Climate Data Management System

Version 5.0

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CHAPTER 1 Introduction

1.1 Overview

The Climate Data Management System is an object-oriented data management system, specialized for organizing multidimensional, gridded data used in climate analysis and simulation.

CDMS is implemented as part of the Climate Data Analysis Tools (CDAT), written in Python. The examples in this chapter assume some familiarity with the language and the Python NumPy module (http://numpy.scipy.org). A number of excellent tutorials on Python are available in books or on the Internet. For example, see http://python.org .

1.2 Variables

The basic unit of computation in CDMS is the *variable*. A variable is essentially a multidimensional data array, augmented with a *domain*, a set of *attributes*, and optionally a spatial and/or temporal *coordinate system* (see "Coordinate Axes" on page 11). Since a variable is a data array, it can be sliced to obtain a portion of the data, and can be used in arithmetic computations. For example, if **u** and **v** are variables representing the eastward and northward components of wind speed, respectively, and both variables are functions of time, latitude, and longitude, then the velocity for time 0 (first index) can be calculated as

```
>>> from cdms2 import MV
>>> vel = MV.sqrt(u[0]**2 + v[0]**2)
```

This illustrates that:

- Square brackets represent the slice operator. Indexing starts at 0, so `u[0]` selects from variable **u** for the first timepoint. The result of this slice operation is another variable. The slice operator can be multidimensional, and follows the syntax of NumPy arrays. In this example, `u[0:10,:,1]` would retrieve data for the first ten timepoints, at all latitudes, for the second longitude.
- Variables can be used in computation. '`**`' is the Python exponentiation operator.
- Arithmetic functions are defined in the **cdms2.MV** module.
- Operations on variables carry along the corresponding metadata where applicable. In the above example, **vel** has the same latitude and longitude coordinates as **u** and **v**, and the time coordinate is the first time of **u** and **v**.

1.3 File I/O

A variable can be obtained from a file or collection of files, or can be generated as the result of a computation. Files can be in any of the self-describing formats netCDF, HDF, GrADS/GRIB (GRIB with a GrADS control file), or PCMDI DRS. (HDF and DRS support is optional, and is configured at the time CDAT is installed.) There is also support for UK Met Office PP format. For instance, to read data from file **sample.nc** into variable **u**:

```
>>> import cdms2 as cdms
>>> f = cdms.open('sample.nc')
>>> u = f('u')
```

Data can be read by index or by world coordinate values. The following reads the n-th timepoint of **u** (the syntax `slice(i,j)` refers to indices k such that i <= k < j):

```
>>> u0 = f('u',time=slice(n,n+1))
```

To read `u` at time 366.0:

```
>>> u1 = f('u',time=366.)
```

A variable can be written to a file with the **write** function:

```
>>> g = cdms2.open('sample2.nc','w')
>>> g.write(u)
<Variable: u, file: sample2.nc, shape: (1, 16, 32)>
>>> g.close()
```

1.4 Coordinate Axes

A *coordinate axis* is a variable that represents coordinate information. Typically an axis is associated with one or more variables in a file or dataset, to represent the indexing and/or spatiotemporal coordinate system(s) of the variable(s).

Often in climate applications an axis is a one-dimensional variable whose values are floating-point and strictly monotonic. In some cases an axis can be multidimensional (see “Grids” on page 17). If an axis is associated with one of the canonical types latitude, longitude, level, or time, then the axis is called *spatiotemporal*.

The shape and physical ordering of a variable is represented by the variable’s *domain*, an ordered tuple of one-dimensional axes. In the previous example, the domain of the variable `u` is the tuple (time, latitude, longitude). This indicates the order of the dimensions, with the slowest-varying dimension listed first (time). The domain may be accessed with the **getAxisList** method:

```
>>> s.getAxisList()
[   id: lat
   Designated a latitude axis.
   units:  degrees_north
   Length: 64
   First:  -87.8637970305
   Last:   87.8637970305
   Other axis attributes:
```

```
      long_name: latitude
      axis: Y
   Python id:  833efa4
,    id: lon
   Designated a longitude axis.
   units:  degrees_east
   Length: 128
   First:  0.0
   Last:   357.1875
   Other axis attributes:
      modulo: 360.0
      topology: circular
      long_name: longitude
      axis: X
   Python id:  833f174
]
```

In the above example, the domain elements are axes that are also spatiotemporal. In general it is not always the case that an element of a domain is spatiotemporal:

- An axis in the domain of a variable need not be spatiotemporal. For example, it may represent a range of indices, an index coordinate system.
- The latitude and/or longitude coordinate axes associated with a variable need not be elements of the domain. In particular this will be true if the variable is defined on a non-rectangular grid (see “Grids” on page 17).

As previously noted, a spatial and/or temporal coordinate system may be associated with a variable. The methods **getLatitude, getLongitude, getLevel, and getTime** return the associated coordinate axes. For example:

```
>>> t = u.getTime()
>>> print t[:]
[   0., 366., 731.,]
>>> print t.units
'days since 2000-1-1'
```

1.5 Attributes

As mentioned above, variables can have associated *attributes*, name-value pairs. In fact, nearly all CDMS objects can have associated attributes, which are accessed using the Python dot notation:

```
>>> u.units='m/s'
>>> print u.units
m/s
```

Attribute values can be strings, scalars, or 1-D NumPy arrays.

When a variable is written to a file, not all the attributes are written. Some attributes, called *internal* attributes, are used for bookkeeping, and are not intended to be part of the external file representation of the variable. In contrast, *external* attributes are written to an output file along with the variable. By default, when an attribute is set, it is treated as external. Every variable has a field **attributes**, a Python dictionary that defines the external attributes:

```
>>> print u.attributes.keys()
['datatype', 'name', 'missing_value', 'units']
```

The Python **dir** command lists the internal attribute names:

```
>>> dir(u)
['_MaskedArray__data', '_MaskedArray__fill_value', ..., 'id',
    'parent']
```

In general internal attributes should not be modified directly. One exception is the **id** attribute, the name of the variable. It is used in plotting and I/O, and can be set directly.

1.6 Masked values

Optionally, variables have a mask that represents where data are missing. If present, the mask is an array of ones and zeros having the shape of the data array. A mask value of one indicates that the corresponding data array element is missing or invalid.

Arithmetic operations in CDMS take missing data into account. The same is true of the functions defined in the **cdms2.MV** module. For example:

```
>>> a = MV.array([1,2,3]) # Create array a, with no mask
>>> b = MV.array([4,5,6]) # Same for b
>>> a+b
variable_13
array([5,7,9,])
>>> a[1]=MV.masked        # Mask the second value of a
>>> a.mask                # View the mask
array([False,  True, False], dtype=bool)
>>> a+b
variable_4
array(data =
[     5 999999      9],
     mask =
[False  True False],
     fill_value=999999)
```

When data is read from a file, the result variable is masked if the file variable has a **missing_value** attribute. The mask is set to one for those elements equal to the missing value, zero elsewhere. If no such attribute is present in the file, the result variable is not masked.

When a variable with masked values is written to a file, data values with a corresponding mask value of one are set to the value of the variable's **missing_value** attribute. The data and **missing_value** attribute are then written to the file.

Masking is covered in Section 2.9. See also the documentation of the Python **NumPy** and **ma** modules, on which **cdms2.MV** is based, at http://numpy.scipy.org .

1.7 File Variables

A variable can be obtained either from a file, a collection of files, or as the result of computation. Consequently there are three types of variables in CDMS:

- A *file variable* is a variable associated with a single data file. Setting or referencing a file variable generates I/O operations.
- A *dataset variable* is a variable associated with a collection of files. Referencing the dataset variable reads data, possibly from multiple files. Dataset variables are read-only.
- A transient variable is an ‘in-memory’ object not associated with a file or dataset. Transient variables result from a computation or I/O operation.

A file variable may be used to inquire information about the variable in a file without actually reading array data. A file variable is obtained by applying the slice operator **[]** to a file, passing the name of the variable, or by calling the **getVariable** function. Note that obtaining a file variable does not actually read the data array:

```
>>> f = cdms2.open('sample.nc','r+')
>>> u = f.getVariable('u')     # or u=f['u']
>>> u.shape
(3, 16, 32)
```

File variables are also useful for fine-grained I/O. They behave like transient variables, but operations on them also affect the associated file. Specifically:

- slicing a file variable reads data,
- setting a slice writes data,
- referencing an attribute reads the attribute,
- setting an attribute writes the attribute,
- and calling a file variable like a function reads data associated with the variable:

```
>>> f = cdms2.open('sample.nc','r+')   # Open read/write
>>> uvar = f['u']  # Note square brackets
>>> uvar.shape
(3, 16, 32)
>>> u0 = uvar[0] # Reads data from sample.nc
>>> u0.shape
(16, 32)
>>> uvar[1]=u0   # Writes data to sample.nc
>>> uvar.units   # Reads the attribute
'm/s'
>>> uvar.units='meters/second' # Writes the attribute
# Calling a variable like a function reads data
>>> u24 = uvar(time=24.0)
```

```
>>> f.close()    # Save changes to sample.nc (I/O may be buffered)
```

When a transient variable is printed, the data is truncated if the size of the array is greater than the *print limit*. This value can be set with the function **MV.set_print_limit** to force all the data to be printed:

```
>>> smallvar.size         # Number of elements
20
>>> MV.get_print_limit()  # Current limit
300
>>> smallvar
small variable
array(
 [[  0.,  1.,  2.,  3.,]
 [  4.,  5.,  6.,  7.,]
 [  8.,  9., 10., 11.,]
 [ 12., 13., 14., 15.,]
 [ 16., 17., 18., 19.,]])

>>> largevar.size
400
>>> largevar
large variable
array(
 array (20,20) , type = d, has 400 elements)

>>> MV.set_print_limit(500)  # Reset the print limit
>>> largevar
large variable
array(
 [[   0.,   1.,   2.,   3.,   4.,   5.,   6.,   7.,   8.,   9.,
    10.,  11.,  12., 13.,  14.,  15.,  16.,  17.,  18.,  19.,]
 ... ])
```

The datatype of the variable is determined with the **dtype** attribute or from the typecode function (for compatibility with Version 4):

```
>>> x.dtype.char
'd'
>>> x.typecode()
'd'
```

1.8 Dataset Variables

The third type of variable, a *dataset variable*, is associated with a *dataset*, an aggregation of files treated as a single file. A dataset is created with the **cdscan** utility. This generates an XML metafile that describes how the files are organized and what metadata are contained in the files. In a climate simulation application, a dataset typically represents the data generated by one run of a general circulation or coupled ocean-atmosphere model.

For example, suppose data for variables `u` and `v` are stored in six files: `u_2000.nc, u_2001.nc, u_2002.nc, v_2000.nc, v_2001.nc`, and `v_2002.nc`. A metafile can be generated with the command:

```
% cdscan -x cdsample.xml [uv]*.nc
```

The metafile `cdsample.xml` is then used like an ordinary data file:

```
>>> f = cdms2.open('cdsample.xml')
>>> u = f('u')
>>> u.shape
(3, 16, 32)
```

1.9 Grids

A latitude-longitude *grid* represents the coordinate information associated with a variable. A grid encapsulates:

- latitude, longitude coordinates
- grid cell boundaries
- area weights

CDMS defines a rich set of grid types to represent the variety of coordinate systems used in climate model applications. Grids can be categorized as *rectangular* or *nonrectangular*.

- A *rectangular* grid has latitude and longitude axes that are one-dimensional, with strictly monotonic values. The grid is essentially the Cartesian product of the axes. If either criterion is not met, the grid is *nonrectangular*.

CDMS supports two types of nonrectangular grid:

- A *curvilinear* grid consists of a latitude and longitude axis, each of which is a two-dimensional coordinate axis. Curvilinear grids are often used in ocean model applications.
- A *generic* grid consists of a latitude and longitude axis, each of which is an *auxiliary* one-dimensional coordinate axis. An auxiliary axis has values that are not necessarily monotonic. As the name suggests, generic grids can represent virtually any type of grid. However, it is more difficult to determine adjacency relationships between grid points.

1.9.1 Example: a curvilinear grid

In this example, variable **`sample`** is defined on a 128x192 curvilinear grid. Note that:

- The domain of variable **`sample`** is (**`y`**,**`x`**) where **`y`** and **`x`** are index coordinate axes.
- The curvilinear grid associated with **`sample`** consists of axes (**`lat`**, **`lon`**), each a two-dimensional coordinate axis.
- **`lat`** and **`lon`** each have domain (**`y`**,**`x`**)

```
>>> f = cdms2.open('sampleCurveGrid.nc')

# lat and lon are coordinate axes, but are grouped
# with data variables
>>> f.variables.keys()
['lat', 'sample', 'bounds_lon', 'lon', 'bounds_lat']

# y and x are index coordinate axes
>>> f.axes.keys()
['y', 'x', 'nvert']

# Read data for variable sample
>>> sample = f('sample')

# The associated grid g is curvilinear
>>> g = sample.getGrid()
>>> g
<TransientCurveGrid, id: grid_1, shape: (128, 192)>

# The domain of the variable consists of index axes
>>> sample.getAxisIds()
['y', 'x']

# Get the coordinate axes associated with the grid
```

```
>>> lat = g.getLatitude()  # or sample.getLatitude()
>>> lon = g.getLongitude()  # or sample.getLongitude()

# lat and lon have the same domain, a subset of
# the domain of 'sample'
>>> lat.getAxisIds()
['y', 'x']

# lat and lon are variables ...
>>> lat.shape
(128, 192)
>>> lat
lat
array(
 array (128,192) , type = d, has 24576 elements)

# ... so can be used in computation
>>> lat_in_radians = lat*numpy.pi/180.0
>>>
```

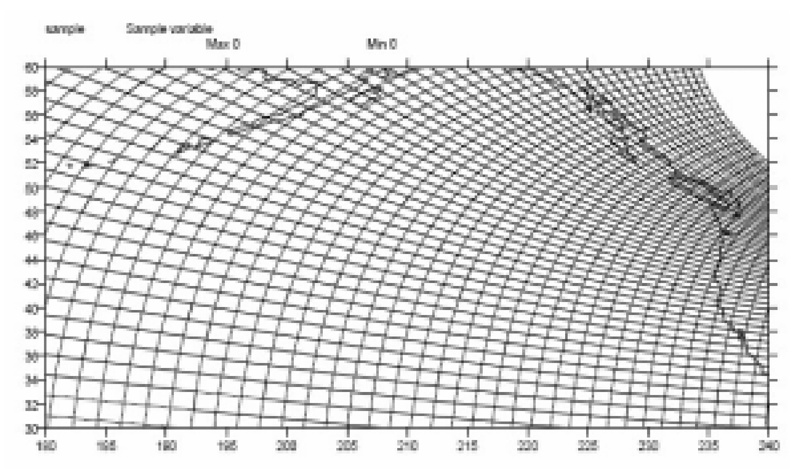


FIGURE 1. Curvilinear grid

1.9.2 Example: a generic grid

In this example variable **zs** is defined on a generic grid. Figure 2 illustrates the grid, in this case a 'geodesic' grid.

```
>>> f.variables.keys()
['lat', 'bounds_lon', 'lon', 'zs', 'bounds_lat']
>>> f.axes.keys()
['cell', 'nvert']
>>> zs = f('zs')
>>> g = zs.getGrid()
>>> g
<TransientGenericGrid, id: grid_1, shape: (2562,)>
>>> lat = g.getLatitude()
>>> lon = g.getLongitude()
>>> lat.shape
(2562,)
>>> lon.shape
(2562,)

# variable zs is defined in terms of a single index coordinate
# axis, 'cell'
>>> zs.shape
(2562,)
>>> zs.getAxisIds()
['cell']

# lat and lon are also defined in terms of the 'cell' axis
>>> lat.getAxisIds()
['cell']

# lat and lon are one-dimensional, 'auxiliary' coordinate
# axes: values are not monotonic
>>> lat.__class__
```

```
<class cdms2.auxcoord.TransientAuxAxis1D at 0x82eea24>
```

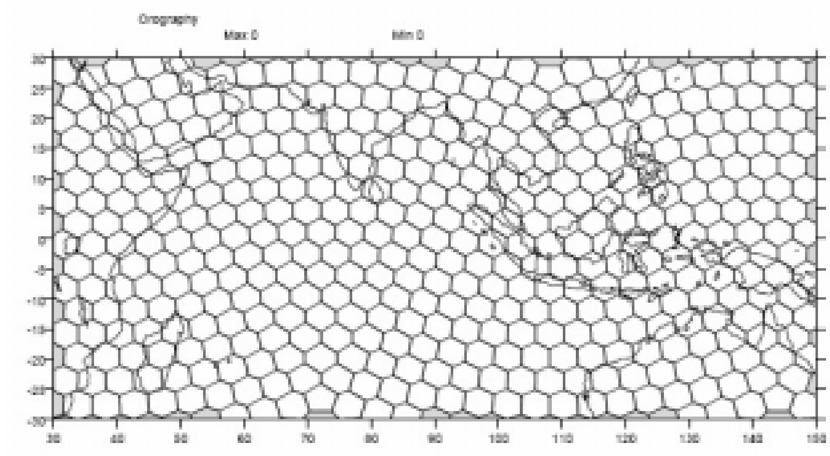


FIGURE 2. Generic grid

Generic grids can be used to represent any of the grid types. The method **toGenericGrid** can be applied to any grid to convert it to a generic representation. Similarly, a rectangular grid can be represented as curvilinear. The method **toCurveGrid** is used to convert a non-generic grid to curvilinear representation:

```
>>> import cdms2 as cdms
>>> f = cdms.open('clt.nc')
>>> clt = f('clt')
>>> rectgrid = clt.getGrid()
>>> rectgrid.shape
(46, 72)
>>> curvegrid = rectgrid.toCurveGrid()
>>> curvegrid
<TransientCurveGrid, id: grid_1, shape: (46, 72)>
>>> genericgrid = curvegrid.toGenericGrid()
>>> genericgrid
<TransientGenericGrid, id: grid_1, shape: (3312,)>
>>>
```

1.10 Regridding

Regridding is the process of mapping variables from one grid to another. CDMS supports two forms of regridding. Which one you use depends on the class of grids being transformed:

- To interpolate from one rectangular grid to another, use the built-in CDMS regridder. CDMS also has built-in regridders to interpolate from one set of pressure levels to another, or from one vertical cross-section to another.
- To interpolate from any lat-lon grid, rectangular or non-rectangular, use the SCRIP regridder.

1.10.1 CDMS Regridder

The built-in CDMS regridder is used to transform data from one rectangular grid to another. For example, to regrid variable **u** (from a rectangular grid) to a 96x192 rectangular Gaussian grid:

```
>>> u = f('u')
>>> u.shape
(3, 16, 32)
>>> t63_grid = cdms2.createGaussianGrid(96)
>>> u63 = u.regrid(t63_grid)
>>> u63.shape
(3, 96, 192)
```

To regrid a variable **uold** to the same grid as variable **vnew**:

```
>>> uold.shape
(3, 16, 32)
>>> vnew.shape
(3, 96, 192)
>>> t63_grid = vnew.getGrid() # Obtain the grid for vnew
>>> u63 = u.regrid(t63_grid)
>>> u63.shape
(3, 96, 192)
```

1.10.2 SCRIP Regridder

To interpolate between any lat-lon grid types, the SCRIP regridder may be used. The SCRIP package was developed at Los Alamos National Laboratory (http://climate.lanl.gov/Software/SCRIP/). SCRIP is written in

Fortran 90, and must be built and installed separately from the CDAT/CDMS installation.

The steps to regrid a variable are:

(external to CDMS)

1. Obtain or generate the grids, in SCRIP netCDF format.
2. Run SCRIP to generate a *remapping* file.

(in CDMS)

3. Read the regridder from the SCRIP remapping file.
4. Call the regridder with the source data, returning data on the target grid.

Steps 1 and 2 need only be done once. The regridder can be used as often as necessary.

For example, suppose the source data on a T42 grid is to be mapped to a POP curvilinear grid. Assume that SCRIP generated a remapping file named ‘rmp_T42_to_POP43_conserv.nc’:

```
# Import regrid2 package for regridder functions
import regrid2, cdms2 as cdms

# Get the source variable
f = cdms.open('sampleT42Grid.nc')
dat = f('src_array')
f.close()

# Read the regridder from the remapper file
remapf = cdms.open('rmp_T42_to_POP43_conserv.nc')
regridf = regrid2.readRegridder(remapf)
remapf.close()

# Regrid the source variable
popdat = regridf(dat)
```

Regridding is discussed in Chapter 4.

1.11 Time types

CDMS provides extensive support for time values in the **cdtime** module. **cdtime** also defines a set of *calendars*, specifying the number of days in a given month.

Two time types are available: *relative time* and *component time*. Relative time is time relative to a fixed base time. It consists of:

- a `units` string, of the form `"units since basetime"`, and
- a floating-point `value`

For example, the time “28.0 days since 1996-1-1” has value=`28.0`, and units=`"days since 1996-1-1".` To create a relative time type:

```
>>> import cdtime
>>> rt = cdtime.reltime(28.0, "days since 1996-1-1")
>>> rt
28.00 days since 1996-1-1
>>> rt.value
28.0
>>> rt.units
'days since 1996-1-1'
```

A component time consists of the integer fields `year, month, day, hour, minute`, and the floating-point field `second`. For example:

```
>>> ct = cdtime.comptime(1996,2,28,12,10,30)
>>> ct
1996-2-28 12:10:30.0
>>> ct.year
1996
>>> ct.month
2
```

The conversion functions **tocomp** and **torel** convert between the two representations. For instance, suppose that the time axis of a variable is represented in units “`days since 1979`”. To find the coordinate value corresponding to January 1, 1990:

```
>>> ct = cdtime.comptime(1990,1)
>>> rt = ct.torel("days since 1979")
>>> rt.value
4018.0
```

Time values can be used to specify intervals of time to read. The syntax `time=(c1,c2)` specifies that data should be read for times t such that c1<=t<=c2:

```
>>> c1 = cdtime.comptime(1990,1)
>>> c2 = cdtime.comptime(1991,1)
>>> ua = f['ua']
>>> ua.shape
(480, 17, 73, 144)
>>> x = ua.subRegion(time=(c1,c2))
>>> x.shape
(12, 17, 73, 144)
```

or string representations can be used:

```
>>> x = ua.subRegion(time=('1990-1','1991-1'))
```

Time types are described in Chapter 3.

