="u1").reshape(3, 10)
>>> y.numeric_type
'uint8'
```

Notice, the value of the *numeric_type* attribute is automatically updated based on the *dtype* of the Numpy array. In this case, from a *float32* to *uint8*. In this other example,

```
>>> try:
...     y.components = np.random.rand(1,10).astype('u1')
... except ValueError as e:
...     print(e)
The shape of the `ndarray`, `(1, 10)`, is inconsistent with the
shape of the components array, `(3, 10)`.
```

a *ValueError* is raised because the shape of the input array (1, 10) is not consistent with the shape of the components array, (3, 10).

Returns

A Numpy array of components.

Raises

ValueError – When assigning an array whose shape is not consistent with the shape of the components array.

components_url

URL where the data components of the dependent variable are stored.

This attribute is only informative and cannot be modified. Its value is a string containing the local or remote address of the file where the data values are stored. The attribute is only valid for dependent variable with type, *external*.

Returns

A string containing the URL.

Raises

AttributeError – When assigned a value.

axis_label

List of formatted string labels for each component of the dependent variable.

This attribute is not a part of the original core scientific dataset model, however, it is a convenient supplementary attribute that provides formatted string ready for labeling the components of the dependent variable. The string at index *i* is formatted as *component_labels[i] / unit* if *component_labels[i]* is a non-empty string, otherwise, *quantity_name / unit*. Here, *quantity_name*, *component_labels*, and *unit* are the attributes of the *:ref:dv_api* instance. For example,

```
>>> y.axis_label
['energy / (s W)', 'energy / (s W)', 'energy / (s W)']
```

Returns

A list of formatted component label strings.

Raises

AttributeError – When assigned a value.

data_structure

Json serialized string describing the `DependentVariable` class instance.

This supplementary attribute is useful for a quick preview of the dependent variable object. For convenience, the values from the `components` attribute are truncated to the first and the last two numbers per component. The `encoding` keyword is also hidden from this view.

```
>>> print(y.data_structure)
{
  "type": "internal",
  "description": "A test image",
  "name": "star",
  "unit": "s * W",
  "quantity_name": "energy",
  "numeric_type": "float32",
  "quantity_type": "pixel_3",
  "components": [
    [
      "0.0, 1.0, ..., 8.0, 9.0"
    ],
    [
      "10.0, 11.0, ..., 18.0, 19.0"
    ],
    [
      "20.0, 21.0, ..., 28.0, 29.0"
    ]
  ]
}
```

Returns

A json serialized string of the dependent variable object.

Raises

AttributeError – When modified.

Method Documentation

to(*unit*)

Convert the unit of the dependent variable to the *unit*.

Parameters

unit – A string containing a unit with the same dimensionality as the components of the dependent variable.

```
>>> y.unit
Unit("s W")
>>> print(y.components[0, 5])
5.0
>>> y.to("mJ")
>>> y.unit
```

(continues on next page)

(continued from previous page)

```
Unit("mJ")
>>> print(y.components[0, 5])
5000.0
```

Note: This method is a wrapper of the *to* method from the [Quantity](#) class.

dict()

Return `DependentVariable` object as a python dictionary.

Example

```
>>> y.dict()
{'type': 'internal', 'description': 'A test image', 'name': 'star',
 'unit': 's * W', 'quantity_name': 'energy', 'encoding': 'none',
 'numeric_type': 'float32', 'quantity_type': 'pixel_3',
 'components': [[0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0],
 [10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0, 17.0, 18.0, 19.0],
 [20.0, 21.0, 22.0, 23.0, 24.0, 25.0, 26.0, 27.0, 28.0, 29.0]]}
```

to_dict()

Alias to the *dict()* method of the class.

copy()

Return a copy of the `DependentVariable` object.

11.5 Statistics

Methods Summary

<i>integral</i>	Evaluate the integral of the dependent variables over all dimensions.
<i>mean</i>	Evaluate the mean coordinate of a dependent variable along each dimension.
<i>var</i>	Evaluate the variance of the dependent variables along each dimension.
<i>std</i>	Evaluate the standard deviation of the dependent variables along each dimension.

Method Documentation

`csdmpy.statistics.integral(csdm)`

Evaluate the integral of the dependent variables over all dimensions.

Parameters

csdm – A csdm object.

Returns

A list of integrals corresponding to the list of the dependent variables. If only one dependent variable is present, return a quantity instead.

Example