1.12 Plotting data

Data read via the CDMS Python interface can be plotted using the **vcs** module. This module, part of the Climate Data Analysis Tool (CDAT) is documented in the VCS reference manual. The **vcs** module provides access to the functionality of the VCS visualization program.

To generate a plot:

- Initialize a canvas with the **vcs init** routine.
- Plot the data using the canvas **plot** routine.

For example:

```
>>> import cdms2 as cdms, vcs
>>> f = cdms.open('sample.nc')
>>> f['time'][:]   # Print the time coordinates
[  0.,  6., 12., 18., 24., 30., 36., 42., 48., 54., 60., 66., 72.,
    78., 84., 90.,]
>>> precip = f('prc', time=24.0)   # Read precip data
>>> precip.shape
(1, 32, 64)
>>> w = vcs.init()                 # Initialize a canvas
'Template' is currently set to P_default.
```

```
Graphics method 'Boxfill' is currently set to Gfb_default.
>>> w.plot(precip)                  # Generate a plot
(generates a boxfill plot)
```

By default for rectangular grids, a boxfill plot of the lat-lon slice is produced. Since variable `precip` includes information on time, latitude, and longitude, the continental outlines and time information are also plotted. If the variable were on a non-rectangular grid, the plot would be a 'meshfill' plot.

The **plot** routine has a number of options for producing different types of plots, such as isofill and x-y plots. See Chapter 5 for details.

1.13 Databases

Datasets can be aggregated together into hierarchical collections, called *databases*. In typical usage, a program:

- connects to a database
- searches for data
- opens a dataset
- accesses data

Databases add the ability to search for data and metadata in a distributed computing environment. At present CDMS supports one particular type of database, based on the Lightweight Directory Access Protocol (LDAP).

Here is an example of accessing data via a database:

```
>>> db = cdms2.connect() # Connect to the default database.
>>> f = db.open('ncep_reanalysis_mo') # Open a dataset.
>>> f.variables.keys() # List the variables in the dataset.
['ua', 'evs', 'cvvta', 'tauv', 'wap', 'cvwhusa', 'rss', 'rls', ...
'prc', 'ts', 'va']
```

Databases are discussed further in Section 2.7.

CHAPTER 2

CDMS Python Application Programming Interface

2.1 Overview

This chapter describes the CDMS Python application programming interface (API). Python is a popular public-domain, object-oriented language. Its features include support for object-oriented development, a rich set of programming constructs, and an extensible architecture. CDMS itself is implemented in a mixture of C and Python. In this chapter the assumption is made that the reader is familiar with the basic features of the Python language.

Python supports the notion of a **module**, which groups together associated classes and methods. The **import** command makes the module accessible to an application. This chapter documents the **cdms2, cdtime,** and **regrid2** modules.

The chapter sections correspond to the CDMS classes. Each section contains tables describing the class internal (non-persistent) attributes, constructors (functions for creating an object), and class methods (functions). A method can return an instance of a CDMS class, or one of the Python types:

Table 2.1 Python types used in CDMS

Type	Description
ndarray, MaskedArray	NumPy or masked multidimensional data array. All elements of the array are of the same type. Defined in the **numpy** and **numpy.core.ma** modules.
Comptime	Absolute time value, a time with representation (year, month, day, hour, minute, second). Defined in the **cdtime** module. cf. **reltime**
Dictionary	An unordered collection of objects, indexed by key. All dictionaries in CDMS are indexed by strings, e.g.: `axes['time']`
Float	Floating-point value.
Integer	Integer value.
List	An ordered sequence of objects, which need not be of the same type. New members can be inserted or appended. Lists are denoted with square brackets, e.g., `[1, 2.0, 'x', 'y']`
None	No value returned.
Reltime	Relative time value, a time with representation (value, "units since basetime"). Defined in the **cdtime** module. cf. **comptime**
Tuple	An ordered sequence of objects, which need not be of the same type. Unlike lists, tuples elements cannot be inserted or appended. Tuples are denoted with parentheses, e.g., `(1, 2.0, 'x', 'y')`

2.2 A first example

The following Python script reads January and July monthly temperature data from an input dataset, averages over time, and writes the results to an output file. The input temperature data is ordered (time, latitude, longitude).

```
 1 #!/usr/bin/env python
 2 import cdms2
 3 from cdms2 import MV
 4 jones = cdms2.open(’/pcmdi/cdms/obs/jones_mo.nc’)
 5 tasvar = jones[’tas’]
 6 jans = tasvar[0::12]
 7 julys = tasvar[6::12]
 8 janavg = MV.average(jans)
 9 janavg.id = "tas_jan"
10 janavg.long_name = "mean January surface temperature"
11 julyavg = MV.average(julys)
12 julyavg.id = "tas_jul"
13 julyavg.long_name = "mean July surface temperature"
14 out = cdms2.open(’janjuly.nc’,’w’)
15 out.write(janavg)
16 out.write(julyavg)
17 out.comment = "Average January/July from Jones dataset"
18 jones.close()
19 out.close()
```

Line	**Notes**
2,3	Makes the cdms2 and MV2 modules available. MV2 defines arithmetic functions.
4	Opens a netCDF file read-only. The result `jones` is a dataset object.
5	Gets the surface air temperature variable. `’tas’` is the name of the variable in the input dataset. This does not actually read the data.

Line	Notes
6	Read all January monthly mean data into a variable **jans**. Variables can be sliced like arrays. The slice operator **[0::12]** means 'take every 12th slice from dimension 0, starting at index 0 and ending at the last index.' If the stride **12** were omitted, it would default to 1. Note that the variable is actually 3-dimensional. Since no slice is specified for the second or third dimensions, all values of those dimensions are retrieved. The slice operation could also have been written **[0::12, : , :]**. Also note that the same script works for multi-file datasets. CDMS opens the needed data files, extracts the appropriate slices, and concatenates them into the result array.
7	Reads all July data into a masked array **julys**.
8	Calculate the average January value for each grid zone. Any missing data is handled automatically.
9,10	Set the variable **id** and **long_name** attributes. The id is used as the name of the variable when plotted or written to a file.
14	Create a new netCDF output file named **'janjuly.nc'** to hold the results.
15	Write the January average values to the output file. The variable will have id "**tas_jan**" in the file. **write** is a utility function which creates the variable in the file, then writes data to the variable. A more general method of data output is first to create a variable, then set a slice of the variable. Note that **janavg** and **julavg** have the same latitude and longitude information as **tasvar**. It is carried along with the computations.
17	Set the global attribute '**comment**'.
18	Close the output file.

2.3 cdms2 module

The **cdms2** module is the Python interface to CDMS. The objects and methods in this chapter are made accessible with the command:

```
import cdms2
```

Version 5 of CDMS is based on the NumPy package. Previous versions were based on the Numeric package, the predecessor to NumPy. In those versions the module was named **cdms**. Although NumPy and Numeric are quite similar, NumPy is a complete rewrite of Numeric. There are enough differences in the structure and behavior of the packages that a change of module name is warranted. Version 5 includes a utility that simplifies the conversion of **Numeric/MA/cdms** scripts to run with **numpy/ma/cdms2**. See the transition guide for details.

The functions described in this section are not associated with a class. Rather, they are called as module functions, e.g.,

```
file = cdms2.open('sample.nc')
```

Table 2.2 cdms2 module functions

Type	Definition
Variable	**asVariable(s)** Transform s into a transient variable. s is a masked array (numpy.core.ma.MaskedArray), NumPy ndarray, or Variable. If s is already a transient variable, s is returned. See also: **isVariable**.

Table 2.2 cdms2 module functions

Type	Definition
Axis	**createAxis(data, bounds=None)** Create a one-dimensional coordinate Axis, which is not associated with a file or dataset. This is useful for creating a grid which is not contained in a file or dataset. *data* is a one-dimensional, monotonic NumPy array. *bounds* is an array of shape (len(data),2), such that for all i, data[i] is in the range [bounds[i,0],bounds[i,1]]. If bounds is not specified, the default boundaries are generated at the midpoints between the consecutive data values, provided that the autobounds mode is 'on' (the default). See **setAutoBounds**. Also see: **CdmsFile.createAxis**
Axis	**createEqualAreaAxis(nlat)** Create an equal-area latitude axis. The latitude values range from north to south, and for all axis values x[i], sin(x[i])-sin(x[i+1]) is constant. *nlat* is the axis length. The axis is not associated with a file or dataset.
Axis	**createGaussianAxis(nlat)** Create a Gaussian latitude axis. Axis values range from north to south. *nlat* is the axis length. The axis is not associated with a file or dataset.
RectGrid	**createGaussianGrid(nlats, xorigin=0.0, order="yx")** Create a Gaussian grid, with shape (nlats, 2*nlats). *nlats* is the number of latitudes. *xorigin* is the origin of the longitude axis. *order* is either "yx" (lat-lon, default) or "xy" (lon-lat)

Table 2.2 cdms2 module functions

Type	Definition
RectGrid	**createGenericGrid(latArray, lonArray, latBounds=None, lonBounds=None, order="yx", mask=None)** Create a generic grid, that is, a grid which is not typed as Gaussian, uniform, or equal-area. The grid is not associated with a file or dataset. *latArray* is a NumPy array of latitude values. *lonArray* is a NumPy array of longitude values *latBounds* is a NumPy array having shape (len(latArray),2), of latitude boundaries. *lonBounds* is a NumPy array having shape (len(lonArray),2), of longitude boundaries. *order* is a string specifying the order of the axes, either “yx” for (latitude, longitude), or “xy” for the reverse. *mask* (optional) is an integer-valued NumPy mask array, having the same shape and ordering as the grid.
RectGrid	**createGlobalMeanGrid(grid)** Generate a grid for calculating the global mean via a regridding operation. The return grid is a single zone covering the range of the input grid. *grid* is a RectGrid.

Table 2.2 cdms2 module functions

Type	Definition
RectGrid	**createRectGrid(lat, lon, order, type="generic", mask=None)** Create a rectilinear grid, not associated with a file or dataset. This might be used as the target grid for a regridding operation. *lat* is a latitude axis, created by cdms2.createAxis. *lon* is a longitude axis, created by cdms2.createAxis. *order* is a string with value “yx” (the first grid dimension is latitude) or “xy” (the first grid dimension is longitude). *type* is one of ’gaussian’,’uniform’,’equalarea’,or ’generic’ If specified, *mask* is a two-dimensional, logical NumPy array (all values are zero or one) with the same shape as the grid. This function creates a global grid. If the latitude bounds are not specified with *lat*, they are assumed to extend from -90 degrees to 90 degrees.

Table 2.2 cdms2 module functions

Type	Definition
RectGrid	**createUniformGrid(startLat, nlat, deltaLat, startLon, nlon, deltaLon, order="yx", mask=None)** Create a uniform rectilinear grid. The grid is not associated with a file or dataset. The grid boundaries are at the midpoints of the axis values. *startLat* is the starting latitude value. *nlat* is the number of latitudes. If nlat is 1, the grid latitude boundaries will be startLat +/- deltaLat/2. *deltaLat* is the increment between latitudes. *startLon* is the starting longitude value. *nlon* is the number of longitudes. If nlon is 1, the grid longitude boundaries will be startLon +/- deltaLon/2. *deltaLon* is the increment between longitudes. *order* is a string with value "yx" (the first grid dimension is latitude) or "xy" (the first grid dimension is longitude). If specified, *mask* is a two-dimensional, logical NumPy array (all values are zero or one) with the same shape as the grid.
Axis	**createUniformLatitudeAxis(startLat, nlat, deltaLat)** Create a uniform latitude axis. The axis boundaries are at the midpoints of the axis values. The axis is designated as a circular latitude axis. *startLat* is the starting latitude value. *nlat* is the number of latitudes. *deltaLat* is the increment between latitudes.
RectGrid	**createZonalGrid(grid)** Create a zonal grid. The output grid has the same latitude as the input grid, and a single longitude. This may be used to calculate zonal averages via a regridding operation. *grid* is a RectGrid.

Table 2.2 cdms2 module functions

Type	Definition
Axis	**createUniformLongitudeAxis(startLon, nlon, deltaLon)** Create a uniform longitude axis. The axis boundaries are at the midpoints of the axis values. The axis is designated as a circular longitude axis. *startLon* is the starting longitude value. *nlon* is the number of longitudes. *deltaLon* is the increment between longitudes.
Variable	**createVariable(array, typecode=None, copy=0, savespace=0, mask=None, fill_value=None, grid=None, axes=None, attributes=None, id=None)** This function is documented in Table 2.34 on page 90.
Integer	**getAutoBounds()** Get the current autobounds mode. Returns 0, 1, or 2. See **setAutoBounds**.
Boolean	**getNumericCompatibility()** Get the Numeric compatibility mode. See **setNumericCompatibility**.
Integer	**isVariable(s)** Return 1 if s is a variable, 0 otherwise. See also: **asVariable**.

Table 2.2 cdms2 module functions

Type	Definition

Dataset or CdmsFile	**open(url,mode='r')**
	Open or create a Dataset or CdmsFile.
	url is a Uniform Resource Locator, referring to a cdunif or XML file. If the URL has the extension '.xml' or '.cdml', a Dataset is returned, otherwise a CdmsFile is returned. If the URL protocol is 'http', the file must be a '.xml' or '.cdml' file, and the mode must be 'r'. If the protocal is 'file' or is omitted, a local file or dataset is opened.
	mode is the open mode. See Table 2.24 on page 70.
	Example: Open an existing dataset:
	`f = cdms2.open("sampleset.xml")`
	Example: Create a netCDF file:
	`f = cdms2.open("newfile.nc",'w')`

List	**order2index (axes, orderstring)** Find the index permutation of axes to match order. Return a list of indices *axes* is a list of axis objects. *orderstring* is defined as in **orderparse**.
List	**orderparse(orderstring)** Parse an order string. Returns a list of axes specifiers. *orderstring* consists of: • Letters t, x, y, z meaning time, longitude, latitude, level • Numbers 0-9 representing position in axes • Dash (-) meaning insert the next available axis here. • The ellipsis ... meaning fill these positions with any remaining axes. • (name) meaning an axis whose id is name

Table 2.2 cdms2 module functions

Type	Definition
None	**setAutoBounds(mode)** Set autobounds mode. In some circumstances CDMS can generate boundaries for 1-D axes and rectilinear grids, when the bounds are not explicitly defined. The autoBounds mode determines how this is done: If *mode* is 'grid' or 2 (the default), the **getBounds** method will automatically generate boundary information for an axis or grid if the axis is designated as a latitude or longitude axis, and the boundaries are not explicitly defined. If *mode* is 'on' or 1, the **getBounds** method will automatically generate boundary information for an axis or grid, if the boundaries are not explicitly defined. If *mode* is 'off' or 0, and no boundary data is explicitly defined, the bounds will NOT be generated; the **getBounds** method will return None for the boundaries. Note: In versions of CDMS prior to V4.0, the default mode was 'on'.
None	**setClassifyGrids(mode)** Set the grid classification mode. This affects how grid type is determined, for the purpose of generating grid boundaries. If mode is 'on' (the default), grid type is determined by a grid classification method, regardless of the value of grid.getType(). If mode is 'off', the value of grid.getType() determines the grid type

Table 2.2 cdms2 module functions

Type	Definition
None	**setNumericCompatibility(mode)** Set the mode for backward compatibility with the Numeric module. If mode is False (the default), 0-D slices of CDMS variables are returned as scalars, and MV functions with an axis arg have a default axis value of None, meaning to ravel the array. If mode is True, 0-D slices are returned as 0-D arrays, and the default axis arg of MV functions is 0, meaning the first axis. This function is new in Version 5.
None	**writeScripGrid**(path, grid, gridTitle=None) Write a grid to a SCRIP grid file. *path* is a string, the path of the SCRIP file to be created. *grid* is a CDMS grid object. It may be rectangular. *gridTitle* is a string ID for the grid.

Table 2.3 Class Tags

Tag	Class
'axis'	Axis
’database’	Database
'dataset'	Dataset, CdmsFile
'grid'	RectGrid
'variable'	Variable
'xlink'	Xlink

2.4 CdmsObj

A CdmsObj is the base class for all CDMS database objects. At the application level, CdmsObj objects are never created and used directly. Rather the subclasses of CdmsObj (Dataset, Variable, Axis, etc.) are the basis of user application programming.

All objects derived from CdmsObj have a special attribute **.attributes**. This is a Python dictionary, which contains all the *external* (persistent) attributes associated with the object. This is in contrast to the *internal*, non-persistent attributes of an object, which are built-in and predefined. When a CDMS object is written to a file, the external attributes are written, but not the internal attributes.

Example: get a list of all external attributes of obj.

```
extatts = obj.attributes.keys()
```

Table 2.4 Attributes common to all CDMS objects

Type	Name	Definition
Dictionary	attributes	External attribute dictionary for this object.

All attributes may be accessed and set using the Python dot notation (**'.'**)

Table 2.5 Getting and setting attributes

Type	Definition
Various	**value = obj.attname** Get an internal or external attribute value. If the attribute is external, it is read from the database. If the attribute is not already in the database, it is created as an external attribute. Internal attributes cannot be created, only referenced.

Table 2.5 Getting and setting attributes

Type	Definition
	obj.attname = value Set an internal or external attribute value. If the attribute is external, it is written to the database.

2.5 CoordinateAxis

A CoordinateAxis is a variable that represents coordinate information. It may be contained in a file or dataset, or may be transient (memory-resident). Setting a slice of a file CoordinateAxis writes to the file, and referencing a file CoordinateAxis slice reads data from the file. Axis objects are also used to define the domain of a Variable.

CDMS defines several different types of CoordinateAxis objects. Table 2.9 on page 44 documents methods that are common to all CoordinateAxis types. Table 2.10 on page 48 specifies methods that are unique to 1D Axis objects.

Table 2.6 CoordinateAxis types

Type	Definition
CoordinateAxis	A variable that represents coordinate information. Has subtypes Axis2D and AuxAxis1D.
Axis	A one-dimensional coordinate axis whose values are strictly monotonic. Has subtypes DatasetAxis, FileAxis, and TransientAxis. May be an index axis, mapping a range of integers to the equivalent floating point value. If a latitude or longitude axis, may be associated with a RectGrid.
Axis2D	A two-dimensional coordinate axis, typically a latitude or longitude axis related to a CurvilinearGrid. Has subtypes DatasetAxis2D, FileAxis2D, and TransientAxis2D.

Table 2.6 CoordinateAxis types

Type	Definition
AuxAxis1D	A one-dimensional coordinate axis whose values need not be monotonic. Typically a latitude or longitude axis associated with a GenericGrid. Has subtypes DatasetAuxAxis1D, FileAuxAxis1D, and TransientAuxAxis1D.

An axis in a CdmsFile may be designated the ‘unlimited’ axis, meaning that it can be extended in length after the initial definition. There can be at most one unlimited axis associated with a CdmsFile.

Table 2.7 CoordinateAxis Internal Attributes

Type	Name	Definition
Dictionary	attributes	External attribute dictionary.
String	id	CoordinateAxis identifer.
Dataset	parent	The dataset which contains the variable.
Tuple	shape	The length of each axis.
Datatype	dtype	NumPy datatype. dtype.char is the typecode. See the NumPy manual.

Table 2.8 Axis Constructors

cdms2.createAxis(data, bounds=None)

Create an axis which is not associated with a dataset or file. See Table 2.2 on page 31.

Dataset.createAxis(name,ar)

Create an Axis in a Dataset. (**This function is not yet implemented.**)

Table 2.8 Axis Constructors

CdmsFile.createAxis(name,ar,unlimited=0)

Create an Axis in a CdmsFile.

name is the string name of the Axis.

ar is a 1-D data array which defines the Axis values. It may have the value None if an unlimited axis is being defined.

At most one Axis in a CdmsFile may be designated as being 'unlimited', meaning that it may be extended in length. To define an axis as unlimited, either:

- set ar to None, and leave *unlimited* undefined, or
- set ar to the initial 1-D array, and set *unlimited* to **cdms2.Unlimited**

cdms2.createEqualAreaAxis(nlat)

See Table 2.2 on page 31.

cdms2.createGaussianAxis(nlat)

See Table 2.2 on page 18.

cdms2.createUniformLatitudeAxis(startlat, nlat, deltalat)

See Table 2.2 on page 18.

cdms2.createUniformLongitudeAxis(startlon, nlon, deltalon)

See Table 2.2 on page 18.

Table 2.9 CoordinateAxis Methods

Type	Method Definition
Array	**array = axis[i:j]** Read a slice of data from the external file or dataset. Data is returned in the physical ordering defined in the dataset. See Table 2.11 on page 51 for a description of slice operators.
None	**axis[i:j] = array** Write a slice of data to the external file. **Dataset axes are read-only.**
None	**assignValue(array)** Set the entire value of the axis. *array* is a NumPy array, of the same dimensionality as the axis.
Axis	**clone(copyData=1)** Return a copy of the axis, as a transient axis. If copyData is 1 (the default) the data itself is copied.
None	**designateLatitude(persistent=0):** Designate the axis to be a latitude axis. If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary. See **isLatitude**.

Table 2.9 CoordinateAxis Methods

Type	Method Definition
None	**designateLevel(persistent=0)** Designate the axis to be a vertical level axis. If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary. See **isLevel**.
None	**designateLongitude(persistent=0, modulo=360.0)** Designate the axis to be a longitude axis. *modulo* is the modulus value. Any given axis value x is treated as equivalent to x+modulus If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary. See **isLongitude**.
None	**designateTime(persistent=0, calendar = cdtime.MixedCalendar)** Designate the axis to be a time axis. If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary. *calendar* is defined as in **getCalendar()**. See **isTime**.

Table 2.9 CoordinateAxis Methods

Type	Method Definition
Array	**getBounds()** Get the associated boundary array. The shape of the return array depends on the type of axis: • Axis: (n,2) • Axis2D: (i,j,4) • AuxAxis1D: (ncell, nvert) where nvert is the maximum number of vertices of a cell. If the boundary array of a latitude or longitude Axis is not explicitly defined, and autoBounds mode is on, a default array is generated by calling genGenericBounds. Otherwise if autoBounds mode is off, the return value is None. See **setAutoBounds**.
Integer	**getCalendar()** Returns the calendar associated with the (time) axis. Possible return values, as defined in the cdtime module, are: • cdtime.GregorianCalendar: the standard Gregorian calendar • cdtime.MixedCalendar: mixed Julian/Gregorian calendar • cdtime.JulianCalendar: years divisible by 4 are leap years • cdtime.NoLeapCalendar: a year is 365 days • cdtime.Calendar360: a year is 360 days • None: no calendar can be identified Note: If the axis is not a time axis, the global, file-related calendar is returned.
Array	**getValue()** Get the entire axis vector.

Table 2.9 CoordinateAxis Methods

Type	Method Definition
Integer	**isLatitude()** Returns true iff the axis is a latitude axis.An axis *ax* is considered a latitude axis if: • *ax*.axis=='Y', or • *ax*.*id*[0:3]=='lat', or • *ax*.id is in the list cdms2.axis.latitude_aliases.
Integer	**isLevel()** Returns true iff the axis is a level axis. *ax* is a level axis if: • *ax*.axis=='Z', or • *ax*.id[0:3]=='lev', *ax*.id[0:5]=='depth', or *ax*.id[0:4]=='plev', or • *ax*.id is in the list cdms2.axis.level_aliases
Integer	**isLongitude()** Returns true iff the axis is a longitude axis. *ax* is a longitude axis if: • *ax*.axis=='X', or • *ax*.id[0:3]=='lon', or • *ax*.id is in the list cdms2.axis.longitude_aliases

Table 2.9 CoordinateAxis Methods

Type	Method Definition
Integer	**isTime()** Returns true iff the axis is a time axis. *ax* is a longitude axis if: • *ax*.axis=='T', or • *ax*.id[0:4]=='time', or • *ax*.id is in cdms2.axis.time_aliases
Integer	**len(axis)** The length of the axis if one-dimensional. If multidimensional, the length of the first dimension.
Integer	**size()** The number of elements in the axis.
String	**typecode()** or ***axis*.dtype.char** The NumPy datatype identifier.

Table 2.10 Axis Methods, additional to CoordinateAxis methods

Type	Method Definition
List of component times	**asComponentTime(calendar=None)** Array version of **cdtime tocomp**. Returns a list of component times.
List of relative times	**asRelativeTime()** Array version of **cdtime torel**. Returns a list of relative times.

Table 2.10 Axis Methods, additional to CoordinateAxis methods

Type	Method Definition
None	**designateCircular(modulo, persistent=0)** Designate the axis to be circular. *modulo* is the modulus value. Any given axis value x is treated as equivalent to x+modulus If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary.
Integer	**isCircular()** Returns true if the axis has circular topology. An axis is defined as circular if: • axis.topology=='circular', or • axis.topology is undefined, and the axis is a longitude The default cycle for circular axes is 360.0
Integer	**isLinear()** Returns true iff the axis has a linear representation.
Tuple	**mapInterval(interval)** Same as **mapIntervalExt**, but returns only the tuple (i,j), and wraparound is restricted to one cycle.

Table 2.10 Axis Methods, additional to CoordinateAxis methods

Type	Method Definition
(i,j,k)	**mapIntervalExt(interval)** Map a coordinate interval to an index interval. *interval* is a tuple having one of the forms: (x,y) (x,y,indicator) (x,y,indicator,cycle) None or ':' where *x* and *y* are coordinates indicating the interval [x,y), and: *indicator* is a two or three-character string, where the first character is 'c' if the interval is closed on the left, 'o' if open, and the second character has the same meaning for the right-hand point. If present, the third character specifies how the interval should be intersected with the axis: • 'n' - select node values which are contained in the interval • 'b' - select axis elements for which the corresponding cell boundary intersects the interval • 'e' - same as 'n', but include an extra node on either side • 's' - select axis elements for which the cell boundary is a subset of the interval The default indicator is `'ccn'`, that is, the interval is closed, and nodes in the interval are selected. **(continued)**

Table 2.10 **Axis Methods, additional to CoordinateAxis methods**

Type	Method Definition
	(mapInterval, continued) If *cycle* is specified, the axis is treated as circular with the given cycle value. By default, if axis.isCircular() is true, the axis is treated as circular with a default modulus of 360.0. An interval of None or ':' returns the full index interval of the axis. The method returns the corresponding index interval as a 3-tuple (i,j,k), where k is the integer stride, and [i.j) is the half-open index interval i<=k<j (i>=k>j if k<0), or None if the intersection is empty. For an axis which is circular (axis.topology == 'circular'), [i,j) is interpreted as follows, where N=len(axis): • if 0<=i<N and 0<=j<=N, the interval does not wrap around the axis endpoint. • otherwise the interval wraps around the axis endpoint. **See also: mapInterval, Variable.subRegion()**
TransientAxis	**subAxis(i,j,k=1)** Create an axis associated with the integer range [i:j:k]. The stride k can be positive or negative. Wraparound is supported for longitude dimensions or those with a modulus attribute.

Table 2.11 **Axis Slice Operators**

Slice	Definition
[i]	The ith element, starting with index 0
[i:j]	The ith element through, but not including, element j

Table 2.11 Axis Slice Operators

Slice	Definition
[i:]	The ith element through and including the end
[:j]	The beginning element through, but not including, element j
[:]	The entire array
[i:j:k]	Every kth element, starting at i, through but not including j
[-i]	The ith element from the end. -1 is the last element.

Example: A longitude axis has value [0.0, 2.0, ..., 358.0], of length 180. Map the coordinate interval -5.0 <= x < 5.0 to index interval(s), with wraparound. The result index interval -2<=n<3 wraps around, since -2<0, and has a stride of 1. This is equivalent to the two contiguous index intervals -2<=n<0 and 0<=n<3

```
> axis.isCircular()
1
> axis.mapIntervalExt((-5.0,5.0,'co'))
(-2,3,1)
>
```

2.6 CdmsFile

A CdmsFile is a physical file, accessible via the cdunif interface. netCDF files are accessible in read-write mode. All other formats (DRS, HDF, GrADS/GRIB, POP, QL) are accessible read-only.

As of CDMS V3, the legacy cuDataset interface is also supported by CdmsFiles. See "cu Module" on page 180.

Table 2.12 CdmsFile Internal Attributes

Type	Name	Definition
Dictionary	attributes	Global, external file attributes

Table 2.12 CdmsFile Internal Attributes

Type	Name	Definition
Dictionary	axes	Axis objects contained in the file.
Dictionary	grids	Grids contained in the file.
String	id	File pathname.
Dictionary	variables	Variables contained in the file.

Table 2.13 CdmsFile Constructors

***fileobj* = cdms2.open(path, mode)**

Open the file specified by path returning a CdmsFile object.

path is the file pathname, a string.

mode is the open mode indicator, as listed in Table 2.24 on page 70.

***fileobj* = cdms2.createDataset(path)**

Create the file specified by *path*, a string.

Table 2.14 CdmsFile Methods

Type	Definition

Transient-Variable	***fileobj*(varname, selector)**
	Calling a CdmsFile object as a function reads the region of data specified by the selector. The result is a transient variable, unless `raw=1` is specified. See “Selectors” on page 102.
	For example, the following reads data for variable ’prc’, year 1980:
	`f = cdms2.open('test.nc')`
	`x = f('prc', time=('1980-1','1981-1'))`

Table 2.14 CdmsFile Methods

Type	Definition

Variable, Axis, or Grid	***fileobj*['*id*']**
	Get the persistent variable, axis or grid object having the string identifier. This does not read the data for a variable.
	For example:
	`f = cdms2.open('sample.nc')`
	`v = f['prc']`
	gets the persistent variable v, equivalent to `v=f.variables['prc']`.
	`t = f['time']`
	gets the axis named 'time', equivalent to `t=f.axes['time']`.

None	**close()** Close the file.
Axis	**copyAxis(axis, newname=None)** Copy axis values and attributes to a new axis in the file. The returned object is persistent: it can be used to write axis data to or read axis data from the file. If an axis already exists in the file, having the same name and coordinate values, it is returned. It is an error if an axis of the same name exists, but with different coordinate values. *axis* is the axis object to be copied. *newname*, if specified, is the string identifier of the new axis object. If not specified, the identifier of the input axis is used.
Grid	**copyGrid(grid, newname=None)** Copy grid values and attributes to a new grid in the file. The returned grid is persistent. If a grid already exists in the file, having the same name and axes, it is returned. An error is raised if a grid of the same name exists, having different axes. *grid* is the grid object to be copied. *newname*, if specified is the string identifier of the new grid object. If unspecified, the identifier of the input grid is used.

Table 2.14 CdmsFile Methods

Type	Definition
Axis	**createAxis(id, ar, unlimited=0)** Create a new Axis. This is a persistent object which can be used to read or write axis data to the file. *id* is an alphanumeric string identifier, containing no blanks. *ar* is the one-dimensional axis array. Set *unlimited* to cdms2.Unlimited to indicate that the axis is extensible.
RectGrid	**createRectGrid(id, lat, lon, order, type="generic", mask=None)** Create a RectGrid in the file. This is not a persistent object: the order, type, and mask are not written to the file. However, the grid may be used for regridding operations. *lat* is a latitude axis in the file. *lon* is a longitude axis in the file. *order* is a string with value “yx” (the first grid dimension is latitude) or “xy” (the first grid dimension is longitude). *type* is one of ’gaussian’,’uniform’,’equalarea’,or ’generic’ If specified, *mask* is a two-dimensional, logical NumPy array (all values are zero or one) with the same shape as the grid.
Variable	**createVariable(String id, String datatype,List axes, fill_value=None)** Create a new Variable. This is a persistent object which can be used to read or write variable data to the file. *id* is a String name which is unique with respect to all other objects in the file. *datatype* is a numpy datatype, e.g., numpy.float, numpy.int. *axes* is a list of Axis and/or Grid objects. *fill_value* is the missing value (optional).

Table 2.14 CdmsFile Methods

Type	Definition
Variable	**createVariableCopy(var, newname=None)** Create a new Variable, with the same name, axes, and attributes as the input variable. An error is raised if a variable of the same name exists in the file. *var* is the Variable to be copied. *newname*, if specified is the name of the new variable. If unspecified, the returned variable has the same name as *var*. Note: Unlike copyAxis, the actual data is not copied to the new variable.
CurveGrid or Generic-Grid	**readScripGrid**(self, whichGrid='destination', check-Grid=1) Read a curvilinear or generic grid from a SCRIP netCDF file. The file can be a SCRIP grid file or remapping file. If a mapping file, *whichGrid* chooses the grid to read, either **`"source"`** or **`"destination"`**. If *checkGrid* is 1 (default), the grid cells are checked for convexity, and 'repaired' if necessary. Grid cells may appear to be nonconvex if they cross a 0 / 2pi boundary. The repair consists of shifting the cell vertices to the same side modulo 360 degrees.
None	**sync()** Writes any pending changes to the file.

Table 2.14 CdmsFile Methods

Type	Definition
Variable	**write(var, attributes=None, axes=None, extbounds=None, id=None, extend=None, fill_value=None, index=None, typecode=None)** Write a variable or array to the file. The return value is the associated file variable. If the variable does not exist in the file, it is first defined and all attributes written, then the data is written. By default, the time dimension of the variable is defined as the 'unlimited' dimension of the file. If the data is already defined, then data is extended or overwritten depending on the value of keywords *extend* and *index*, and the unlimited dimension values associated with *var*. *var* is a Variable, masked array, or NumPy array. *attributes* is the attribute dictionary for the variable. The default is var.attributes. *axes* is the list of file axes comprising the domain of the variable. The default is to copy var.getAxisList(). *extbounds* is the unlimited dimension bounds. Defaults to var.getAxis(0).getBounds() *id* is the variable name in the file. Default is var.id. *extend*=1 causes the first dimension to be 'unlimited': iteratively writeable. The default is None, in which case the first dimension is extensible if it is time.Set to 0 to turn off this behaviour. *fill_value* is the missing value flag. *index* is the extended dimension index to write to. The default index is determined by lookup relative to the existing extended dimension. Note: data can also be written by setting a slice of a file variable, and attributes can be written by setting an attribute of a file variable.

Table 2.15 CDMS Datatypes

CDMS Datatype	Definition
CdChar	character
CdDouble	double-precision floating-point
CdFloat	floating-point
CdInt	integer
CdLong	long integer
CdShort	short integer

2.7 Database

A Database is a collection of datasets and other CDMS objects. It consists of a hierarchical collection of objects, with the database being at the root, or top of the hierarchy. A database is used to:

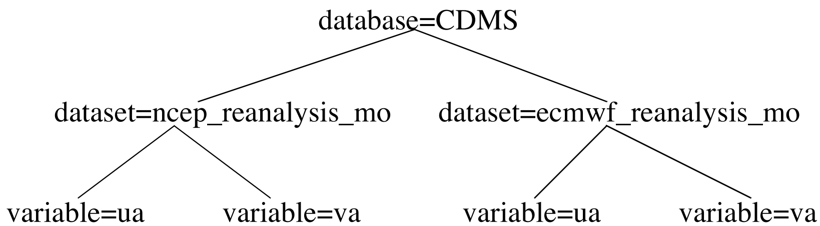
- search for metadata
- access data
- provide authentication and access control for data and metadata

The figure below illustrates several important points:

- Each object in the database has a *relative name* of the form *tag=id*. The id of an object is unique with respect to all objects contained in the parent.
- The *name* of the object consists of its relative name followed by the relative name(s) of its antecedent objects, up to and including the database name. In the figure below, one of the variables has name

  `"variable=ua, dataset=ncep_reanalysis_mo,database=CDMS".`

- Subordinate objects are thought of as being contained in the parent. In this example, the database ‘CDMS’ contains two datasets, each of which contain several variables.



2.7.1 Overview

To access a database:

1. Open a connection. The **connect** method opens a database connection. **connect** takes a database URI and returns a database object:
```
db = cdms2.connect(“ldap://dbhost.llnl.gov/
    database=CDMS,ou=PCMDI,o=LLNL,c=US”)
```
2. Search the database, locating one or more datasets, variables, and/or other objects.

The database **searchFilter** method searches the database. A single database connection may be used for an arbitrary number of searches.

For example, to find all observed datasets:

```
result = db.searchFilter("category=observed",tag=”dataset”)
```

Searches can be restricted to a subhierarchy of the database. This example searches just the dataset ‘ncep_reanalysis_mo’:

```
result = db.searchFilter(relbase=”dataset=ncep_reanalysis”)
```

3. Refine the search results if necessary. The result of a search can be narrowed with the **searchPredicate** method.
4. Process the results. A search result consists of a sequence of entries. Each entry has a name, the name of the CDMS object, and an attribute dictionary, consisting of the attributes located by the search:
```
for entry in result:
    print entry.name, entry.attributes
```
5. Access the data. The CDMS object associated with an entry is obtained from the **getObject** method:
```
obj = entry.getObject()
```

If the id of a dataset is known, the dataset can be opened directly with the **open** method:

```
dset = db.open(“ncep_reanalysis_mo”)
```

6. Close the database connection:
```
db.close()
```

Table 2.16 Database Internal Attributes

Type	Name	Summary
Dictionary	attributes	Database attribute dictionary
LDAP	db	(LDAP only) LDAP database object
String	netloc	Hostname, for server-based databases
String	path	path name
String	uri	Uniform Resource Identifier.

Table 2.17 **Database Constructors**

db = cdms2.connect(uri=None, user="", password="")

Connect to the database.

uri is the Universal Resource Indentifier of the database. The form of the URI depends on the implementation of the database. For a Lightweight Directory Access Protocol (LDAP) database, the form is:

```
ldap://host[:port]/dbname
```

For example, if the database is located on host ‘dbhost.llnl.gov’, and is named ’database=CDMS,ou=PCMDI,o=LLNL,c=US’, the URI is:

```
ldap://dbhost.llnl.gov/database=CDMS,ou=PCMDI,o=LLNL,c=US
```

If unspecified, the URI defaults to the value of environment variable **CDMSROOT**.

user is the user ID. If unspecified, an anonymous connection is made.

password is the user password. A password is not required for an anonymous connection.

Table 2.18 **Database Methods**

Type	Definition
None	**close()** Close a database connection.
List	**listDatasets()** Return a list of the dataset IDs in this database. A dataset ID can be passed to the **open** command.

Table 2.18 Database Methods

Type	Definition
Dataset	**open(dsetid, mode='r')** Open a dataset. *dsetid* is the string dataset identifier *mode* is the open mode, 'r' - read-only, 'r+' - read-write, 'w' - create. **openDataset** is a synonym for **open**.

Table 2.18 **Database Methods**

Type	Definition

SearchResult	**searchFilter(filter=None, tag=None, relbase=None, scope=Subtree, attnames=None, timeout=None)**
	Search a CDMS database.
	filter is the string search filter. Simple filters have the form "tag = value". Simple filters can be combined using logical operators '&', '|', '!' in prefix notation. For example, the filter '(&(objectclass=variable)(id=cli))' finds all variables named "cli". A formal definition of search filters is provided in the following section.
	tag restricts the search to objects with that tag ("dataset" | "variable" | "database" | "axis" | "grid").
	relbase is the relative name of the base object of the search. The search is restricted to the base object and all objects below it in the hierarchy. For example, to search only dataset 'ncep_reanalysis_mo', specify:
	`relbase="dataset=ncep_reanalysis_mo".`
	To search only variable 'ua' in ncep_reanalysis_mo, use:
	`relbase="variable=ua, dataset=ncep_reanalysis_mo"`
	If no base is specified, the entire database is searched. See the *scope* argument also.
	scope is the search scope (**Subtree | Onelevel | Base**). **Subtree** searches the base object and its descendants. **Onelevel** searches the base object and its immediate descendants. **Base** searches the base object alone. The default is **Subtree**.
	attnames: list of attribute names. Restricts the attributes returned. If None, all attributes are returned. Attributes 'id' and 'objectclass' are always included in the list.
	timeout: integer number of seconds before timeout. The default is no timeout.

2.7.2 Searching a database

The **searchFilter** method is used to search a database. The result is called a *search result*, and consists of a sequence of *result entries*.

In its simplest form, **searchFilter** takes an argument consisting of a string filter. The search returns a sequence of entries, corresponding to those objects having an attribute which matches the filter. Simple filters have the form (*tag* = *value)*, where *value* can contain wildcards. For example:

```
'(id = ncep*)'
'(project = AMIP2)'
```

Simple filters can be combined with the logical operators '&', '|', '!'. For example,

```
'(&(id = bmrc*)(project = AMIP2))'
```

matches all objects with id starting with 'bmrc', and a 'project' attribute with value 'AMIP2'.

Formally, search filters are strings defined as follows:

```
filter     ::=   "(" filtercomp ")"
filtercomp ::=   "&" filterlist | # and
                 "|" filterlist | # or
                 "!" filterlist | # not
                 simple
filterlist ::= filter | filter filterlist
simple     ::= tag op value
op         ::=   "="  | # equality
                 "~=" | # approximate equality
                 "<=" | # lexicographically less than or equal to
                 ">="   # lexicographically greater than or equal to
tag        ::= string attribute name
value      ::= string attribute value, may include '*' as a wild card
```

Attribute names are defined in the chapter on “Climate Data Markup Language (CDML)” on page 147. In addition, some special attributes are defined for convenience:

- **category** is either “experimental” or “observed”
- **parentid** is the ID of the parent dataset

- **project** is a project identifier, e.g., “AMIP2”
- **objectclass** is the list of tags associated with the object.

The set of objects searched is called the search *scope*. The top object in the hierarchy is the *base object*. By default, all objects in the database are searched, that is, the database is the base object. If the database is very large, this may result in an unnecessarily slow or inefficient search. To remedy this the search scope can be limited in several ways:

- The base object can be changed.
- The scope can be limited to the base object and one level below, or to just the base object.
- The search can be restricted to objects of a given class (dataset, variable, etc.)
- The search can be restricted to return only a subset of the object attributes
- The search can be restricted to the result of a previous search.