```
>>> import csdmpy.statistics as stat
>>> x = np.arange(100) * 2 - 100.0
>>> gauss = np.exp(-((x - 5.) ** 2) / (2 * 4. ** 2))
>>> csdm = cp.as_csdm(gauss, unit='T')
>>> csdm.dimensions[0] = cp.as_dimension(x, unit="m")
>>> stat.integral(csdm)
<Quantity 10.0265131 m T>
```

`csdmpy.statistics.mean(csdm)`

Evaluate the mean coordinate of a dependent variable along each dimension.

Parameters

csdm – A csdm object.

Returns

A list of tuples, where each tuple represents the mean coordinates of the dependent variables. If only one dependent variable is present, return a tuple of coordinates instead.

Example

```
>>> stat.mean(csdm)
(<Quantity 5. m>,)
```

`csdmpy.statistics.var(csdm)`

Evaluate the variance of the dependent variables along each dimension.

Parameters

csdm – A csdm object.

Returns

A list of tuples, where each tuple is the variance along the dimensions of the dependent variables. If only one dependent variable is present, return a tuple instead.

Example

```
>>> stat.var(csdm)
(<Quantity 16. m2>,)

```

`csdmpy.statistics.std(csdm)`

Evaluate the standard deviation of the dependent variables along each dimension.

Parameters

csdm – A csdm object.

Returns

A list of tuples, where each tuple is the standard deviation along the dimensions of the dependent variables. If only one dependent variable is present, return a tuple instead.

Example

```
>>> stat.std(csdm)
(<Quantity 4. m>,)

```

11.6 CSDMAxes

class `csdmpy.helper_functions.CSDMAxes` (*fig, rect, facecolor=None, frameon=True, sharex=None, sharey=None, label="", xscale=None, yscale=None, box_aspect=None, **kwargs*)

Bases: `Axes`

A custom CSDM data plot axes.

Methods Summary

<code>plot</code>	Generate a figure axes using the <i>plot</i> method from the matplotlib library.
<code>scatter</code>	Generate a figure axes using the <i>scatter</i> method from the matplotlib library.
<code>imshow</code>	Generate a figure axes using the <i>imshow</i> method from the matplotlib library.
<code>contour</code>	Generate a figure axes using the <i>contour</i> method from the matplotlib library.
<code>contourf</code>	Generate a figure axes using the <i>contourf</i> method from the matplotlib library.

Method Documentation

plot (*csdm*, *args, **kwargs)

Generate a figure axes using the *plot* method from the matplotlib library.

Apply to all 1D datasets with single-component dependent-variables. For multiple dependent variables, the data from individual dependent-variables is plotted on the same figure.

Parameters

- **csdm** – A CSDM object of a one-dimensional dataset.
- **kwargs** – Additional keyword arguments for the matplotlib plot() method.

Example

```
>>> ax = plt.subplot(projection='csdm')
>>> ax.plot(csdm_object)
>>> plt.show()
```

scatter (*csdm*, *args, **kwargs)

Generate a figure axes using the *scatter* method from the matplotlib library.

Apply to all 1D datasets with single-component dependent-variables. For multiple dependent variables, the data from individual dependent-variables is plotted on the same figure.

Parameters

- **csdm** – A CSDM object of a one-dimensional dataset.
- **kwargs** – Additional keyword arguments for the matplotlib plot() method.

Example

```
>>> ax = plt.subplot(projection='csdm')
>>> ax.scatter(csdm_object)
>>> plt.show()
```

imshow (*csdm*, *origin*='lower', *args, **kwargs)

Generate a figure axes using the *imshow* method from the matplotlib library.

Apply to all 2D datasets with either single-component (scalar), three-components (pixel_3), or four-components (pixel_4) dependent-variables. For single-component (scalar) dependent-variable, a colormap image is produced. For three-components (pixel_3) dependent-variable, an RGB image is produced. For four-components (pixel_4) dependent-variable, an RGBA image is produced.

For multiple dependent variables, the data from individual dependent-variables is plotted on the same figure.

Parameters

- **csdm** – A CSDM object of a two-dimensional dataset with scalar, pixel_3, or pixel_4 quantity_type dependent variable.
- **origin** – The matplotlib *origin* argument. In matplotlib, the default is 'upper'. In csdmpy, however, the default to 'lower'.
- **kwargs** – Additional keyword arguments for the matplotlib imshow() method.

Example