A search result is accessed sequentially within a for loop:

```
result = db.searchFilter('(&(category=obs*)(id=ncep*))')
for entry in result:
    print entry.name
```

Search results can be narrowed using **searchPredicate**. In the following example, the result of one search is itself searched for all variables defined on a 94x192 grid:

```
>>> result = db.searchFilter('parentid=ncep*',tag="variable")
>>> len(result)
65
>>> result2 = result.searchPredicate(lambda x:
        x.getGrid().shape==(94,192))
>>> len(result2)
3
>>> for entry in result2: print entry.name
variable=rluscs,dataset=ncep_reanalysis_mo,database=CDMS,ou=PCMDI,
        o=LLNL, c=US
variable=rlds,dataset=ncep_reanalysis_mo,database=CDMS,ou=PCMDI,
        o=LLNL, c=US
variable=rlus,dataset=ncep_reanalysis_mo,database=CDMS,ou=PCMDI,
        o=LLNL, c=US
>>>
```

Table 2.19 SearchResult Methods

Type	Definition

ResultEntry	**[i]**
	Return the i-th search result. Results can also be returned in a **for** loop:
	`for entry in db.searchResult(tag="dataset"):`
	`    ...`

Integer	**len()** Number of entries in the result.
SearchResult	**searchPredicate(predicate, tag=None)** Refine a search result, with a predicate search. *predicate* is a function which takes a single CDMS object and returns true (1) if the object satisfies the predicate, 0 if not. *tag* restricts the search to objects of the class denoted by the tag. Note: In the current implementation, **searchPredicate** is much less efficient than **searchFilter**. For best performance, use **searchFilter** to narrow the scope of the search, then use **searchPredicate** for more general searches.

A search result is a sequence of result entries. Each entry has a string name, the name of the object in the database hierarchy, and an attribute dictionary. An entry corresponds to an object found by the search, but differs from the object, in that only the attributes requested are associated with the entry. In general, there will be much more information defined for the associated CDMS object, which is retrieved with the **getObject** method.

Table 2.20 ResultEntry Attributes

Type	Name	Summary
String	name	The name of this entry in the database.
Dictionary	attributes	The attributes returned from the search. attributes[key] is a list of all string values associated with the key.

Table 2.21 ResultEntry Methods

Type	Definition
CdmsObj	**getObject()** Return the CDMS object associated with this entry. Note: For many search applications it is unnecessary to access the associated CDMS object. For best performance this function should be used only when necessary, for example, to retrieve data associated with a variable.

2.7.3 Accessing data

To access data via CDMS:

1. Locate the dataset ID. This may involve searching the metadata.
2. Open the dataset, using the open method.
3. Reference the portion of the variable to be read.

In the next example, a portion of variable 'ua' is read from dataset 'ncep_reanalysis_mo':

```
dset = db.open('ncep_reanalysis_mo')
ua = dset.variables['ua']
data = ua[0,0]
```

2.7.4 Examples of database searches

In the following examples, `db` is the database opened with

```
db = cdms2.connect()
```

This defaults to the database defined in environment variable CDMSROOT.

List all variables in dataset 'ncep_reanalysis_mo':

```
for entry in db.searchFilter(filter="parentid=ncep_reanalysis_mo",
        tag="variable"):
    print entry.name
```

Find all axes with bounds defined:

```
for entry in db.searchFilter(filter="bounds=*",tag="axis"):
    print entry.name
```

Locate all GDT datasets:

```
for entry in
        db.searchFilter(filter="Conventions=GDT*",tag="dataset"):
    print entry.name
```

Find all variables with missing time values, in observed datasets:

```
def missingTime(obj):
    time = obj.getTime()
    return time.length != time.partition_length

result = db.searchFilter(filter="category=observed")
for entry in result.searchPredicate(missingTime):
    print entry.name
```

Find all CMIP2 datasets having a variable with id "hfss":

```
for entry in
        db.searchFilter(filter="(&(project=CMIP2)(id=hfss))",tag="var
        iable"):
    print entry.getObject().parent.id
```

Find all observed variables on 73x144 grids:

```
result = db.searchFilter('category=obs*')
for entry in result.searchPredicate(lambda x:
        x.getGrid().shape==(73,144),tag="variable"):
    print entry.name
```

Find all observed variables with more than 1000 timepoints:

```
result = db.searchFilter('category=obs*')
for entry in result.searchPredicate(lambda x: len(x.getTime())>1000,
        tag="variable"):
    print entry.name, len(entry.getObject().getTime())
```

Find the total number of each type of object in the database

```
print len(db.searchFilter(tag="database")),"database"
print len(db.searchFilter(tag="dataset")),"datasets"
print len(db.searchFilter(tag="variable")),"variables"
print len(db.searchFilter(tag="axis")),"axes"
```

2.8 Dataset

A Dataset is a virtual file. It consists of a metafile, in CDML/XML representation, and one or more data files.

As of CDMS V3, the legacy cuDataset interface is supported by Datasets. See “cu Module” on page 180.

Table 2.22 Dataset Internal Attributes

Type	Name	Summary
Dictionary	attributes	Dataset external attributes.
Dictionary	axes	Axes contained in the dataset.
String	datapath	Path of data files, relative to the parent database. If no parent, the datapath is absolute.

Table 2.22 Dataset Internal Attributes

Type	Name	Summary
Dictionary	grids	Grids contained in the dataset.
String	mode	Open mode.
Database	parent	Database which contains this dataset. If the dataset is not part of a database, the value is None.
String	uri	Uniform Resource Identifier of this dataset.
Dictionary	variables	Variables contained in the dataset.
Dictionary	xlinks	External links contained in the dataset.

Table 2.23 Dataset Constructors

***datasetobj* = cdms2.open(String uri, String mode='r')**

Open the dataset specified by the Universal Resource Indicator, a CDML file. Returns a Dataset object. mode is one of the indicators listed in Table 2.24 on page 70.

openDataset is a synonym for **open**.

Table 2.24 Open Modes

Mode	Definition
'r'	read-only
'r+'	read-write
'a'	read-write. Open the file if it exists, otherwise create a new file
'w'	Create a new file, read-write

Table 2.25 Dataset Methods

Type	Definition

Transient-Variable	***datasetobj*(varname, selector)**
	Calling a Dataset object as a function reads the region of data defined by the selector. The result is a transient variable, unless `raw=1` is specified. See "Selectors" on page 102.
	For example, the following reads data for variable 'prc', year 1980:
	`f = cdms2.open('test.xml')`
	`x = f('prc', time=('1980-1','1981-1'))`

Variable, Axis, or Grid	***datasetobj*['*id*']**
	The square bracket operator applied to a dataset gets the persistent variable, axis or grid object having the string identifier. This does not read the data for a variable. Returns None if not found.
	For example:
	`f = cdms2.open('sample.xml')`
	`v = f['prc']`
	gets the persistent variable v, equivalent to `v=f.variables['prc']`.
	`t = f['time']`
	gets the axis named 'time', equivalent to `t=f.axes['time']`.

None	**close()** Close the dataset.
Axis	**getAxis(id)** Get an axis object from the file or dataset. *id* is the string axis identifier.

Table 2.25 Dataset Methods

Type	Definition
Grid	**getGrid(id)** Get a grid object from a file or dataset. *id* is the string grid identifier.
List	**getPaths()** Get a sorted list of pathnames of datafiles which comprise the dataset. This does not include the XML metafile path, which is stored in the .uri attribute.
Variable	**getVariable(id)** Get a variable object from a file or dataset. *id* is the string variable identifier.
CurveGrid or Generic-Grid	**readScripGrid**(self, whichGrid='destination', check-Grid=1) Read a curvilinear or generic grid from a SCRIP dataset. The dataset can be a SCRIP grid file or remapping file. If a mapping file, *whichGrid* chooses the grid to read, either `"source"` or `"destination"`. If *checkGrid* is 1 (default), the grid cells are checked for convexity, and 'repaired' if necessary. Grid cells may appear to be nonconvex if they cross a 0 / 2pi boundary. The repair consists of shifting the cell vertices to the same side modulo 360 degrees.
None	**sync()** Write any pending changes to the dataset.

2.9 MV2 module

The fundamental CDMS data object is the variable. A variable is comprised of:

- a masked data array, as defined in the NumPy numpy.core.ma module.
- a domain: an ordered list of axes and/or grids.
- an attribute dictionary.

The MV2 module is a work-alike replacement for the numpy.core.ma module, that carries along the domain and attribute information where appropriate. MV2 provides the same set of functions as numpy.core.ma. However, MV2 functions generate transient variables as results. Often this simplifies scripts that perform computation. numpy.core.ma is part of the Python NumPy package, documented at http://numpy.scipy.org.

MV can be imported with the command:

```
import MV2
```

or

```
from cdms2 import MV2
```

Note that **cdms2.MV** is an alias for **cdms2.MV2**.

The command

```
from MV2 import *
```

allows use of MV2 commands without any prefix.

Table 2.26 on page 74 lists the constructors in **MV2**. All functions return a transient variable. In most cases the keywords *axes, attributes*, and *id* are available. *axes* is a list of axis objects which specifies the domain of the variable. *attributes* is a dictionary. *id* is a special attribute string that serves as the identifier of the variable, and should not contain blanks or non-printing characters. It is used when the variable is plotted or written to a file. Since the id is just an attribute, it can also be set like any attribute:

```
var.id = 'temperature'
```

For completeness MV2 provides access to all the numpy.core.ma functions. The functions not listed in the following tables are identical to the corresponding numpy.core.ma function: **allclose, allequal, common_fill_value, compress, create_mask, dot, e, fill_value, filled, get_print_limit, getmask, getmaskarray, identity, indices, innerproduct, isMA, isMaskedArray, is_mask, isarray, make_mask, make_mask_none, mask_or, masked, pi, put, putmask, rank, ravel, set_fill_value, set_print_limit, shape, size**. See the documentation at http://numpy.scipy.org for a description of these functions.

Table 2.26 **Variable Constructors in module MV2**

arrayrange(start, stop=None, step=1, typecode=None, axis=None, attributes=None, id=None, dtype=None) Just like numpy.core.ma.arange() except it returns a variable whose type can be specfied by the keyword argument typecode. The axis, attribute dictionary, and string identifier of the result variable may be specified. Synonym: **arange**
masked_array(a, mask=None, fill_value=None, axes=None, attributes=None, id=None) Same as numpy.core.ma.masked_array but creates a variable instead. If no axes are specified, the result has default axes, otherwise *axes* is a list of axis objects matching a.shape.
masked_object(data, value, copy=1, axes=None, attributes=None, id=None) Create variable masked where exactly data equal to value. Create the variable with the given list of axis objects, attribute dictionary, and string id.

Table 2.26 Variable Constructors in module MV2

masked_values(data, value, rtol=1e-05, atol=1e-08, copy=1, axes=None, attributes=None, id=None) Constructs a variable with the given list of axes and attribute dictionary, whose mask is set at those places where abs (data - value) < atol + rtol * abs (data). This is a careful way of saying that those elements of the data that have value = value (to within a tolerance) are to be treated as invalid. If data is not of a floating point type, calls masked_object instead.
ones(shape, typecode=Float, axes=None, attributes=None, id=None, grid=None, dtype=None) Return an array of all ones of the given length or shape.
reshape(a, newshape, axes=None, attributes=None, id=None, grid=None) Copy of a with a new shape.
resize(a, new_shape, axes=None, attributes=None, id=None, grid=None) Return a new array with the specified shape. The original array's total size can be any size.
zeros(shape, typecode=Float, axes=None, attributes=None, id=None, grid=None, dtype=None) An array of all zeros of the given length or shape.

The following table describes the MV2 non-constructor functions. With the exception of **argsort**, all functions return a transient variable.

Table 2.27 **MV2 functions**

Definition
argsort(x, axis=-1, fill_value=None) Return a NumPy array of indices for sorting along a given axis.
asarray(data, typecode=None, dtype=None) Same as cdms2.createVariable(data, typecode, copy=0). This is a short way of ensuring that something is an instance of a variable of a given type before proceeding, as in `data = asarray(data)` Also see the variable **astype()** function.
average(a, axis=0, weights=None, returned=0) computes the average value of the non-masked elements of x along the selected axis. If weights is given, it must match the size and shape of x, and the value returned is: sum(a*weights)/sum(weights) In computing these sums, elements that correspond to those that are masked in x or weights are ignored.
choose(condition, t) has a result shaped like array *condition*. t must be a tuple of two arrays t1 and t2. Each element of the result is the corresponding element of t1 where condition is true, and the corresponding element of t2 where condition is false. The result is masked where condition is masked or where the selected element is masked.
concatenate(arrays, axis=0, axisid=None, axisattributes=None) Concatenate the arrays along the given axis. Give the extended axis the id and attributes provided - by default, those of the first array.
count(a, axis=None) Count of the non-masked elements in a, or along a certain axis.

Table 2.27 MV2 functions

Definition
isMaskedVariable(x) Return true if x is an instance of a variable.
masked_equal(x, value) x masked where x equals the scalar value For floating point value consider masked_values(x, value) instead.
masked_greater(x, value) x masked where x > value
masked_greater_equal(x, value) x masked where x >= value
masked_less(x, value) x masked where x < value
masked_less_equal(x, value) x masked where x <= value
masked_not_equal(x, value) x masked where x != value
masked_outside(x, v1, v2) x with mask of all values of x that are outside [v1,v2]
masked_where(condition, x, copy=1) Return x as a variable masked where *condition* is true. Also masked where x or condition masked. *condition* is a masked array having the same shape as x.
maximum(a, b=None) Compute the maximum valid values of x if y is None; with two arguments, return the element-wise larger of valid values, and mask the result where either x or y is masked.

Table 2.27 MV2 functions

Definition
minimum(a, b=None) Compute the minimum valid values of x if y is None; with two arguments, return the element-wise smaller of valid values, and mask the result where either x or y is masked.
outerproduct(a, b) Return a variable such that result[i, j] = a[i] * b[j]. The result will be masked where a[i] or b[j] is masked.
power(a, b) a**b
product(a, axis=0, fill_value=1, dtype=None) Product of elements along axis using *fill_value* for missing elements.
repeat(ar, repeats, axis=None) Return *ar* repeated *repeats* times along axis. *repeats* is a sequence of length ar.shape[axis] telling how many times to repeat each element.
set_default_fill_value(value_type, value) Set the default fill value for *value_type* to *value*. *value_type* is a string: `'real'`,`'complex'`,`'character'`,`'integer'`,or `'object'`. *value* should be a scalar or single-element array.
sort(ar, axis=-1) Sort array *ar* elementwise along the specified axis. The corresponding axis in the result has dummy values.
sum(a, axis=None, fill_value=0, dtype=None) Sum of elements along a certain axis using *fill_value* for missing.
take(a, indices, axis=None) Return a selection of items from *a*. See the documentation in the NumPy manual.

Table 2.27 MV2 functions

Definition
transpose(ar, axes=None) Perform a reordering of the axes of array *ar* depending on the tuple of indices *axes*;thedefault is to reverse the order of the axes.
where(condition, x, y) x where *condition* is true, y otherwise.

2.10 HorizontalGrid

A HorizontalGrid represents a latitude-longitude coordinate system. In addition, it optionally describes how lat-lon space is partitioned into cells. Specifically, a HorizontalGrid:

- consists of a latitude and longitude coordinate axis.
- may have associated boundary arrays describing the grid cell boundaries,
- may optionally have an associated logical mask.

CDMS supports several types of HorizontalGrids:

Table 2.28

Grid Type	Description
RectGrid	Associated latitude an longitude are 1-D axes, with strictly monotonic values.
CurveGrid	Latitude and longitude are 2-D coordinate axes (Axis2D).
GenericGrid	Latitude and longitude are 1-D auxiliary coordinate axis (AuxAxis1D)

Table 2.29 **HorizontalGrid Internal Attributes**

Type	Name	Definition
Dictionary	attributes	External attribute dictionary.
String	id	The grid identifier.
Dataset or CdmsFile	parent	The dataset or file which contains the grid.
Tuple	shape	The shape of the grid, a 2-tuple.

Table 2.31 on page 81 describes the methods that apply to all types of HorizontalGrids. Table 2.32 on page 85 describes the additional methods that are unique to RectGrids.

Table 2.30 **RectGrid Constructors**

cdms2.createRectGrid(lat, lon, order, type="generic", mask=None)

Create a grid not associated with a file or dataset.

See Table 2.2 on page 31.

CdmsFile.createRectGrid(id, lat, lon, order, type="generic", mask=None)

Create a grid associated with a file. See Table 2.14 on page 53.

Dataset.createRectGrid(id, lat, lon, order, type="generic", mask=None)

Create a grid associated with a dataset. See Table 2.25 on page 71.

cdms2.createGaussianGrid(nlats, xorigin=0.0, order=”yx”)

See Table 2.2 on page 31.

Table 2.30 RectGrid Constructors

cdms2.createGenericGrid(latArray, lonArray, latBounds=None, lonBounds=None, order="yx", mask=None)

See Table 2.2 on page 18.

cdms2.createGlobalMeanGrid(grid)

See Table 2.2 on page 18.

cdms2.createRectGrid(lat, lon, order, type="generic", mask=None)

See Table 2.2 on page 18.

cdms2.createUniformGrid(startLat, nlat, deltaLat, startLon, nlon, deltaLon, order="yx", mask=None)

See Table 2.2 on page 18.

cdms2.createZonalGrid(grid)

See Table 2.2 on page 18.

Table 2.31 HorizontalGrid Methods

Type	Definition
Horizontal-Grid	**clone()** Return a transient copy of the grid.
Axis	**getAxis(Integer n)** Get the n-th axis. n is either 0 or 1.

Table 2.31 HorizontalGrid Methods

Type	Definition
Tuple	**getBounds()** Get the grid boundary arrays. Returns a tuple (latitudeArray, longitudeArray), where latitudeArray is a NumPy array of latitude bounds, and similarly for longitudeArray.The shape of latitudeArray and longitudeArray depend on the type of grid: • for rectangular grids with shape (nlat, nlon), the boundary arrays have shape (nlat,2) and (nlon,2). • for curvilinear grids with shape (nx, ny), the boundary arrays each have shape (nx, ny, 4). • for generic grids with shape (ncell,), the boundary arrays each have shape (ncell, nvert) where nvert is the maximum number of vertices per cell. For rectilinear grids: If no boundary arrays are explicitly defined (in the file or dataset), the result depends on the autoBounds mode (see **cdms2.setAutoBounds**) and the grid classification mode (see **cdms2.setClassifyGrids**). By default, autoBounds mode is enabled, in which case the boundary arrays are generated based on the type of grid. If disabled, the return value is (None,None). For rectilinear grids: The grid classification mode specifies how the grid type is to be determined. By default, the grid type (Gaussian, uniform, etc.) is determined by calling **grid.classifyInFamily.** If the mode is 'off' **grid.getType** is used instead
Axis	**getLatitude()** Get the latitude axis of this grid.
Axis	**getLongitude()** Get the latitude axis of this grid.

Table 2.31 HorizontalGrid Methods

Type	Definition
Array	**getMask()** Get the mask array of this grid, if any. Returns a 2-D NumPy array, having the same shape as the grid. If the mask is not explicitly defined, the return value is None.
Array	**getMesh(self, transpose=None)** Generate a mesh array for the meshfill graphics method. If transpose is defined to a tuple, say (1,0), first transpose latbounds and lonbounds according to the tuple, in this case (1,0,2).
None	**setBounds(latBounds, lonBounds, persistent=0)** Set the grid boundaries. *latBounds* is a NumPy array of shape (n,2), such that the boundaries of the kth axis value are [*latBounds*[k,0],*latBounds*[k,1]]. *lonBounds* is defined similarly for the longitude array. Note: By default, the boundaries are not written to the file or dataset containing the grid (if any). This allows bounds to be set on read-only files, for regridding. If the optional argument *persistent* is set to 1, the boundary array is written to the file.
None	**setMask(mask, persistent=0)** Set the grid mask. If persistent==1, the mask values are written to the associated file, if any. Otherwise, the mask is associated with the grid, but no I/O is generated. *mask* is a two-dimensional, Boolean-valued NumPy array, having the same shape as the grid.

Table 2.31 HorizontalGrid Methods

Type	Definition
Horizontal-Grid	**subGridRegion(latInterval, lonInterval)** Create a new grid corresponding to the coordinate region defined by latInterval, lonInterval. *latInterval* and *lonInterval* are the coordinate intervals for latitude and longitude, respectively. Each interval is a tuple having one of the forms: (x,y) (x,y,indicator) (x,y,indicator,cycle) None where *x* and *y* are coordinates indicating the interval [x,y), and: *indicator* is a two-character string, where the first character is 'c' if the interval is closed on the left, 'o' if open, and the second character has the same meaning for the right-hand point. (Default: 'co') If *cycle* is specified, the axis is treated as circular with the given cycle value. By default, if grid.isCircular() is true, the axis is treated as circular with a default value of 360.0. An interval of None returns the full index interval of the axis. If a mask is defined, the subgrid also has a mask corresponding to the index ranges. Note: The result grid is not associated with any file or dataset.

Table 2.31 HorizontalGrid Methods

Type	Definition
Transient-CurveGrid	**toCurveGrid**(gridid=None) Convert to a curvilinear grid. If the grid is already curvilinear, a copy of the grid object is returned. *gridid* is the string identifier of the resulting curvilinear grid object. If unspecified, the grid ID is copied. Note: This method does not apply to generic grids.
Transient-GenericGrid	**toGenericGrid**(gridid=None) Convert to a generic grid. If the grid is already generic, a copy of the grid is returned. *gridid* is the string identifier of the resulting curvilinear grid object. If unspecified, the grid ID is copied.

Table 2.32 RectGrid Methods, additional to HorizontalGrid Methods

String	**getOrder()** Get the grid ordering, either “yx” if latitude is the first axis, or “xy” if longitude is the first axis.
String	**getType()** Get the grid type, either “gaussian”, “uniform”, “equalarea”, or “generic”.

Table 2.32 RectGrid Methods, additional to HorizontalGrid Methods

(Array,Array)	**getWeights()**
	Get the normalized area weight arrays, as a tuple (latWeights, lonWeights). It is assumed that the latitude and longitude axes are defined in degrees.
	The latitude weights are defined as:
	`latWeights[i] = 0.5 * abs(sin(latBounds[i+1]) - sin(latBounds[i]))`
	The longitude weights are defined as:
	`lonWeights[i] = abs(lonBounds[i+1] - lonBounds[i])/360.0`
	For a global grid, the weight arrays are normalized such that the sum of the weights is 1.0
	Example: Generate the 2-D weights array, such that weights[i.j] is the fractional area of grid zone [i,j].
	`from cdms2 import MV`
	`latwts, lonwts = grid.getWeights()`
	`weights = MV.outerproduct(latwts, lonwts)`
	Also see the function **area_weights** in module **pcmdi.weighting**.

None	**setType(gridtype)** Set the grid type. *gridtype* is one of “gaussian”, “uniform”, “equalarea”, or “generic”.

Table 2.32 **RectGrid Methods, additional to HorizontalGrid Methods**

RectGrid	**subGrid((latStart,latStop),(lonStart,lonStop))** Create a new grid, with latitude index range [latStart : latStop] and longitude index range [lonStart : lonStop]. Either index range can also be specified as None, indicating that the entire range of the latitude or longitude is used. For example, `newgrid = oldgrid.subGrid(None, (lonStart, lonStop))` creates `newgrid` corresponding to all latitudes, and index range [lonStart:lonStop] of `oldgrid`. If a mask is defined, the subgrid also has a mask corresponding to the index ranges. Note: The result grid is not associated with any file or dataset.
RectGrid	**transpose()** Create a new grid, with axis order reversed. The grid mask is also transposed. Note: The result grid is not associated with any file or dataset.

2.11 Variable

A Variable is a multidimensional data object, consisting of:

- a multidimensional data array, possibly masked,
- a collection of attributes
- a domain, an ordered tuple of CoordinateAxis objects.

A Variable which is contained in a Dataset or CdmsFile is called a *persistent* variable. Setting a slice of a persistent Variable writes data to the Dataset or file, and referencing a Variable slice reads data from the Dataset. Variables may also be *transient*, not associated with a Dataset or CdmsFile.

Variables support arithmetic operations. The basic Python operators are +,-,*,/,**, abs, and sqrt, together with the operations defined in the **MV2** module. The result of an arithmetic operation is a transient variable, that is, the axis information is transferred to the result.

The methods subRegion and subSlice return transient variables. In addition, a transient variable may be created with the **cdms2.createVariable** method. The **vcs** and **regrid2** module methods take advantage of the attribute, domain, and mask information in a transient variable.

Table 2.33 Variable Internal Attributes

Type	**Name**	**Definition**
Dictionary	attributes	External attribute dictionary.
String	id	Variable identifier.
String	name_in_file	The name of the variable in the file or files which represent the dataset. If different from **id**, the variable is ‘aliased’.
Dataset or CdmsFile	parent	The dataset or file which contains the variable.
Tuple	shape	The length of each axis of the variable.

Table 2.34 Variable Constructors

CdmsFile.createVariable(String id, String datatype, List axesOrGrids)

Create a Variable in a CdmsFile.

id is the name of the variable.

datatype is the NumPy typecode, for example, numpy.float.

axesOrGrids is a list of Axis and/or Grid objects, on which the variable is defined. Specifying a rectilinear grid is equivalent to listing the grid latitude and longitude axes, in the order defined for the grid. Note: this argument can either be a list or a tuple. If the tuple form is used, and there is only one element, it must have a following comma, e.g.: (axisobj,).

Table 2.34 **Variable Constructors**

cdms2.createVariable(array, typecode=None, copy=0, mask=None, fill_value=None, grid=None, axes=None, attributes=None, id=None, copyaxes=1, dtype=None, order=None)

Create a transient variable, not associated with a file or dataset.

array is the data values: a Variable, masked array, or NumPy array.

typecode is the numpy typecode of the array. Defaults to the typecode of *array*. Note: in Version 5, this argument is superseded by *dtype*.

copy is an integer flag: if 1, the variable is created with a copy of the array, if 0 the variable data is shared with *array*.

mask is an array of integers with value 0 or 1, having the same shape as *array*. *array* elements with a corresponding mask value of 1 are considered 'invalid', and are not used for subsequent NumPy operations. The default mask is obtained from array if present, otherwise is None.

fill_value is the missing value flag. The default is obtained from *array* if possible, otherwise is set to 1.0e20 for floating point variables, 0 for integer-valued variables.

grid is a rectilinear grid object.

axes is a tuple of axis objects. By default the axes are obtained from *array* if present. Otherwise for a dimension of length n, the default axis has values [0., 1., ..., double(n)].

attributes is a dictionary of attribute values. The dictionary keys must be strings. By default the dictionary is obtained from *array* if present, otherwise is empty.

id is the string identifier of the variable. By default the *id* is obtained from array if possible, otherwise is set to 'variable_n' for some integer n.

copyaxes is an integer flag: if 1, and the *axes* argument is specified, the variable is created with copies of the axes in the variable domain. If 0, the domain includes the axes themselves.

dtype is a numpy datatype object or character code. Commonly used character codes are 'f' for single-precision float, 'd' for double-precision float, and 'l' for single-precision integer. See the numpy documentation for a complete list of character codes. New in Version 5.

If *order* is 'Fortran', the resulting array will be in Fortran order, otherwise in 'C' order. New in Version 5.

Table 2.35 Variable Methods

Type	Definition
Variable	**tvar = *var*[i:j, m:n]** Read a slice of data from the file or dataset, resulting in a transient variable. Singleton dimensions are 'squeezed' out. Data is returned in the physical ordering defined in the dataset. The forms of the slice operator are listed in Table 2.36 on page 101.
	***var*[i:j, m:n] = array** Write a slice of data to the external dataset. The forms of the slice operator are listed in Table 2.21 on page 32. (Variables in CdmsFiles only)
Variable	**tvar = *var*(*selector*)** Calling a variable as a function reads the region of data defined by the *selector*. The result is a transient variable, unless `raw=1` keyword is specified. 'See "Selectors" on page 102.
None	**assignValue(Array ar)** Write the entire data array. Equivalent to var[:] = ar. (Variables in CdmsFiles only).
Variable	**astype(typecode)** Cast the variable to a new datatype. Typecodes are as for MV2, numpy.core.ma, and NumPy modules.
Variable	**clone(copyData=1)** Return a copy of a transient variable. If copyData is 1 (the default) the variable data is copied as well. If copyData is 0, the result transient variable shares the original transient variable's data array.

Table 2.35 Variable Methods

Type	Definition
Transient Variable	**crossSectionRegrid(newLevel, newLatitude, method="log", missing=None, order=None)** Return a lat/level vertical cross-section regridded to a new set of latitudes *newLatitude* and levels *newLevel*. The variable should be a function of latitude, level, and (optionally) time. *newLevel* is an axis of the result pressure levels. *newLatitude* is an axis of the result latitudes. *method* is optional, either "`log`" to interpolate in the log of pressure (default), or "`linear`" for linear interpolation. *missing* is a missing data value. The default is var.getMissing() *order* is an order string such as "tzy" or "zy". The default is var.getOrder() See also: **regrid2**, **pressureRegrid**.
Axis	**getAxis(n)** Get the n-th axis. *n* is an integer.
List	**getAxisIds()** Get a list of axis identifiers.
Integer	**getAxisIndex(axis_spec)** Return the index of the axis specificed by *axis_spec*. Return -1 if no match. axis_spec is a specification as defined for **getAxisList**

Table 2.35 Variable Methods

Type	Definition
List	**getAxisList(axes=None, omit=None, order=None)** Get an ordered list of axis objects in the domain of the variable.. If *axes* is not None, include only certain axes. Otherwise *axes* is a list of specifications as described below. Axes are returned in the order specified unless the *order* keyword is given. If *omit* is not None, omit those specified by an integer dimension number. Otherwise *omit* is a list of specifications as described below. *order* is an optional string determining the output order. Specifications for the axes or omit keywords are a list, each element having one of the following forms: • an integer dimension index, starting at 0. • a string representing an axis id or one of the strings **'time', 'latitude', 'lat', 'longitude', 'lon', 'lev'** or **'level'**. • a function that takes an axis as an argument and returns a value. If the value returned is true, the axis matches. • an axis object; will match if it is the same object as axis. order can be a string containing the characters **t,x,y,z**, or **-**. If a dash ('-') is given, any elements of the result not chosen otherwise are filled in from left to right with remaining candidates.
List	**getAxisListIndex(axes=None, omit=None, order=None)** Return a list of indices of axis objects. Arguments are as for **getAxisList**.

Table 2.35 **Variable Methods**

Type	Definition
List	**getDomain()** Get the domain. Each element of the list is itself a tuple of the form `(axis,start,length,true_length)` where *axis* is an axis object, *start* is the start index of the domain relative to the axis object, *length* is the length of the axis, and *true_length* is the actual number of (defined) points in the domain. See also: **getAxisList**.
Horizontal-Grid	**getGrid()** Return the associated grid, or None if the variable is not gridded.
Axis	**getLatitude()** Get the latitude axis, or None if not found.
Axis	**getLevel()** Get the vertical level axis, or None if not found.
Axis	**getLongitude()** Get the longitude axis, or None if not found.
Various	**getMissing()** Get the missing data value, or None if not found.

Table 2.35 Variable Methods

Type	Definition
String	**getOrder()** Get the order string of a spatio-temporal variable. The order string specifies the physical ordering of the data. It is a string of characters with length equal to the rank of the variable, indicating the order of the variable's time, level, latitude, and/or longitude axes. Each character is one of: 't': time 'z': vertical level 'y: latitude 'x': longitude '-': the axis is not spatio-temporal. **Example**: A variable with ordering "tzyx" is 4-dimensional, where the ordering of axes is (time, level, latitude, longitude). Note: The order string is of the form required for the *order* argument of a regridder function.
List	**getPaths(*intervals)** Get the file paths associated with the index region specified by intervals. *intervals* is a list of scalars, 2-tuples representing [i,j), slices, and/or Ellipses. If no argument(s) are present, all file paths associated with the variable are returned. Returns a list of tuples of the form (path,slicetuple), where *path* is the path of a file, and *slicetuple* is itself a tuple of slices, of the same length as the rank of the variable, representing the portion of the variable in the file corresponding to *intervals*. Note: This function is not defined for transient variables.
Axis	**getTime()** Get the time axis, or None if not found.

Table 2.35 Variable Methods

Type	Definition
Integer	**len(var)** The length of the first dimension of the variable. If the variable is zero-dimensional (scalar), a length of 0 is returned. Note: **.size** returns the total number of elements.
Transient Variable	**pressureRegrid (newLevel, method="log", missing=None, order=None)** Return the variable regridded to a new set of pressure levels *newLevel*. The variable must be a function of latitude, longitude, pressure level, and (optionally) time. *newLevel* is an axis of the result pressure levels. *method* is optional, either "`log`" to interpolate in the log of pressure (default), or "`linear`" for linear interpolation. *missing* is a missing data value. The default is var.getMissing() *order* is an order string such as "tzyx" or "zyx". The default is var.getOrder() See also: **regrid2**, **crossSectionRegrid**.
Integer	**rank()** The number of dimensions of the variable.

Table 2.35 Variable Methods

Type	Definition
Transient Variable	**regrid (togrid, missing=None, order=None, mask=None)** Return the variable regridded to the horizontal grid *togrid*. *missing* is a Float specifying the missing data value. The default is 1.0e20. *order* is a string indicating the order of dimensions of the array. It has the form returned from **variable.getOrder()**. For example, the string "tzyx" indicates that the dimension order of *array* is (time, level, latitude, longitude). If unspecified, the function assumes that the last two dimensions of *array* match the input grid. *mask* is a NumPy array, of datatype Integer or Float, consisting of ones and zeros. A value of 0 or 0.0 indicates that the corresponding data value is to be ignored for purposes of regridding. If *mask* is two-dimensional of the same shape as the input grid, it overrides the mask of the input grid. If the mask has more than two dimensions, it must have the same shape as *array*. In this case, the *missing* data value is also ignored. Such an n-dimensional mask is useful if the pattern of missing data varies with level (e.g., ocean data) or time. Note: If neither *missing* or *mask* is set, the default mask is obtained from the mask of the array if any. See also: **crossSectionRegrid**, **pressureRegrid**.
None	**setAxis(n, axis)** Set the n-th axis (0-origin index) of to a copy of *axis*.
None	**setAxisList(axislist)** Set all axes of the variable. *axislist* is a list of axis objects.
None	**setMissing(value)** Set the missing value.

Table 2.35 **Variable Methods**

Type	Definition
Integer	**.size** Number of elements of the variable.
Variable	**subRegion(*region, time=None, level=None, latitude=None, longitude=None, squeeze=0, raw=0)** Read a coordinate region of data, returning a transient variable. A region is a hyperrectangle in coordinate space. *region* is an argument list, each item of which specifies an interval of a coordinate axis. The intervals are listed in the order of the variable axes. If trailing dimensions are omitted, all values of those dimensions are retrieved. If an axis is circular (**axis.isCircular()** is true) or cycle is specified (see below), then data will be read with wraparound in that dimension. Only one axis may be read with wraparound. A coordinate interval has one of the forms listed in Table 2.37 on page 101. Also see **axis.mapIntervalExt**. The optional keyword arguments *time, level, latitude*, and *longitude* may also be used to specify the dimension for which the interval applies. This is particularly useful if the order of dimensions is not known in advance. An exception is raised if a keyword argument conflicts with a positional *region* argument. The optional keyword argument *squeeze* determines whether or not the shape of the returned array contains dimensions whose length is 1; by default this argument is 0, and such dimensions are not 'squeezed out'. The optional keyword argument *raw* specifies whether the return object is a variable or a masked array. By default, a transient variable is returned, having the axes and attributes corresponding to the region read. If *raw*=1, an ma masked array is returned, equivalent to the transient variable without the axis and attribute information.

Table 2.35 Variable Methods

Type	Definition
Variable	**subSlice(*specs, time=None, level=None, latitude=None, longitude=None, squeeze=0, raw=0)** Read a slice of data, returning a transient variable. This is a functional form of the slice operator [] with the squeeze option turned off. *specs* is an argument list, each element of which specifies a slice of the corresponding dimension. There can be zero or more positional arguments, each of the form: (a) a single integer n, meaning slice(n, n+1) (b) an instance of the slice class (c) a tuple, which will be used as arguments to create a slice (d) ':', which means a slice covering that entire dimension (e) Ellipsis (...), which means to fill the slice list with ':' leaving only enough room at the end for the remaining positional arguments (f) a Python slice object, of the form slice(i,j,k) If there are fewer slices than corresponding dimensions, all values of the trailing dimensions are read. The keyword arguments are defined as in **subRegion**. There must be no conflict between the positional arguments and the keywords. In (a)-(c) and (f), negative numbers are treated as offsets from the end of that dimension, as in normal Python indexing.
String	**typecode()** or ***variable*.dtype.char** The NumPy datatype identifier.

Example: Get a region of data.

Variable ta is a function of (time, latitude, longitude). Read data corresponding to all times, latitudes -45.0 up to but not including +45.0, longitudes 0.0 through and including longitude 180.0:

```
data = ta.subRegion(':', (-45.0,45.0,'co'), (0.0, 180.0))
```

or equivalently:

```
data = ta.subRegion(latitude=(-45.0,45.0,'co'), longitude=(0.0,
    180.0)
```

Read all data for March, 1980:

```
data = ta.subRegion(time=('1980-3','1980-4','co'))
```

Table 2.36 Variable Slice Operators

[i]	The ith element, zero-origin indexing.
[i:j]	The ith element through, but not including, element j
[i:]	The ith element through the end
[:j]	The beginning element through, but not including, element j
[:]	The entire array
[i:j:k]	Every kth element
[i:j, m:n]	Multidimensional slice
[i, ..., m]	(Ellipsis) All dimensions between those specified.
[-1]	Negative indices 'wrap around'. -1 is the last element.

Table 2.37 Index and Coordinate Intervals

Interval	Definition	Example
x	single point, such that axis[i]==x In general x is a scalar. If the axis is a time axis, x may also be a cdtime relative time type, component time type, or string of the form 'yyyy-mm-dd hh:mi:ss' (where trailing fields of the string may be omitted.	180.0 cdtime.reltime(48,"hours since 1980-1") '1980-1-3'
(x,y)	indices i such that x <= axis[i] <= y	(-180,180)

Table 2.37 **Index and Coordinate Intervals**

Interval	Definition	Example
(x,y,'co')	x <= axis[i] < y The third item is defined as in mapInterval.	(-90,90,'cc')
(x,y,'co',cycle)	x<= axis[i] < y, with wraparound Note: It is not necesary to specify the cycle of a circular longitude axis, that is, for which axis.isCircular() is true.	(180, 180, 'co', 360.0)
slice(i,j,k)	slice object, equivalent to i:j:k in a slice operator. Refers to the indices i, i+k, i+2k, ... up to but not including index j. If i is not specified or is None it defaults to 0. If j is not specified or is None it defaults to the length of the axis. The stride k defaults to 1. k may be negative.	slice(1,10) slice(,,-1) reverses the direction of the axis.
':'	all axis values of one dimension	
Ellipsis	all values of all intermediate axes	

2.11.1 Selectors

A *selector* is a specification of a region of data to be selected from a variable. For example, the statement

```
x = v(time='1979-1-1', level=(1000.0,100.0))
```

means 'select the values of variable v for time '1979-1-1' and levels 1000.0 to 100.0 inclusive, setting x to the result.' Selectors are generally used to represent regions of space and time.

The form for using a selector is

```
result = v(s)
```

where **v** is a variable and **s** is the selector. An equivalent form is

```
result = f('varid', s)
```

where **f** is a file or dataset, and **'varid'** is the string ID of a variable.

A selector consists of a list of *selector components*. For example, the selector

```
time='1979-1-1', level=(1000.0,100.0)
```

has two components: `time='1979-1-1'`, and `level=(1000.0,100.0)`. This illustrates that selector components can be defined with keywords, using the form:

```
keyword=value
```

Note that for the keywords `time`, `level`, `latitude`, and `longitude`, the selector can be used with any variable. If the corresponding axis is not found, the selector component is ignored. This is very useful for writing general purpose scripts. The `required` keyword overrides this behavior. These keywords take values that are coordinate ranges or index ranges as defined in Table 2.37 on page 101.

The following keywords are available:

Table 2.38 Selector keywords

Keyword	Description	Value
axisid	Restrict the axis with ID *axisid* to a value or range of values.	See Table 2.37 on page 101
`grid`	Regrid the result to the grid.	Grid object
`latitude`	Restrict latitude values to a value or range. Short form: lat	See Table 2.37 on page 101
`level`	Restrict vertical levels to a value or range. Short form: lev	See Table 2.37 on page 101
`longitude`	Restrict longitude values to a value or range. Short form: lon	See Table 2.37 on page 101
`order`	Reorder the result.	Order string, e.g., “tzyx”
`raw`	Return a masked array (ma.MaskedArray) rather than a transient variable.	0: return a transient variable (default); =1: return a masked array.

Table 2.38 Selector keywords

Keyword	Description	Value
required	Require that the axis IDs be present.	List of axis identifiers.
squeeze	Remove singleton dimensions from the result.	0: leave singleton dimensions (default); 1: remove singleton dimensions.
time	Restrict time values to a value or range.	See Table 2.37 on page 101

Another form of selector components is the *positional* form, where the component order corresponds to the axis order of a variable. For example:

```
x9 = hus(('1979-1-1','1979-2-1'),1000.0)
```

reads data for the range `('1979-1-1','1979-2-1')` of the first axis, and coordinate value `1000.0` of the second axis. Non-keyword arguments of the form(s) listed in Table 2.37 on page 101 are treated as positional. Such selectors are more concise, but not as general or flexible as the other types described in this section.