```
>>> ax = plt.subplot(projection='csdm')
>>> ax.imshow(csdm_object)
>>> plt.show()
```

contour (*csdm*, *args, **kwargs)

Generate a figure axes using the *contour* method from the matplotlib library.

Apply to all 2D datasets with a single-component (scalar) dependent-variables. For multiple dependent variables, the data from individual dependent-variables is plotted on the same figure.

Parameters

- **csdm** – A CSDM object of a two-dimensional dataset with scalar dependent variable.
- **kwargs** – Additional keyword arguments for the matplotlib `contour()` method.

Example

```
>>> ax = plt.subplot(projection='csdm')
>>> ax.contour(csdm_object)
>>> plt.show()
```

contourf (*csdm*, *args, **kwargs)

Generate a figure axes using the *contourf* method from the matplotlib library.

Apply to all 2D datasets with a single-component (scalar) dependent-variables. For multiple dependent variables, the data from individual dependent-variables is plotted on the same figure.

Parameters

- **csdm** – A CSDM object of a two-dimensional dataset with scalar dependent variable.
- **kwargs** – Additional keyword arguments for the matplotlib `contourf()` method.

Example

```
>>> ax = plt.subplot(projection='csdm')
>>> ax.contourf(csdm_object)
>>> plt.show()
```

11.7 Numpy methods

11.7.1 Supported NumPy functions

The *csdm* object supports the use of NumPy functions, as

```
>>> y = np.func(x)
```

where *x* and *y* are the *csdm* objects, and *func* is any one of the following functions. These functions apply to each component of the dependent variables from a given *csdm* object, *x*.

Trigonometric functions

The trigonometric functions apply to the components of the dependent variables from a csdm object.

Note: The components must be dimensionless quantities.

Table 11.1: A list of supported trigonometric functions.

Functions	Description
<code>sin</code>	Apply sine to the components of the dependent variables
<code>cos</code>	Apply cosine to the components of the dependent variables
<code>tan</code>	Apply tangent to the components of the dependent variables
<code>arcsin</code>	Apply inverse sine to the components of the dependent variables
<code>arccos</code>	Apply inverse cosine to the components of the dependent variables
<code>arctan</code>	Apply inverse tangent to the components of the dependent variables
<code>sinh</code>	Apply hyperbolic sine to the components of the dependent variables
<code>cosh</code>	Apply hyperbolic cosine to the components of the dependent variables
<code>tanh</code>	Apply hyperbolic tangent to the components of the dependent variables
<code>arcsinh</code>	Apply inverse hyperbolic sine to the components of the dependent variables
<code>arccosh</code>	Apply inverse hyperbolic cosine to the components of the dependent variables
<code>arctanh</code>	Apply inverse hyperbolic tangent to the components of the dependent variables

Mathematical operations

The following mathematical functions apply to the components of the dependent variables from a csdm object.

Note: The components must be dimensionless quantities.

Table 11.2: A list of supported mathematical functions.

Functions	Description
<code>exp</code>	Calculate the exponential of the components of the dependent variables.
<code>expm1</code>	Apply $e^x - 1$, where x are the components of the dependent variables.
<code>exp2</code>	Calculate 2^x , where x are the components of the dependent variables.
<code>log</code>	Calculate natural logarithm of the components of the dependent variables.
<code>log1p</code>	Calculate natural logarithm plus one on the components of the dependent variables.
<code>log2</code>	Calculate base-2 logarithm of the components of the dependent variables.
<code>log10</code>	Calculate base-10 logarithm of the components of the dependent variables.

The following mathematical functions apply to the components of the dependent variables from a csdm object irrespective of the components' dimensionality.

Table 11.3: Arithmetic operations

Functions	Description
<code>reciprocal</code>	Return element-wise reciprocal.
<code>positive</code>	Return element-wise numerical positive.
<code>negative</code>	Return element-wise numerical negative.

Table 11.4: Miscellaneous

Functions	Description
<code>sqrt</code>	Return element-wise non-negative square-root.
<code>cbrt</code>	Return element-wise cube-root.
<code>square</code>	Return element-wise square.
<code>absolute</code>	Return element-wise absolute value.
<code>fabs</code>	Return element-wise absolute value.
<code>sign</code>	Return element-wise sign of the values.

Table 11.5: Handling complex numbers

Functions	Description
<code>angle</code>	Return element-wise angle of a complex value.
<code>real</code>	Return element-wise real part of a complex value.
<code>imag</code>	Return element-wise imaginary part of a complex value.
<code>conj</code>	Return element-wise conjugate.
<code>conjugate</code>	Return element-wise conjugate.

Table 11.6: Sums, products, differences

Functions	Description
<code>prod</code>	Return the product of the components of a dependent variable along a dimension.
<code>sum</code>	Return the sum of the components of a dependent variable along a dimension.

Table 11.7: Rounding

Functions	Description
<code>rint</code>	Round elements to the nearest integer.
<code>around</code>	Round elements to the given number of decimals.
<code>round</code>	Round elements to the given number of decimals.

Other functions

- `min`
- `max`
- `mean`
- `var`
- `std`

11.7.2 Dimension specific Apodization methods

The following methods of form

$$y = f(ax), \quad (11.2)$$

where a is the function argument, and x are the coordinates along the dimension, apodize the components of the dependent variables along the respective dimensions. The dimensionality of a must be the reciprocal of that of x . The resulting CSDM object has the same number of dimensions as the original object.

Method Summary

<code>sin(csdm, arg[, dimension])</code>	Apodize the components along the <i>dimension</i> with $\sin(ax)$.
<code>cos(csdm, arg[, dimension])</code>	Apodize the components along the <i>dimension</i> with $\cos(ax)$.
<code>tan(csdm, arg[, dimension])</code>	Apodize the components along the <i>dimension</i> with $\tan(ax)$.
<code>arcsin(csdm, arg[, dimension])</code>	Apodize the components along the <i>dimension</i> with $\arcsin(ax)$.
<code>arccos(csdm, arg[, dimension])</code>	Apodize the components along the <i>dimension</i> with $\arccos(ax)$.