Selectors are objects in their own right. This means that a selector can be defined and reused, independent of a particular variable. Selectors are constructed using the cdms2.selectors.Selector class. The constructor takes an argument list of selector components. For example:

```
from cdms2.selectors import Selector
sel = Selector(time=('1979-1-1','1979-2-1'), level=1000.)
x1 = v1(sel)
x2 = v2(sel)
```

For convenience CDMS provides several predefined selectors, which can be used directly or can be combined into more complex selectors. The selectors `time, level, latitude, longitude`, and `required` are equivalent to their keyword counterparts. For example:

```
from cdms2 import time, level
x = hus(time('1979-1-1','1979-2-1'), level(1000.))
```

and

```
x = hus(time=('1979-1-1','1979-2-1'), level=1000.)
```

are equivalent. Additionally, the predefined selectors **latitudeslice, longitudeslice, levelslice**, and **timeslice** take arguments (startindex, stopindex[, stride]):

```
from cdms2 import timeslice, levelslice
x = v(timeslice(0,2), levelslice(16,17))
```

Finally, a collection of selectors is defined in module **cdutil.region**:

```
from cdutil.region import *
NH=NorthernHemisphere=domain(latitude=(0.,90.)
SH=SouthernHemisphere=domain(latitude=(-90.,0.))
Tropics=domain(latitude=(-23.4,23.4))
NPZ=AZ=ArcticZone=domain(latitude=(66.6,90.))
SPZ=AAZ=AntarcticZone=domain(latitude=(-90.,-66.6))
```

Selectors can be combined using the & operator, or by refining them in the call:

```
from cdms2.selectors import Selector
from cdms2 import level
sel2 = Selector(time=('1979-1-1','1979-2-1'))
sel3 = sel2 & level(1000.0)
x1 = hus(sel3)
x2 = hus(sel2, level=1000.0)
```

2.11.2 Selector examples

CDMS provides a variety of ways to select or slice data. In the following examples, variable 'hus' is contained in file sample.nc, and is a function of (time, level, latitude, longitude). Time values are monthly starting at 1979-1-1. There are 17 levels, the last level being 1000.0. The name of the vertical level axis is 'plev'. All the examples select the first two times and the last level. The last two examples remove the singleton level dimension from the result array.

```
import cdms2

f = cdms2.open('sample.nc')
hus = f.variables['hus']

# Keyword selection
x = hus(time=('1979-1-1','1979-2-1'), level=1000.)
```

```
# Interval indicator (see mapIntervalExt)
x = hus(time=('1979-1-1','1979-3-1','co'), level=1000.)

# Axis ID (plev) as a keyword
x = hus(time=('1979-1-1','1979-2-1'), plev=1000.)

# Positional
x9 = hus(('1979-1-1','1979-2-1'),1000.0)

# Predefined selectors
from cdms2 import time, level
x = hus(time('1979-1-1','1979-2-1'), level(1000.))

from cdms2 import timeslice, levelslice
x = hus(timeslice(0,2), levelslice(16,17))

# Call file as a function
x = f('hus', time=('1979-1-1','1979-2-1'), level=1000.)

# Python slices
x = hus(time=slice(0,2), level=slice(16,17))

# Selector objects
from cdms2.selectors import Selector
sel = Selector(time=('1979-1-1','1979-2-1'), level=1000.)
x = hus(sel)

sel2 = Selector(time=('1979-1-1','1979-2-1'))
sel3 = sel2 & level(1000.0)
x = hus(sel3)
x = hus(sel2, level=1000.0)

# Squeeze singleton dimension (level)
x = hus[0:2,16]
x = hus(time=('1979-1-1','1979-2-1'), level=1000., squeeze=1)

f.close()
```

2.12 Examples

In this example, two datasets are opened, containing surface air temperature ('tas') and upper-air temperature ('ta') respectively. Surface air temperature is a function of (time, latitude, longitude). Upper-air temperature is a function of (time, level, latitude, longitude). Time is assumed to have a relative representation in the datasets (e.g., with units “months since basetime”).

Data is extracted from both datasets for January of the first input year through December of the second input year. For each time and level, three quantities are calculated: slope, variance, and correlation. The results are written to a netCDF file. For brevity, the functions corrCoefSlope and removeSeasonalCycle are omitted.

```
1   import cdms2
    import MV2 as MV

    # Calculate variance, slope, and correlation of
    # surface air temperature with upper air temperature
    # by level, and save to a netCDF file. 'pathTa' is the location of
    # the file containing ta, 'pathTas' is the file with contains tas.
    # Data is extracted from January of year1 through December of year2.
    def ccSlopeVarianceBySeasonFiltNet(pathTa,pathTas,month1,month2):

        # Open the files for ta and tas
        fta  = cdms2.open(pathTa)
        ftas = cdms2.open(pathTas)

2       # Get upper air temperature
        taObj = fta['ta']
        levs  = taObj.getLevel()

3       # Get the surface temperature for the closed interval [time1,time2]
        tas = ftas('tas', time=(month1,month2,'cc'))

        # Allocate result arrays
        newaxes = taObj.getAxisList(omit='time')
        newshape = tuple([len(a) for a in newaxes])
4       cc = MV.zeros(newshape, typecode=MV.Float, axes=newaxes, id='correlation')
        b = MV.zeros(newshape, typecode=MV.Float, axes=newaxes, id='slope')
        v = MV.zeros(newshape, typecode=MV.Float, axes=newaxes, id='variance')

        # Remove seasonal cycle from surface air temperature
        tas = removeSeasonalCycle(tas)

        # For each level of air temperature, remove seasonal cycle
        # from upper air temperature, and calculate statistics
5       for ilev in range(len(levs)):
            ta = taObj(time=(month1,month2,'cc'), \
                 level=slice(ilev, ilev+1), squeeze=1)
            ta = removeSeasonalCycle(ta)
            cc[ilev], b[ilev]  = corrCoefSlope(tas ,ta)
            v[ilev] = MV.sum( ta**2 )/(1.0*ta.shape[0])

        # Write slope, correlation, and variance variables
6       f = cdms2.open('CC_B_V_ALL.nc','w')
        f.title = 'filtered'
        f.write(b)
        f.write(cc)
        f.write(v)
        f.close()
```

```
  if __name__=='__main__':
7     pathTa = '/pcmdi/cdms/sample/ccmSample_ta.xml'
      pathTas = '/pcmdi/cdms/sample/ccmSample_tas.xml'
      # Process Jan80 through Dec81
      ccSlopeVarianceBySeasonFiltNet(pathTa,pathTas,'80-1','81-12')
```

Notes:

1. Two modules are imported, **cdms2**, and **MV2**. **MV2** implements arithmetic functions.
2. `taObj` is a file (persistent) variable. At this point, no data has actually been read. This happens when the file variable is sliced, or when the **subRegion** function is called. `levs` is an axis.
3. Calling the file like a function reads data for the given variable and time range. Note that `month1` and `month2` are time strings.
4. In contrast to `taObj`, the variables `cc, b`, and `v` are transient variables, not associated with a file. The assigned names are used when the variables are written.
5. Another way to read data is to call the variable as a function. The **squeeze** option removes singleton axes, in this case the level axis.
6. Write the data. Axis information is written automatically.
7. This is the main routine of the script. `pathTa` and `pathTas` pathnames. Data is processed from January 1980 through December 1981.

In the next example, the pointwise variance of a variable over time is calculated, for all times in a dataset. The name of the dataset and variable are entered, then the variance is calculated and plotted via the vcs module.

```
  #!/usr/bin/env python
  #
  # Calculates gridpoint total variance
  # from an array of interest
  #

  import cdms2
  from MV2 import *

  # Wait for return in an interactive window
  def pause():
      print 'Hit return to continue: ',
      line = sys.stdin.readline()

  # Calculate pointwise variance of variable over time
8 # Returns the variance and the number of points
  # for which the data is defined, for each grid point
  def calcVar(x):
```

```
    # Check that the first axis is a time axis
    firstaxis = x.getAxis(0)
    if not firstaxis.isTime():
        raise 'First axis is not time, variable:', x.id

    n = count(x,0)
    sumxx = sum(x*x)
    sumx = sum(x)
    variance = (n*sumxx - (sumx * sumx))/(n * (n-1.))

    return variance,n

if __name__=='__main__':
    import vcs, sys

    print 'Enter dataset path [/pcmdi/cdms/obs/erbs_mo.xml]: ',
    path = string.strip(sys.stdin.readline())
    if path=='': path='/pcmdi/cdms/obs/erbs_mo.xml'

    # Open the dataset
9   dataset = cdms2.open(path)

    # Select a variable from the dataset
    print 'Variables in file:',path
    varnames = dataset.variables.keys()
    varnames.sort()
    for varname in varnames:
        var = dataset.variables[varname]
        if hasattr(var,'long_name'):
            long_name = var.long_name
        elif hasattr(var,'title'):
            long_name = var.title
        else:
            long_name = '?'
        print '%-10s: %s'%(varname,long_name)
    print 'Select a variable: ',
    varname = string.strip(sys.stdin.readline())
10  var = dataset(varname)
    dataset.close()

    # Calculate variance, count, and set attributes
    variance,n = calcVar(var)
    variance.id = 'variance_%s'%var.id
    n.id = 'count_%s'%var.id
    if hasattr(var,'units'):
        variance.units = '(%s)^2'%var.units

    # Plot variance
    w=vcs.init()
11  w.plot(variance)
    pause()
    w.clear()
    w.plot(n)
    pause()
    w.clear()
```

The result of running this script is as follows:

```
% calcVar.py
Enter dataset path [/pcmdi/cdms/sample/obs/erbs_mo.xml]:
 Variables in file: /pcmdi/cdms/sample/obs/erbs_mo.xml
albt      : Albedo TOA [%]
albtcs    : Albedo TOA clear sky [%]
rlcrft    : LW Cloud Radiation Forcing TOA [W/m^2]
rlut      : LW radiation TOA (OLR) [W/m^2]
rlutcs    : LW radiation upward TOA clear sky [W/m^2]
rscrft    : SW Cloud Radiation Forcing TOA [W/m^2]
rsdt      : SW radiation downward TOA [W/m^2]
rsut      : SW radiation upward TOA [W/m^2]
rsutcs    : SW radiation upward TOA clear sky [W/m^2]
Select a variable: albt

<The variance is plotted>

Hit return to continue:

<The number of points is plotted>
```

Notes:

8. **`n = count(x, 0)`** returns the pointwise number of valid values, summing across axis 0, the first axis. **`count`** is an MV2 function.
9. **`dataset`** is a Dataset or CdmsFile object, depending on whether a .xml or .nc pathname is entered. **`dataset.variables`** is a dictionary mapping variable name to file variable.
10. **`var`** is a transient variable.
11. Plot the variance and count variables. Spatial longitude and latitude information are carried with the computations, so the continents are plotted correctly.

CHAPTER 3

cdtime Module

3.1 Time types

The cdtime module implements the CDMS time types, methods, and calendars. These are made available with the command

```
import cdtime
```

Two time types are available: *relative time* and *component time*. Relative time is time relative to a fixed base time. It consists of:

- a **`units`** string, of the form **`"units since basetime"`**, and
- a floating-point **`value`**

For example, the time "28.0 days since 1996-1-1" has value=**`28.0`**, and units=**`"days since 1996-1-1"`**

Component time consists of the integer fields **`year, month, day, hour, minute`**, and the floating-point field **`second`**. A sample component time is 1996-2-28 12:10:30.0

The **cdtime** module contains functions for converting between these forms, based on the common calendars used in climate simulation. Basic arithmetic and comparison operators are also available.

3.2 Calendars

A calendar specifies the number of days in each month, for a given year. cdtime supports these calendars:

- **`cdtime.GregorianCalendar`**: years evenly divisible by four are leap years, except century years not evenly divisible by 400. This is sometimes called the *proleptic* Gregorian calendar, meaning that the algorithm for leap years applies for all years.
- **`cdtime.MixedCalendar`**: mixed Julian/Gregorian calendar. Dates before 1582-10-15 are encoded with the Julian calendar, otherwise are encoded with the Gregorian calendar. The day immediately following 1582-10-4 is 1582-10-15. This is the default calendar.
- **`cdtime.JulianCalendar`**: years evenly divisible by four are leap years,
- **`cdtime.NoLeapCalendar`**: all years have 365 days,
- **`cdtime.Calendar360`**: all months have 30 days.

Several **cdtime** functions have an optional calendar argument. The default calendar is the **`MixedCalendar`**. The default calendar may be changed with the command:

```
cdtime.DefaultCalendar = newCalendar
```

3.3 Time Constructors

The following table describes the methods for creating time types.

Table 3.1 Time Constructors

Type	Definition
Reltime	**cdtime.reltime(value, relunits)** Create a relative time type. *value* is an integer or floating point value. *relunits* is a string of the form `"`*unit*`(s) [since` *basetime*`]"` where ***unit*** = **`[second | minute | hour | day | week | month | season | year]`** ***basetime*** has the form **`yyyy-mm-dd hh:mi:ss`**. The default basetime is **`1979-1-1`**, if no since clause is specified. Example: **`r = cdtime.reltime(28, "days since 1996-1-1")`**
Comptime	**cdtime.comptime(year, month=1, day=1, hour=0, minute=0, second=0.0)** Create a component time type. *year* is an integer. *month* is an integer in the range 1 .. 12 *day* is an integer in the range 1 .. 31 *hour* is an integer in the range 0 .. 23 *minute* is an integer in the range 0 .. 59 *second* is a floating point number in the range 0.0 ,, 60.0 Example: **`c = cdtime.comptime(1996, 2, 28)`**

Table 3.1 Time Constructors

Type	Definition
Comptime	**[Deprecated] cdtime.abstime(absvalue, absunits)** Create a component time from an absolute time representation. *absvalue* is a floating-point encoding of an absolute time. *absunits* is the units template, a string of the form **"*unit* as *format*"**, where ***unit*** is one of **second, minute, hour, day, calendar_month,** or **calendar_year**. ***format*** is a string of the form **"%x[%x[...]][.%f]"**, where **x** is one of the format letters '**Y**' (year, including century), '**m**' (two digit month, 01=January), '**d**' (two-digit day within month), '**H**' (hours since midnight), '**M**' (minutes), or '**S**' (seconds). The optional '**.%f**' denotes a floating-point fraction of the unit. Example: **c = cdtime.abstime(19960228.0, "day as %Y%m%d.%f")**

3.4 Relative Time

A relative time type has two members, **value** and **units**. Both can be set.

Table 3.2 Relative Time Members

Type	Name	Summary
Float	value	Number of units
String	units	Relative units, of the form **"unit(s) since basetime"**

3.5 *Component Time*

A component time type has six members, all of which are settable.

Table 3.3 Component Time Members

Type	**Name**	**Summary**
Integer	year	Year value
Integer	month	Month, in the range 1..12
Integer	day	Day of month, in the range 1 .. 31
Integer	hour	Hour, in the range 0 .. 23
Integer	minute	Minute, in the range 0 .. 59
Float	second	Seconds, in the range 0.0 .. 60.0

3.6 *Time Methods*

The following methods apply both to relative and component times.

Table 3.4 Time Methods

Type	Definition

Comptime or Reltime	**t.add(value, intervalUnits, calendar=cdtime.DefaultCalendar)**
	Add an interval of time to a time type t. Returns the same type of time.
	value is the Float number of interval units.
	intervalUnits is `cdtime.[Second(s) | Minute(s) | Hour(s) | Day(s) | Week(s) | Month(s) | Season(s) | Year(s)]`
	calendar is the calendar type.
	Example:
	`>>> from cdtime import *`
	`>>> c = comptime(1996,2,28)`
	`>>> r = reltime(28,"days since 1996-1-1")`
	`>>> print r.add(1,Day)`
	`29.00 days since 1996-1-1`
	`>>> print c.add(36,Hours)`
	`1996-2-29 12:0:0.0`
	Note: When adding or subtracting intervals of months or years, only the month and year of the result are significant. The reason is that intervals in months/years are not commensurate with intervals in days or fractional days. This leads to results that may be surprising. For example:
	`>>> c = comptime(1979,8,31)`
	`>>> c.add(1,Month)`
	`1979-9-1 0:0:0.0`
	In other words, the day component of `c` was ignored in the addition, and the day/hour/minute components of the results are just the defaults. If the interval is in years, the interval is converted internally to months:
	`>>> c = comptime(1979,8,31)`
	`>>> c.add(2,Years)`
	`1981-8-1 0:0:0.0`

Table 3.4 Time Methods

Type	Definition

Integer	**t.cmp(t2, calendar=cdtime.DefaultCalendar)**
	Compare time values t and t2. Returns -1, 0, 1 as t is less than, equal to, or greater than t2 respectively.
	t2 is the time to compare.
	calendar is the calendar type.
	Example:
	`>>> from cdtime import *`
	`>>> r = cdtime.reltime(28,"days since 1996-1-1")`
	`>>> c = comptime(1996,2,28)`
	`>>> print r.cmp(c)`
	`-1`
	`>>> print c.cmp(r)`
	`1`
	`>>> print r.cmp(r)`
	`0`

Comptime or Reltime	**t.sub(value, intervalUnits, calendar=cdtime.Default-Calendar)**
	Subtract an interval of time from a time type t. Returns the same type of time.
	value is the Float number of interval units.
	intervalUnits is **`cdtime.[Second(s) | Minute(s) | Hour(s) | Day(s) | Week(s) | Month(s) | Season(s) | Year(s)]`**
	calendar is the calendar type.
	Example:
	`>>> from cdtime import *`
	`>>> r = cdtime.reltime(28,"days since 1996-1-1")`
	`>>> c = comptime(1996,2,28)`
	`>>> print r.sub(10,Days)`
	`18.00 days since 1996-1-1`
	`>>> print c.sub(30,Days)`
	`1996-1-29 0:0:0.0`
	For intervals of years or months, see the note under **add()**.

Table 3.4 Time Methods

Type	Definition

Comptime	**t.tocomp(calendar = cdtime.DefaultCalendar)**
	Convert to component time. Returns the equivalent component time.
	calendar is the calendar type.
	Example:
	`>>> r = cdtime.reltime(28,"days since 1996-1-1")`
	`>>> r.tocomp()`
	`1996-1-29 0:0:0.0`

Reltime	**t.torel(units, calendar=cdtime.DefaultCalendar)**
	Convert to relative time. Returns the equivalent relative time.
	Example:
	`>>> c = comptime(1996,2,28)`
	`>>> print c.torel("days since 1996-1-1")`
	`58.00 days since 1996-1-1`
	`>>> r = reltime(28,"days since 1996-1-1")`
	`>>> print r.torel("days since 1995")`
	`393.00 days since 1995`
	`>>> print r.torel("days since 1995").value`
	`393.0`

CHAPTER 4 Regridding Data

4.1 Overview

CDMS provides several methods for interpolating gridded data:

- from one rectangular, lat-lon grid to another (CDMS regridder)
- between any two lat-lon grids (SCRIP regridder)
- from one set of pressure levels to another
- from one vertical (lat/level) cross-section to another vertical cross-section.

4.1.1 CDMS horizontal regridder

The simplest method to regrid a variable from one rectangular, lat/lon grid to another is to use the **regrid** function defined for variables. This function takes the target grid as an argument, and returns the variable regridded to the target grid:

```
>>> import cdms2
>>> f = cdms2.open('/pcmdi/cdms/exp/cmip2/ccc/perturb.xml')
>>> rlsf = f('rls')  # Read the data
>>> rlsf.shape
(4, 48, 96)
```

```
>>> g = cdms2.open('/pcmdi/cdms/exp/cmip2/mri/perturb.xml')
>>> rlsg = g['rls']  # Get the file variable (no data read)
>>> outgrid = rlsg.getGrid() # Get the target grid
>>> rlsnew = rlsf.regrid(outgrid)
>>> rlsnew.shape
(4, 46, 72)
>>> outgrid.shape
(46, 72)
```

A somewhat more efficient method is to create a regridder function. This has the advantage that the mapping is created only once and can be used for multiple arrays. Also, this method can be used with data in the form of an ma.MaskedArray or NumPy array. The steps in this process are:

- Given an input grid and output grid, generate a regridder function.
- Call the regridder function on a NumPy array, resulting in an array defined on the output grid. The regridder function can be called with any array or variable defined on the input grid.

The following example illustrates this process. The regridder function is generated at line 9, and the regridding is performed at line 10:

```
1   #!/usr/bin/env python
2   import cdms2
3   from regrid2 import Regridder
4   f = cdms2.open('/pcmdi/cdms/exp/cmip2/ccc/perturb.xml')
5   rlsf = f['rls']
6   ingrid = rlsf.getGrid()
7   g = cdms2.open('/pcmdi/cdms2/exp/cmip2/mri/perturb.xml')
8   outgrid = g['rls'].getGrid()
9   regridfunc = Regridder(ingrid, outgrid)
10  rlsnew = regridfunc(rlsf)
11  f.close()
12  g.close()
```

Line	Notes
2	Makes the CDMS module available.
3	Makes the `Regridder` class available from the `regrid2` module.

Line	Notes
4	Opens the input dataset.
5	Gets the variable object named **`'rls'`**. No data is read.
6	Gets the input grid.
7	Opens a dataset to retrieve the output grid.
8	The output grid is the grid associated with the variable named **`'rls'`** in dataset **`g`**. Just the grid is retrieved, not the data.
9	Generates a regridder function **`regridfunc`**.
10	Reads all data for variable **`rlsf`**, and calls the regridder function on that data, resulting in a transient variable **`rlsnew`**.

4.1.2 SCRIP horizontal regridder

To interpolate between grids where one or both grids is non-rectangular, CDMS provides an interface to the SCRIP regridder package developed at Los Alamos National Laboratory (http://climate.lanl.gov/Software/SCRIP). Figure 3 illustrates the process:

- Obtain or generate the source and target grids in SCRIP netCDF format. A CDMS grid can be written to a netCDF file, in SCRIP format, using the **writeScripGrid** method.
- Edit the input namelist file **`scrip_in`** to reference the grids and select the method of interpolation, either conservative, bilinear, bicubic, or distance-weighted. See the SCRIP documentation for detailed instructions.
- Run the scrip executable to generate a remapping file containing the transformation coefficients.
- In CDMS, open the remapping file and create a regridder function with the **readRegridder** method.
- Call the regridder function on the input variable, defined on the source grid. The return value is the variable interpolated to the new grid. Note that the variable

may have more than two dimensions. Also note that the input arguments to the regridder function depend on the type of regridder. For example, the bicubic interpolation has additional arguments for the gradients of the variable.