<code>arctan(csdm, arg[, dimension])</code>	Apodize the components along the <i>dimension</i> with $\arctan(ax)$.
<code>exp(csdm, arg[, dimension])</code>	Apodize the components along the <i>dimension</i> with $\exp(ax)$.

Method Documentation

`csdmpy.apodize.sin(csdm, arg, dimension=0)`

Apodize the components along the *dimension* with $\sin(ax)$.

Parameters

- **csdm** – A CSDM object.
- **arg** – String or Quantity object. The function argument a .
- **dimension** – An integer or tuple of m integers cooresponding to the index/indices of the dimensions along which the sine of the dependent variable components is performed.

Returns

A CSDM object with $d-m$ dimensions, where d is the total number of dimensions from the original *csdm* object.

`csdmpy.apodize.cos(csdm, arg, dimension=0)`

Apodize the components along the *dimension* with $\cos(ax)$.

Parameters

- **csdm** – A CSDM object.
- **arg** – String or Quantity object. The function argument a .
- **dimension** – An integer or tuple of m integers cooresponding to the index/indices of the dimensions along which the cosine of the dependent variable components is performed.

Returns

A CSDM object with $d-m$ dimensions, where d is the total number of dimensions from the original *csdm* object.

`csdmpy.apodize.tan(csdm, arg, dimension=0)`

Apodize the components along the *dimension* with $\tan(ax)$.

Parameters

- **csdm** – A CSDM object.
- **arg** – String or Quantity object. The function argument a .

- **dimension** – An integer or tuple of m integers cooresponding to the index/indices of the dimensions along which the tangent of the dependent variable components is performed.

Returns

A CSDM object with $d-m$ dimensions, where d is the total number of dimensions from the original *csdm* object.

`csdmpy.apodize.arcsin(csdm, arg, dimension=0)`

Apodize the components along the *dimension* with $\arcsin(ax)$.

Parameters

- **csdm** – A CSDM object.
- **arg** – String or Quantity object. The function argument a .
- **dimension** – An integer or tuple of m integers cooresponding to the index/indices of the dimensions along which the inverse sine of the dependent variable components is performed.

Returns

A CSDM object with $d-m$ dimensions, where d is the total number of dimensions from the original *csdm* object.

`csdmpy.apodize.arccos(csdm, arg, dimension=0)`

Apodize the components along the *dimension* with $\arccos(ax)$.

Parameters

- **csdm** – A CSDM object.
- **arg** – String or Quantity object. The function argument a .
- **dimension** – An integer or tuple of m integers cooresponding to the index/indices of the dimensions along which the inverse cosine of the dependent variable components is performed.

Returns

A CSDM object with $d-m$ dimensions, where d is the total number of dimensions from the original *csdm* object.

`csdmpy.apodize.arctan(csdm, arg, dimension=0)`

Apodize the components along the *dimension* with $\arctan(ax)$.

Parameters

- **csdm** – A CSDM object.
- **arg** – String or Quantity object. The function argument a .
- **dimension** – An integer or tuple of m integers cooresponding to the index/indices of the dimensions along which the inverse tangent of the dependent variable components is performed.

Returns

A CSDM object with $d-m$ dimensions, where d is the total number of dimensions from the original *csdm* object.

`csdmpy.apodize.exp(csdm, arg, dimension=0)`

Apodize the components along the *dimension* with $\exp(ax)$.

Parameters

- **csdm** – A CSDM object.
- **arg** – String or Quantity object. The function argument a .

- **dimension** – An integer or tuple of m integers cooresponding to the index/indices of the dimensions along which the exp of the dependent variable components is performed.

Returns

A CSDM object with $d-m$ dimensions, where d is the total number of dimensions from the original *csdm* object.

CHANGELOG

12.1 v0.5.0

12.1.1 What's new

- Add support for `np.cumsum`, `np.cumprod`, `np.argmin`, `np.argmax` functions to CSDM objects.

12.1.2 Bugfix

- Bugfix involving plot of datasets with dependent-variable quantity type of *vector_1* or *pixel_1*.
- Bugfix when assigning DimensionList/DependentVariableList to the CSDM dimensions and dependent_variables attribute #45
- Bugfix in CSDM object serializing when using Astropy.units v4.0 and higher. #44
- Bugfix for incorrect class name. #39

12.1.3 Deprecated

- `add_x`, `add_y` functions are removed.

12.2 v0.4.1

Patch update for the CSDM dimension's `quantity_name` attribute value from units compatible with astropy>=4.3

12.3 v0.4

12.3.1 What's new

- The `add_dimension` and `add_dependent_variable` from CSDM class are deprecated.

12.3.2 Bugfix

- Fixed error in calculating the nmr dimensionless frequency ratio (ppm) when `dimension.complex_fft=False`

12.4 v0.3.5

- Fix the missing library error from pip installation.

12.5 v0.3.4

12.5.1 Changes

- Image and Contour plots of csdm objects no longer draw colorbar. Colorbar can be requested separately using `plt.colorbar()`.

12.6 v0.3.3

12.6.1 What's new!