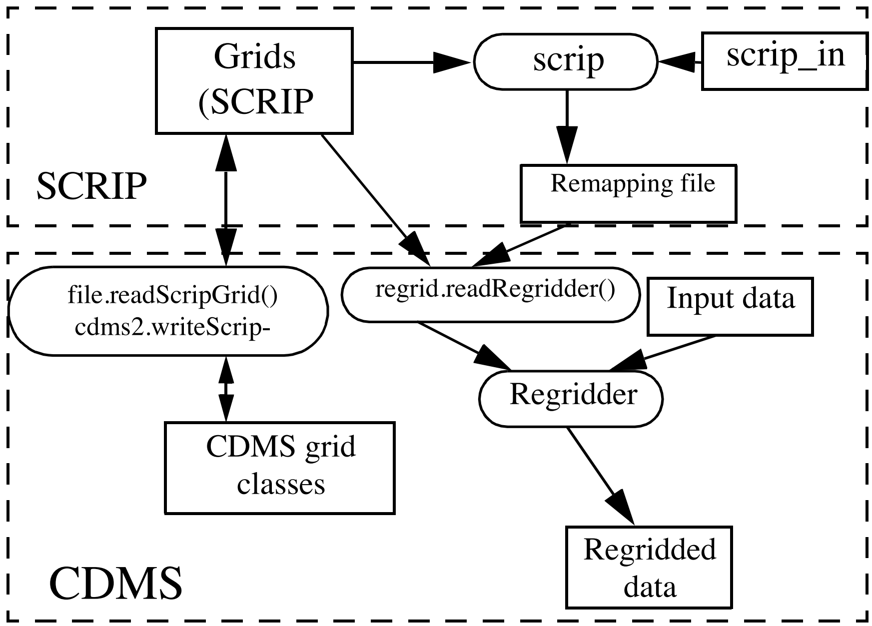


FIGURE 3. Regridding data with SCRIP

Example: Regrid data from a T42 to POP4/3 grid, using the first-order, conservative interpolator.

In this example:

- The input grid is defined in remap_grid_T42.nc.
- The output grid is defined in remap_grid_POP43.nc.
- The input data is variable src_array in file sampleT42Grid.nc.
- The file **`scrip_in`** has contents:

```
&remap_inputs
    num_maps = 1
```

```
    grid1_file = 'remap_grid_T42.nc'
    grid2_file = 'remap_grid_POP43.nc'
    interp_file1 = 'rmp_T42_to_POP43_conserv.nc'
    interp_file2 = 'rmp_POP43_to_T42_conserv.nc'
    map1_name = 'T42 to POP43 Conservative Mapping'
    map2_name = 'POP43 to T42 Conservative Mapping'
    map_method = 'conservative'
    normalize_opt = 'frac'
    output_opt = 'scrip'
    restrict_type = 'latitude'
    num_srch_bins = 90
    luse_grid1_area = .false.
    luse_grid2_area = .false.
/
```

num_maps specifies the number of mappings generated, either 1 or 2. For a single mapping, **grid1_file** and **grid2_file** are the source and target grid definitions, respectively. The **map_method** specifies the type of interpolation, either **'conservative'**, **'bilinear'**, **'bicubic'**, or **'distwgt'** (distance-weighted). The remaining parameters are described in the SCRIP documentation.

Once the grids and input file are defined, run the scrip executable to generate the remapping file **rmp_T42_to_POP43_conserv.nc**:

```
% scrip
 Using latitude bins to restrict search.
  Computing remappings between:
 T42 Gaussian Grid
                           and
 POP 4/3 Displaced-Pole T grid
 grid1 sweep
 grid2 sweep
 Total number of links =         63112
```

Next, run CDAT and create the regridder:

```
# Import regrid package for regridder functions
import regrid2, cdms2

# Read the regridder from the remapper file
remapf = cdms2.open('rmp_T42_to_POP43_conserv.nc')
regridf = regrid2.readRegridder(remapf)
remapf.close()
```

Then read the input data and regrid:

```
# Get the source variable
f = cdms2.open('sampleT42Grid.nc')
t42dat = f('src_array')
f.close()
```

```
# Regrid the source variable
popdat = regridf(dat)
```

Note that `t42dat` can have rank greater than 2. The trailing dimensions must match the input grid shape. For example, if `t42dat` has shape (12, 64, 128), then the input grid must have shape (64,128). Similarly if the variable had a generic grid with shape (8092,), the last dimension of the variable would have length 8092.

4.1.3 Pressure-level regridder

To regrid a variable which is a function of latitude, longitude, pressure level, and (optionally) time to a new set of pressure levels, use the **pressureRegrid** function defined for variables. This function takes an axis representing the target set of pressure levels, and returns a new variable d regridded to that dimension.

```
>>> var.shape
(3, 16, 32)
>>> var.getAxisIds()
['level', 'latitude', 'longitude']
>>> len(levout)
2
>>> result = var.pressureRegrid(levout)
>>> result.shape
(2, 16, 32)
```

4.1.4 Cross-section regridder

To regrid a variable which is a function of latitude, height, and (optionally) time to a new latitude/height cross-section, use the **crossSectionRegridder** defined for variables. This function takes as arguments the new latitudes and heights, and returns the variable regridded to those axes.

```
>>> varin.shape
(11, 46)
>>> varin.getAxisIds()
['level', 'latitude']
>>> levOut[:]
[   10.,   30.,   50.,   70.,  100.,  200.,  300.,  400.,  500.,
    700.,  850.,
       1000.,]
>>> varout = varin.crossSectionRegrid(levOut, latOut)
>>> varout.shape
```

```
(12, 64)
```

4.2 regrid2 module

The **regrid2** module implements the CDMS regridding functionality as well as the SCRIP interface. Although this module is not strictly a part of CDMS, it is designed to work with CDMS objects.

4.2.1 CDMS horizontal regridder

The Python command

```
from regrid2 import Regridder
```

makes the CDMS Regridder class available within a Python program. An instance of Regridder is a function which regrids data from rectangular input to output grids.

Table 4.1 CDMS Regridder Constructor

regridFunction = Regridder(inputGrid, outputGrid) Create a regridder function which interpolates a data array from input to output grid. Table 4.3 on page 129 describes the calling sequence of this function. *inputGrid* and *outputGrid* are CDMS grid objects. Note: To set the mask associated with *inputGrid* or *outputGrid*, use the grid **setMask** function.

4.2.2 SCRIP Regridder

SCRIP regridder functions are created with the **regrid.readRegridder** function :

Table 4.2 SCRIP Regridder Constructor

regridFunction = regrid.readRegridder(fileobj, mapMethod=None, checkGrid=1)
Read a regridder from an open CDMS file object.
fileobj is a CDMS file object, as returned from **cdms2.open.**
mapMethod is one of • **'conservative'** : conservative remapper, suitable where area-integrated fields such as water or heat fluxes must be conserved. • **'bilinear'** : bilinear interpolation • **'bicubic'** : bicubic interpolation • **'distwgt'** : distance-weighted interpolation.
It is only necessary to specify the map method if it is not defined in the file.
If *checkGrid* is 1 (default), the grid cells are checked for convexity, and 'repaired' if necessary. Grid cells may appear to be nonconvex if they cross a 0 / 2pi boundary. The repair consists of shifting the cell vertices to the same side modulo 360 degrees.

4.3 regridder functions

4.3.1 CDMS regridder functions

A CDMS regridder function is an instance of the CDMS Regridder class. The function is associated with rectangular input and output grids. Typically its use is straightforward: the function is passed an input array and returns the regridded array. However, when the array has missing data, or the input and/or output grids are masked, the logic becomes more complicated.

Step 1: The regridder function first forms an *input mask*. This mask is either two-dimensional or 'n-dimensional', depending on the rank of the user-supplied mask. If no mask or missing value is specified, the mask is obtained from the data array mask if present.

Two-dimensional case:

- Let *mask_1* be the two-dimensional user mask supplied via the **`mask`** argument, or the mask of the input grid if no user mask is specified.
- If a missing-data value is specified via the **`missing`** argument, let the *implicit_mask* be the two-dimensional mask defined as 0 where the first horizontal slice of the input array is missing, 1 elsewhere.
- The input mask is the logical AND(*mask_1*, *implicit_mask*)

N-dimensional case: If the user mask is 3 or 4-dimensional with the same shape as the input array, it is used as the input mask.

Step 2: The data is then regridded. In the two-dimensional case, the input mask is 'broadcast' across the other dimensions of the array. In other words, it assumes that all horizontal slices of the array have the same mask. The result is a new array, defined on the output grid. Optionally, the regridder function can also return an array having the same shape as the output array, defining the fractional area of the output array which overlaps a non-missing input grid cell. This is useful for calculating area-weighted means of masked data.

Step 3: Finally, if the output grid has a mask, it is applied to the result array. Where the output mask is 0, data values are set to the missing data value, or 1.0e20 if undefined. The result array or transient variable will have a mask value of 1 (invalid value) for those output grid cells which completely overlap input grid cells with missing values.

Table 4.3 CDMS Regridder function

Type	
Array or Transient-Variable	***regridFunction*(array, missing=None, order=None, mask=None)** Interpolate a gridded data array to a new grid. The interpolation preserves the area-weighted mean on each horizontal slice. If array is a Variable, a TransientVariable of the same rank as the input array is returned, otherwise a masked array is returned. *array* is a Variable, masked array, or NumPy array of rank 2, 3, or 4. *missing* is a Float specifying the missing data value. The default is 1.0e20. *order* is a string indicating the order of dimensions of the array. It has the form returned from **variable.getOrder()**. For example, the string "tzyx" indicates that the dimension order of *array* is (time, level, latitude, longitude). If unspecified, the function assumes that the last two dimensions of *array* match the input grid. *mask* is a NumPy array, of datatype Integer or Float, consisting of a fractional number between 0 and 1. A value of 1 or 1.0 indicates that the corresponding data value is to be ignored for purposes of regridding. A value of 0 or 0.0 indicates that the corresponding data value is valid. This is consistent with the convention for masks used by the numpy.core.ma module. A fractional value between 0.0 and 1.0 indicates the fraction of the data value (e.g., the corresponding cell) to be ignored when regridding. This is useful if a variable is regridded first to grid A and then to another grid B; the mask when regridding from A to B would be (1.0 - f) where f is the maskArray returned from the initial grid operation using the returnTuple argument. If *mask* is two-dimensional of the same shape as the input grid, it overrides the mask of the input grid. If the mask has more than two dimensions, it must have the same shape as *array*. In this case, the *missing* data value is also ignored. Such an n-dimensional mask is useful if the pattern of missing data varies with level (e.g., ocean data) or time. Note: If neither *missing* or *mask* is set, the default mask is obtained from the mask of the array if any.

Table 4.3 CDMS Regridder function

Type	
Array, Array	***regridFunction*(ar, missing=None, order=None, mask=None, returnTuple=1)** If called with the optional returnTuple argument equal to 1, the function returns a tuple (*dataArray*, *maskArray*). *dataArray* is the result data array. *maskArray* is a Float32 array of the same shape as *dataArray*, such that *maskArray*[i,j] is fraction of the output grid cell [i,j] overlapping a non-missing cell of the input grid.

4.3.2 SCRIP Regridder functions

A SCRIP regridder function is an instance of the ScripRegridder class. Such a function is created by calling the **regrid.readRegridder** method. Typical usage is straightforward:

```
>>> regridf = regrid2.readRegridder(remap_file)
>>> outdat = regridf(indat)
```

The bicubic regridder takes four arguments:

```
>>> outdat = regridf(indat, gradlat, gradlon, gradlatlon)
```

A regridder function also has associated methods to retrieve the following fields:

- Input grid
- Output grid
- Source fraction: the fraction of each source (input) grid cell participating in the interpolation.
- Destination fraction: the fraction of each destination (output) grid cell participating in the interpolation.

In addition, a conservative regridder has the associated grid cell areas for source and target grids.

Table 4.4 SCRIP Regridder functions

Return Type	
Array or Transient-Variable	**[conservative, bilinear, and distance-weighted regridders]** ***regridFunction*(array)** Interpolate a gridded data array to a new grid. The return value is the regridded data variable. *array* is a Variable, MaskedArray, or NumPy array. The rank of the array may be greater than the rank of the input grid, in which case the input grid shape must match a trailing portion of the array shape. For example, if the input grid is curvilinear with shape (64,128), the last two dimensions of the array must match. Similarly, if the input grid is generic with shape (2560,), the last dimension of the array must have that length.

Table 4.4 SCRIP Regridder functions

Return Type	
Array or Transient-Variable	**[bicubic regridders]** ***regridFunction*(array, gradientLat, gradientLon, gradientLatLon)** Interpolate a gridded data array to a new grid, using a bicubic regridder. The return value is the regridded data variable. *array* is a Variable, MaskedArray, or NumPy array. The rank of the array may be greater than the rank of the input grid, in which case the input grid shape must match a trailing portion of the array shape. For example, if the input grid is curvilinear with shape (64,128), the last two dimensions of the array must match. Similarly, if the input grid is generic with shape (2560,), the last dimension of the array must have that length. *gradientLat*: df/di (see the SCRIP documentation). Same shape as *array*. *gradientLon*: df/dj. Same shape as *array*. *gradientLatLon*: d(df)/(di)(dj). Same shape as *array*.
NumPy array	**getDestinationArea**() **[conservative regridders only]** Return the area of the destination (output) grid cell. The array is 1-D, with length equal to the number of cells in the output grid.
NumPy array	**getDestinationFraction**() Return the area fraction of the destination (output) grid cell that participates in the regridding. The array is 1-D, with length equal to the number of cells in the output grid.
CurveGrid or Generic-Grid	**getInputGrid**() Return the input grid, or None if no input grid is associated with the regridder.

Table 4.4 SCRIP Regridder functions

Return Type	
CurveGrid or Generic-Grid	**getOutputGrid**() Return the output grid.
NumPy array	**getSourceArea**() **[conservative regridders only]** Return the area of the source (input) grid cell. The array is 1-D, with length equal to the number of cells in the input grid.
NumPy array	**getSourceFraction**() Return the area fraction of the source (input) grid cell that participates in the regridding. The array is 1-D, with length equal to the number of cells in the input grid.

4.4 Examples

4.4.1 CDMS regridder

Example: Regrid data to a uniform output grid.

```
#!/usr/local/bin/python
import cdms2
from regrid2 import Regridder
f = cdms2.open('rls_ccc_per.nc')
rlsf = f.variables['rls']
ingrid = rlsf.getGrid()
outgrid = cdms2.createUniformGrid(90.0, 46, -4.0, 0.0, 72,
 5.0)
regridFunc = Regridder(ingrid, outgrid)
newrls = regridFunc(rlsf)
```

```
10  f.close()
```

Line	Notes
4	Open a netCDF file for input.
7	Create a 4 x 5 degree output grid. Note that this grid is not associated with a file or dataset
8	Create the regridder function
9	Read all data and regrid. The missing data value is obtained from variable rlsf.

Example: Get a mask from a separate file, and set as the input grid mask.

```
 1  import cdms2
 2  from regrid2 import Regridder
 3  #
 4  f = cdms2.open('so_ccc_per.nc')
 5  sof = f.variables['so']
 6  ingrid = sof.getGrid()
 7  g = cdms2.open('rls_mri_per.nc')
 8  rlsg = g.variables['rls']
 9  outgrid = rlsg.getGrid()
10  regridFunc = Regridder(ingrid,outgrid)
11  h = cdms2.open('sft_ccc.nc')
12  sfmaskvar = h.variables['sfmask']
13  sfmask = sfmaskvar[:]
14  outArray = regridFunc(sof.subSlice(time=0),mask=sfmask)
15  f.close()
16  g.close()
17  h.close()
```

Line	Notes
6	Get the input grid.

Line	Notes
9	Get the output grid
10	Create the regridder function.
13	Get the mask.
14	Regrid with a user mask. The subslice call returns a transient variable corresponding to variable sof at time 0. Note: Although it cannot be determined from the code, both **`mask`** and the input array **`sof`** are four-dimensional. This is the ‘n-dimensional’ case.

Example: Generate an array of zonal mean values.

```
1  f = cdms2.open('rls_ccc_per.nc')
2  rlsf = f.variables['rls']
3  ingrid = rlsf.getGrid()
4  outgrid = cdms2.createZonalGrid(ingrid)
5  regridFunc = Regridder(ingrid,outgrid)
6  mean = regridFunc(rlsf)
7  f.close()
```

Line	Notes
3	Get the input grid.
4	Create a zonal grid. **`outgrid`** has the same latitudes as **`ingrid`**, and a singleton longitude dimension. **createGlobalMeanGrid** could be used here to generate a global mean array.
5	Generate the regridder function.

Line	Notes
6	Generate the zonal mean array.

Example: Regrid an array with missing data, and calculate the area-weighted mean of the result.

```
 1  from cdms2.MV import *
    ...
 2  outgrid = cdms2.createUniformGrid(90.0, 46, -4.0, 0.0, 72,
    5.0)
 3  outlatw, outlonw = outgrid.getWeights()
 4  outweights = outerproduct(outlatw, outlonw)
 5  grid = var.getGrid()
 6  sample = var[0,0]
 7  latw, lonw = grid.getWeights()
 8  weights = outerproduct(latw, lonw)
 9  inmask = where(greater(absolute(sample),1.e15),0,1)
10  mean = add.reduce(ravel(inmask*weights*sample))/
    add.reduce(ravel(inmask*weights))
11  regridFunc = Regridder(grid, outgrid)
12  outsample, outmask = regridFunc(sample, mask=inmask,
    returnTuple=1)
13  outmean = add.reduce(ravel(outmask*outweights*outsample))/
    add.reduce(ravel(outmask*outweights))
```

Line	Notes
2	Create a uniform target grid.
3	Get the latitude and longitude weights.
4	Generate a 2-D weights array.
5	Get the input grid. **`var`** is a 4-D variable.
6	Get the first horizontal slice from **`var`**.

Line	Notes
7-8	Get the input weights, and generate a 2-D weights array.
9	Set the 2-D input mask.
10	Calculate the input array area-weighted mean.
11	Create the regridder function.
12	Regrid. Because **returnTuple** is set to 1, the result is a tuple (dataArray, maskArray).
13	Calculate the area-weighted mean of the regridded data. **mean** and **outmean** should be approximately equal.

4.4.2 SCRIP regridder

Example: Regrid from a curvilinear to a generic grid, using a conservative remapping. Compute the area-weighted means on input and output for comparison.

```
import cdms2, regrid2, numpy.core.ma as MA

# Open the SCRIP remapping file and data file
direc = ''
fremap = cdms2.open(direc+'rmp_T42_to_C02562_conserv.nc')
fdat = cdms2.open(direc+'sampleT42Grid.nc')

# Input data array
dat = fdat('src_array')

# Read the SCRIP regridder
regridf = regrid2.readRegridder(fremap)

# Regrid the variable
outdat = regridf(dat)

# Get the cell area and fraction arrays. Areas are computed only
# for conservative regridding.
srcfrac = regridf.getSourceFraction()
srcarea = regridf.getSourceArea()
dstfrac = regridf.getDestinationFraction()
dstarea = regridf.getDestinationArea()

# Calculate area-weighted means
inmean = MA.sum(srcfrac*srcarea*MA.ravel(dat)) / MA.sum(srcfrac*srcarea)
outmean = MA.sum(dstfrac*dstarea*MA.ravel(outdat)) / MA.sum(dstfrac*dstarea)
print 'Input mean:', inmean
print 'Output mean:', outmean
```

```
fremap.close()
fdat.close()
```

CHAPTER 5

Plotting CDMS data in Python

5.1 Overview

Data read via the CDMS Python interface can be plotted using the **vcs** module. This module, part of the Climate Data Analysis Tool (CDAT) is documented in the CDAT reference manual. The **vcs** module provides access to the functionality of the VCS visualization program.

Examples of plotting data accessed from CDMS are given below, as well as documentation for the **plot** routine keywords.

5.2 Examples

In the following examples, it is assumed that variable `psl` is dimensioned (time, latitude, longitude). `psl` is contained in the dataset named `'sample.xml'`.

5.2.1 Example: plotting a gridded variable

```
import cdms2, vcs
#
```

```
3  f = cdms2.open('sample.xml')
4  psl = f.variables['psl']
5  sample = psl[0]
6  w=vcs.init()
7  #
8  w.plot(sample)
9  f.close()
```

Notes:

Line	Notes
5	Get a horizontal slice, for the first timepoint.
6	Create a VCS Canvas **`w`**.
8	Plot the data. Because **`sample`** is a transient variable, it encapsulates all the time, latitude, longitude, and attribute information.
9	Close the file. This must be done after the reference to the persistent variable **`psl`**.

That's it! The axis coordinates, variable name, description, units, etc. are obtained from variable **`sample`**.

What if the units are not explicitly defined for **`psl`**, or a different description is desired? **plot** has a number of other keywords which 'fill in' the extra plot information.

5.2.2 Example: using plot keywords.

```
w.plot(array, units='mm/day', file_comment='High-frequency
    reanalysis', long_name="Sea level pressure", comment1="Sample
    plot", hms="18:00:00", ymd="1978/01/01")
```

Note: Keyword arguments can be listed in any order.

5.2.3 Example: plotting a time-latitude slice

Assuming that variable **psl** has domain (time,latitude,longitude), this example selects and plots a time-latitude slice:

```
1  samp = psl[:,:,0]
2  w = vcs.init()
3  w.plot(samp, name='sea level pressure')
```

Notes:

Line	Notes
1	**samp** is a slice of psl, at index 0 of the last dimension. Since **samp** was obtained from the slice operator, it is a transient variable, which includes the latitude and time information.
3	The **name** keyword defines the identifier, by default the name in the file.

5.2.4 Example: plotting subsetted data

Calling the variable **psl** as a function reads a subset of the variable. The result variable **samp** can be plotted directly:

```
...
samp = psl(time=(0.0,100.0), longitude=180.0)
w = vcs.init()
w.plot(samp)
```

5.3 plot method

The **plot** method is documented in the CDAT Reference Manual. This section augments the documentation with a description of the optional keyword arguments.

The general form of the plot command is:

canvas.**plot**(*array* [, *args*] [,*key=value* [, *key=value* [, ...]]])

where:

- *canvas* is a VCS Canvas object, created with the **vcs.init** method.
- *array* is a variable, masked array, or NumPy array having between two and five dimensions. The last dimensions of the array is termed the 'x' dimension, the next-to-last the 'y' dimension, then 'z', 't', and 'w'. For example, if *array* is three-dimensional, the axes are (z,y,x), and if *array* is four-dimensional, the axes are (t,z,y,x). (Note that the 't' dimension need have no connection with time; any spatial axis can be mapped to any plot dimension. For a graphics method which is two-dimensional, such as boxfill, the y-axis is plotted on the horizontal, and the x-axis on the vertical.