- Add `size` method to the CSDM object.
- Added alias for the csdm keywords that are short and easy for coding. The following is the list of aliases
 - *dependent_variables* -> *y*
 - *dimensions* -> *x*
 - *add_dependent_variable* -> *add_x*
 - *add_dimension* -> *add_x*
 - *coordinates* -> *coords*

12.6.2 Bug fixes

- Fixed bug causing a false error when reading sparse datasets.

12.7 v0.3.2

12.7.1 Bug fixes

- Bugfix in `fft` method when applied to multi-dimensional CSDM objects.
- Added new tutorial examples.

12.8 v0.3.1

12.8.1 Bug fixes

- Bugfix regarding the phase multiplier for the `CSDM.fft()` methods where an incorrect phase was multiplied to the signal vector.

12.9 v0.3.0

12.9.1 What's new!

- Support for `matplotlib.pyplot` functions from **CSDM** objects.
 - `plot`,
 - `scatter`,
 - `imshow`,
 - `contour`, and
 - `contourf`

Now you can directly plot CSDM objects as an argument to the above matplotlib methods.

12.10 v0.2.2

12.10.1 Bug fixes

- Fixed bug where the metadata from the `csdm.application` key was not serialized to the file when using `csdm.save()` method.
- Fixed a bug where the transpose of a CSDM object failed to retain the `quantity_type` information after the transpose.

12.10.2 Other changes

- Add a new diffusion tensor MRI dataset to the example gallery.
- Added `dict()` as an alias to the `to_dict()` method for all objects.
- Added an alias of the `cp.plot()` function to the CSDM object as the `plot()` method.

12.11 v0.2.1

12.11.1 What's new!

- Add `reciprocal_coordinates()` and `reciprocal_increment()` methods to the *LinearDimension* class.
- Added `fft()` function to the CSDM class.
- Added `transpose()` method to the CSDM class.

12.12 v0.2.0

12.12.1 What's new!

- Added following methods to the **CSDM** class:
 - `__eq__()` for all class
 - `__add__()` = Adds two csdm object.
 - `__iadd__()` = Adds two csdm objects in-place.
 - `__sub__()` = Subtrace two csdm objects.
 - `__isub__()` = Subtrace two csdm objects in-place.
 - `__mul__()` = Multiply the components of the csdm object by a scalar.
 - `__imul__()` = Multiply the components of the csdm object by a scalar in-place.
 - `__truediv__()` = Divide the components of the csdm object by a scalar.
 - `__itruediv__()` = Divide the components of the csdm object by a scalar in-place.
 - `split()` = Split the dependent-variables into individual csdm objects.
- Support for Numpy dimension reduction functions
 - `sum()`: Sum along a given dimension.
 - `prod()`: Product along a given dimension.
- Support for Numpy ufunc functions:
 - `sin, cos, tan, arcsin, arccos, arctan, sinh, cosh, tanh, arcsinh, arccosh, arctanh, exp, exp2, log, log2, log10, expm1, log1p, negative, positive, square, absolute, fabs, rint, sign, conj, conjugate, sqrt, cbrt, reciprocal`
- Added apodization functions.
 - `sin, cos, tan, arcsin, arccos, arctan, exp`

12.12.2 Bug fixes

- Fixed a bug in `cp.plot()` method.

12.13 v0.1.5

- Added method to convert the frequency dimension to nmr dimensionless frequency ratio with syntax, `dimension.to('ppm', 'nmr_frequency_ratio')`, where *dimension* is a `LinearDimension` object.
- The `csdmpy.plot()` method also displays the dimension index on the axis label.

12.14 v0.1.4

- Added `to_dict()` method to the CSDM, Dimension, and DependentVariable objects.

12.15 v0.1.3

- Fixed warning message when physical quantity name is not found in the astropy units package.
- Added dumps and loads function to dump and load the data model as json serialized string, respectively without serializing it to a file.

12.16 v0.0.11 to v0.1.2

- Add a required *unsigned_integer_type* for SparseSampling dimension.
- Fixed minor bugs.
- Added a tags attribute to the CSDmodel object.
- Changed 'sampling_interval' key to 'count'.
- Changed 'quantity' key to 'quantity_name'.
- Changed 'index_zero_value' key to 'coordinates_offset'.
- Changed 'fft_output_order' key to 'complex_fft'.
- Renamed IndependentVariable class to Dimension.
- Renamed LinearlySpacedDimension class to LinearDimension.
- Renamed ArbitrarilySpacedDimension class to MonotonicDimension.
- Added a reciprocal attribute to LinearDimension and MonotonicDimension classes.
- Removed the reverse attribute from all Dimension classes.
- Changed 'sampling_interval' keyword to 'increment'.
- Changed 'reference_offset' keyword to 'index_zero_value'.
- Changed 'linear_spacing' literal to 'linear'.
- Changed 'arbitrarily_sampled' literal to 'monotonic'.

- Changed the defining of the coordinates for the LinearDimension from

$$X^{\text{ref}} = m_k J_k - c_k \mathbf{1} \quad (12.1)$$

to

$$X^{\text{ref}} = m_k J_k + c_k \mathbf{1}, \quad (12.2)$$

where c_k is the reference offset, m_k is the increment, and J_k is the set of integer indices along the dimension.

- Added 'description' key to 'Dimension', 'DependentVariable' and 'CSDM' object.
 - Changed 'CSDM' keyword to 'csdm'
 - Changed 'FFT_output_order' keyword to 'fft_output_order'
 - Changed 'components_URL' keyword to 'components_url'
-

CHAPTER
THIRTEEN

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