  If array is a gridded variable on a rectangular grid, the plot function uses a boxfill graphics method. If it is non-rectangular, the meshfill graphics method is used.

  Note that some plot keywords apply only to rectangular grids only.
- *args* are optional positional arguments:

  args := *template_name, graphics_method, graphics_name*

template_name:	the name of the VCS template (e.g., 'AMIP')
graphics_method :	the VCS graphics method ('boxfill')
graphics_name:	the name of the specific graphics method ('default')

  See the CDAT Reference Manual and VCS Reference Manual for a detailed description of these arguments.
- *key=value*, ... are optional keyword/value pairs, listed in any order. These are defined in Table 5.1 on page 143.

Table 5.1 plot keywords

key	type	value
comment1	string	Comment plotted above file_comment
comment2	string	Comment plotted above comment1
comment3	string	Comment plotted above comment2
continents	0 or 1	if ==1, plot continental outlines (default: plot if xaxis is longitude, yaxis is latitude -or- xname is ’longitude’ and yname is ’latitude’
file_comment	string	Comment, defaults to variable.parent.comment)
grid	CDMS grid object	Grid associated with the data. Defaults to variable.getGrid()
hms	string	Hour, minute, second
long_name	string	Descriptive variable name, defaults to variable.long_name.
missing_value	same type as array	Missing data value, defaults to variable.getMissing()
name	string	Variable name, defaults to variable.id
time	cdtime relative or absolute time	time associated with the data. Example: cdtime.reltime(30.0, “days since 1978-1-1”)
units	string	Data units. Defaults to variable.units

Table 5.1 plot keywords

key	type	value
variable	CDMS variable object	Variable associated with the data. The variable grid must have the same shape as the data array.
xarray ([y|z|t|w]array)	1-D NumPy array	[rectangular grids only] Array of coordinate values, having the same length as the corresponding dimension. Defaults to xaxis[:] (y|z|t|waxis[:])
xaxis ([y|z|t|w]axis)	CDMS axis object	[rectangular grids only] Axis object. **xaxis** defaults to grid.getAxis(0), **yaxis** defaults to grid.getAxis(1)
xbounds (ybounds)	2-D NumPy array	[rectangular grids only] Boundary array of shape (n,2) where n is the axis length. Defaults to xaxis.getBounds(), or xaxis.genGenericBounds() if None, similarly for **ybounds**.
xname ([y|z|t|w]name)	string	[rectangular grids only] Axis name. Defaults to xaxis.id ([y|z|t|w]axis.id)

Table 5.1 **plot keywords**

key	type	value
xrev (yrev)	0 or 1	If **xrev** (**yrev**) is 1, reverse the direction of the x-axis (y-axis). Defaults to 0, with the following exceptions: • If the y-axis is latitude, and has decreasing values, yrev defaults to 1 • If the y-axis is a vertical level, and has increasing pressure levels, yrev defaults to 1.
xunits ([y|z|t|w]units)	string	[rectangular grids only] Axis units. Defaults to xaxis.units ([y|z|t|w]axis.units).

CHAPTER 6

Climate Data Markup Language (CDML)

6.1 Introduction

The Climate Data Markup Language (CDML) is the markup language used to represent metadata in CDMS. CDML is based on the W3C XML standard (http://www.w3.org). This chapter defines the syntax of CDML. Read this section if you will be building or maintaining a CDMS database.

XML, the eXtensible Markup Language, makes it possible to define interoperable dialects of markup languages. The most recent version of HTML, the Web hypertext markup language, is an XML dialect. CDML is also an XML dialect, geared toward the representation of gridded climate datasets. XML provides rigor to the metadata representation, ensuring that applications can access it correctly. XML also deals with internationalization issues, and holds forth the promise that utilities for browsing, editing, and other common tasks will be available in the future.

CDML files have the file extension **.xml** or **.cdml**.

6.2 *Elements*

A CDML document consists of a nested collection of *elements*. An *element* is a description of the metadata associated with a CDMS object. The form of an element is:

```
<tag attribute-list> element-content </tag>

or

<tag attribute-list />
```

where

- `tag` is a string which defines the type of element
- `attribute-list` is a blank-separated list of attribute-value pairs, of the form:

  `attribute = "value"`

- `element-content` depends on the type of element. It is either a list of elements, or text which defines the element values. For example, the content of an axis element either is a list of axis values, or is a **linear** element. For datasets, the content is the blank-separated list of elements corresponding to the axes, grids, and variables contained in the dataset.

The CDML elements are:

Table 6.1 CDML Tags

Tag	Description
attr	Extra attribute
axis	Coordinate axis
domain	Axes on which a variable is defined
domElem	Element of a variable domain
linear	Linearly-spaced axis values

Table 6.1 CDML Tags

Tag	Description
rectGrid	Rectilinear Grid
variable	Variable

6.3 Special Characters

XML reserves certain characters for markup. If they appear as content, they must be encoded to avoid confusion with markup:

Table 6.2 Special Character Encodings

Character	Encoding
<	&lt
>	&gt
&	&amp
“	&quot
‘	&apos

For example, the comment

```
Certain “special characters”, such as <, >, and ‘, must
be encoded.
```

would appear in an attribute string as:

```
comment = “Certain &quotspecial characters&quot, such
as &lt, &gt, and &apos, must be encoded.”
```

6.4 Identifiers

In CDMS, all objects in a dataset have a unique string *identifier*. The **id** attribute holds the value of this identifier. If the variable, axis, or grid has a string name within a data file, then the **id** attribute ordinarily has this value. Alternatively, the name of the object in a data file can be stored in the **name_in_file** attribute, which can differ from the **id**. Datasets also have IDs, which can be used within a larger context (databases).

An identifer must start with an alphabetic character (upper or lower case), an underscore (_), or a colon (:). Characters after the first must be alphanumeric, an underscore, or colon. There is no restriction on the length of an identifier.

6.5 CF Metadata Standard

The CF metadata standard (http://www.cgd.ucar.edu/cms/eaton/netcdf/CF-current.htm) defines a set of conventions for usage of netCDF. This standard is supported by CDML. The document defines names and usage for metadata attributes. CF supersedes the GDT 1.3 standard.

6.6 CDML Syntax

The following notation is used in this section:

- `Courier font` is used for a syntax specification. **`Bold font`** highlights literals.
- `(R|S)` denotes 'either R or S'.
- `R*` denotes 'zero or more R'.
- `R+` denotes 'one or more R'.

A CDML document consists of a prolog followed by a single dataset element.

1. `CDML-document ::=  prolog dataset-element`

The prolog defines the XML version, and the Document Type Definition (DTD), a formal specification of the document syntax. See http://www.w3.org/TR/1998/REC-xml-19980210 for a formal definition of XML Version 1.0.

2.
```
prolog ::=
<?xml version="1.0"?>
<!DOCTYPE dataset SYSTEM "http://www-pcmdi.llnl.gov/
~drach/cdms/cdml.dtd">
```

6.6.1 Dataset Element

A dataset element describes a single dataset. The content is a list of elements corresponding to the axes, grids, and variables contained in the dataset. Axis, variable, and grid elements can be listed in any order, and an element ID can be used before the element is actually defined.

3.
```
dataset-element ::= <dataset dataset-attributes>
dataset-content </dataset>
```

4.
```
dataset-content ::= (axis-element | grid-element |
variable-element)* extra-attribute-element+
```

Table 6.3 Dataset Attributes

Attribute	Required	CF	GDT	Notes
appendi-ces	N	N	Y	Version number
calendar	N	N	Y	Calendar used for encoding time axes. “gregorian” | “julian” | “noleap” | “360_day” | “proleptic_gregorian” | “standard” Note: for the CF convention, the calendar attribute is placed on the time axis.
comment	N	Y	Y	Additional dataset information

Table 6.3 Dataset Attributes

Attribute	Required	CF	GDT	Notes
Conventions	Y	Y	Y	The netCDF metadata standard. Example: “CF-1.0”
cdms_filemap	Y	N	N	Map of partitioned axes to files. See note below.
directory	N	N	N	Root directory of the dataset
frequency	N	N	N	Temporal frequency
history	N	Y	Y	Evolution of the data
id	Y	N	N	Dataset identifier
institution	N	Y	Y	Who made or supplied the data
production	N	N	Y	How the data was produced (see source)
project	N	N	N	Project associated with the data Example: “CMIP 2”
references	N	Y	N	Published or web-based references that describe the data or methods used to produce it.
source	N	Y	N	The method of production of the original data.
template	N	N	N	Filename template. This is an alternate mechanism, other than cdms_filemap, for describing the file mapping. See ‘cdimport -h’ for details.
title	N	Y	N	A succinct description of the data.

Notes:

- The cdms_filemap attribute describes how the dataset is partitioned into files. The format is:

```
filemap ::= [ varmap, varmap, ...]
varmap ::= [ namelist, slicelist ]
namelist ::= [ name, name, ... ]
```

```
slicelist ::= [ indexlist, indexlist, ,,, ]
indexlist ::= [ time0, time1, lev0, lev1, path ]
```

`name` ::= variable name
`time0` ::= first index of time in the file, or '-' if not split on time
`time1` ::= last index of time + 1, in the file, or '-' if not split on time
`lev0` ::= first index of vertical levels in the file, or '-' if not split on level
`lev1` ::= last index +1 of vertical levels in the file, or '-' if not split on level
`path` ::= pathname of the file containing data for this time/level range.

The pathname is appended to the value of the directory attribute, to obtain an absolute pathname.

6.6.2 Axis Element

An axis element describes a single coordinate axis. The content can be a blank-separated list of axis values or a linear element. A linear element is a representation of a linearly-spaced axis as (start, delta, length).

5. `axis-element ::= <axis axis-attributes> axis-content> </axis>`
6. `axis-content ::= (axis-values | linear-element) extra-attribute-element*`
7. `axis-values ::= [value*]`
8. `linear-element ::= <linear delta="value" length="Integer" start="value"> </linear>`

Table 6.4 Axis Attributes

Attribute	Required?	CF	GDT	Notes
associate	N	N	Y	IDs of variables containing alternative sets of coordinates.
axis	N	Y	Y	The spatial type of the axis: "T" - time "X" - longitude "Y" - latitude "Z" - vertical level "-" - not spatiotemporal
bounds	N	Y	Y	ID of the boundary variable
calendar	N	Y	N	See dataset.calendar
climatology	N	Y	N	Range of dates to which climatological statistics apply.
comment	N	Y	N	String comment
compress	N	Y	Y	Dimensions which have been compressed by gathering
datatype	Y	N	N	Char, Short, Long, Float, Double, or String
dates	N	Y	N	Range of dates to which statistics for a typical diurnal cycle apply.
expand	N	N	Y	Coordinates prior to contraction
formula_terms	N	Y	N	Variables that correspond to the terms in a formula.
id	Y	N	N	Axis identifier. Also the name of the axis in the underlying file(s), if **name_in_file** is undefined.

Table 6.4 Axis Attributes

Attribute	Requ ired?	CF	GDT	Notes
isvar	N	N	N	“true” | “false” “false” if the axis does not have coordinate values explicitly defined in the underlying file(s). Default: “true”
leap_month	N	Y	N	For a user-defined calendar, the month which is lengthened by a day in leap years.
leap_year	N	Y	N	An example of a leap year for a user-defined calendar. All years that differ from this year by a multiple of four are leap years.
length	N	N	N	Number of axis values, including values for which no data is defined. Cf. **partition_length**.
long_name	N	Y	Y	Long description of a physical quantity
modulo	N	N	Y	Arithmetic modulo of an axis with circular topology.
month_lengths	N	Y	N	Length of each month in a non-leap year for a user-defined calendar.
name_in_file	N	N	N	Name of the axis in the underlying file(s). See id.
partition	N	N	N	How the axis is split across files.
partition_length	N	N	N	Number of axis points for which data is actually defined. If data is missing for some values, this will be smaller than the **length**.
positive	N	Y	Y	Direction of positive for a vertical axis
standard_name	N	Y	N	Reference to an entry in the standard name table.

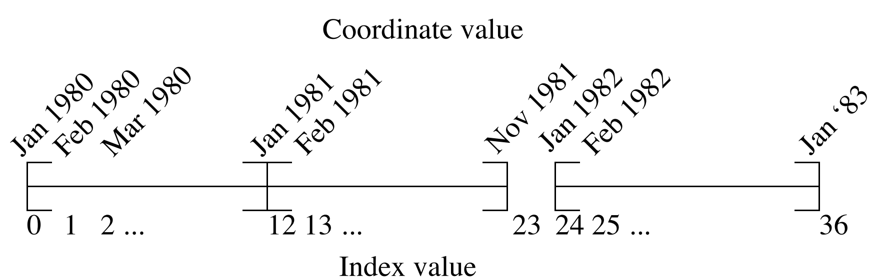
Table 6.4 Axis Attributes

Attribute	Required?	CF	GDT	Notes
topology	N	N	Y	Axis topology. “circular” | “linear”
units	Y	Y	Y	Units of a physical quantity
weights	N	N	N	Name of the weights array

6.6.3 partition attribute

For an axis in a dataset, the **.partition** attribute describes how an axis is split across files. It is a list of the start and end indices of each axis partition.

FIGURE 4. Partitioned axis



For example, Figure 4 shows a time axis, representing the 36 months, January 1980 through December 1982, with December 1981 missing. The first partition interval is (0,12), the second is (12,23), and the third is (24,36), where the interval (i,j) represents all indices k such that i <= k < j. The .partition attribute for this axis would be the list:

```
[0, 12, 12, 23, 24, 36]
```

Note that the end index of the second interval is strictly less than the start index of the following interval. This indicates that data for that period is missing.

6.6.4 Grid Element

A grid element describes a horizontal, latitude-longitude grid which is rectilinear in topology,

9. `grid-element ::= <rectGrid grid-attributes> extra-attribute-element* </rectGrid>`

Table 6.5 RectGrid Attributes

Attribute	Required?	GDT?	Notes
id	Y	N	Grid identifier
type	Y	N	Grid classification “gaussian” | “uniform” | “equalarea” | “generic” Default: “generic”
latitude	Y	N	Latitude axis name
longitude	Y	N	Longitude axis name
mask	N	N	Name of associated mask variable
order	Y	N	Grid ordering “yx” | “xy” Default: “yx”, axis order is latitude, longitude

6.6.5 Variable Element

A variable element describes a data variable. The domain of the variable is an ordered list of *domain elements* naming the axes on which the variable is defined. A domain element is a reference to an axis or grid in the dataset.

The **length** of a domain element is the number of axis points for which data can be retrieved. The **partition_length** is the number of points for which data is actually defined. If data is missing, this is less than the **length**.

10. `variable-element ::= <variable variable-attributes> variable-content </variable>`
11. `variable-content ::= variable-domain extra-attribute-element*`
12. `variable-domain ::= <domain> domain-element* </domain>`
13. `domain-element ::= <domElem name="axis-name" start="Integer" length="Integer" partition_length="Integer"/>`

Table 6.6 Variable Attributes

Attribute	Required?	CF	GDT	Notes
id	Y	N	N	Variable identifier. Also, the name of the variable in the underlying file(s), if **name_in_file** is undefined.
add_offset	N	Y	Y	Additive offset for packing data. See **scale_factor**.
associate	N	N	Y	IDs of variables containing alternative sets of coordinates
axis	N	N	Y	Spatio-temporal dimensions. Ex: “TYX” for a variable with domain (time, latitude, longitude) Note: for CF, applies to axes only.
cell_methods	N	Y	N	The method used to derive data that represents cell values, e.g., “maximum”, “mean”, “variance”, etc.
comments	N	N	N	Comment string

Table 6.6 Variable Attributes

Attribute	Requi red?	CF	GDT	Notes
coordinates	N	Y	N	IDs of variables containing coordinate data.
datatype	Y	N	N	Char, Short, Long, Float, Double, or String
grid_name	N	N	N	Id of the grid
grid_type	N	N	N	"gaussian" | "uniform" | "equalarea" | "generic"
long_name	N	Y	Y	Long description of a physical quantity.
missing_value	N	Y	Y	Value used for data that are unknown or missint.
name_in_file	N	N	N	Name of the variable in the underlying file(s). See id.
scale_factor	N	Y	Y	Multiplicative factor for packing data. See **add_offset**.
standard_name	N	Y	N	Reference to an entry in the standard name table.
subgrid	N	N	Y	Records how data values represent subgrid variation.
template	N	N	N	Name of the file template to use for this variable. Overrides the dataset value.
units	N	Y	Y	Units of a physical quantity.
valid_max	N	Y	Y	Largest valid value of a variable
valid_min	N	Y	Y	Smallest valid value of a variable
valid_range	N	Y	Y	Largest and smallest valid values of a variable

6.6.6 Attribute Element

Attributes which are not explicitly defined by the GDT convention are represented as extra attribute elements. Any dataset, axis, grid, or variable element can have an extra attribute as part of its content. This representation is also useful if the attribute value has non-blank whitespace characters (carriage returns, tabs, linefeeds) which are significant.

The datatype is one of: Char, Short, Long, Float, Double, or String.

14. `extra-attribute-element ::=` **`<attr name=`**`attribute-name` **`datatype=`**`"attribute-datatype"`**`>`** `attribute-value` **`</attr>`**

6.7 A Sample CDML Document

Dataset 'sample' has two variables, and six axes.

Note:

- The file is indented for readability. This is not required; the added whitespace is ignored.
- The dataset contains three axes and two variables. Variables u and v are functions of time, latitude, and longitude.
- The global attribute cdms_filemap describes the mapping between variables and files. The entry **`[[u],[[0,1,-,-,u_2000.nc],[1,2,-,-,u_2001.nc],[2,3,-,-,u_2002.nc]]`** indicates that variable u is contained in file u_2000.nc for time index 0, u_2001.nc for time index 1, etc.

```
<?xml version="1.0"?>
<?xml version="1.0"?>
<!DOCTYPE dataset SYSTEM "http://www-pcmdi.llnl.gov/software/cdms/cdml.dtd">
<dataset
    Conventions="CF-1.0"
    id  ="sample"
    calendar="gregorian"
    directory=""
    cdms_filemap="[[[u],[[0,1,-,-,u_2000.nc],[1,2,-,-,u_2001.nc],[2,3,-,-
        ,u_2002.nc]]],[[v],[[0,1,-,-,v_2000.nc],[1,2,-,-,v_2001.nc],[2,3,-,-
        ,v_2002.nc]]]]"
    history="
[2002-1-7 18:21:41] /idoru/cdat/3.1/bin/cdscan -d sample -x sample.xml u_2000.nc
```

```
    u_2001.nc u_2002.nc v_2000.nc v_2001.nc v_2002.nc"
>
<axis
    id  ="latitude"
    length="16"
    units="degrees_north"
    datatype="Double"
    >
    [-90. -78. -66. -54. -42. -30. -18.  -6.   6.  18.  30.  42.  54.  66.
    78.
   90.]
    </axis>
<axis
    id  ="longitude"
    length="32"
    units="degrees_east"
    datatype="Double"
    >
    [   0.     11.25   22.5    33.75   45.     56.25   67.5    78.75   90.
   101.25  112.5   123.75  135.    146.25  157.5   168.75  180.    191.25
   202.5   213.75  225.    236.25  247.5   258.75  270.    281.25  292.5
   303.75  315.    326.25  337.5   348.75]
    </axis>
<axis
    id  ="time"
    partition="[0 1 1 2 2 3]"
    calendar="gregorian"
    units="days since 2000-1-1"
    datatype="Double"
    length="3"
    name_in_file="time"
    >
    [   0.  366.  731.]
    </axis>
<variable
    id  ="u"
    missing_value="-99.9"
    units="m/s"
    datatype="Double"
    >
    <domain
        >
        <domElem name="time" length="3" start="0"/>
        <domElem name="latitude" length="16" start="0"/>
        <domElem name="longitude" length="32" start="0"/>
        </domain>
    </variable>
<variable
    id  ="v"
    missing_value="-99.9"
    units="m/s"
    datatype="Double"
    >
    <domain
        >
        <domElem name="time" length="3" start="0"/>
        <domElem name="latitude" length="16" start="0"/>
        <domElem name="longitude" length="32" start="0"/>
        </domain>
    </variable>
</dataset>
```

CHAPTER 7

CDMS Utilities

7.1 cdscan: Importing datasets into CDMS

7.1.1 Overview

A dataset is a partitioned collection of files. To create a dataset, the files must be scanned to produce a text representation of the dataset. CDMS represents datasets as an XML metafile in the CDML markup language. The file contains all metadata, together with information describing how the dataset is partitioned into files. (Note: CDMS provides a direct interface to individual files as well. It is not necessary to scan an individual file in order to access it.)

For CDMS applications to work correctly, it is important that the CDML metafile be valid. The **cdscan** utility generates a metafile from a collection of data files.

CDMS assumes that there is some regularity in how datasets are partitioned:

- A variable can be partitioned (split across files) in at most two dimensions. The partitioned dimension(s) must be either time or vertical level dimensions; variables may not be partitioned across longitude or latitude. Datasets can be partitioned by variable as well. For example, one set of files might contain heat fluxes, while another set contains wind speeds.

Otherwise, there is considerable flexibility in how a dataset can be partitioned:

- Files can contain a single variable or all variables in the dataset.
- The time axis can have gaps.
- Horizontal grid boundary information and related information can be duplicated across files.
- Variables can be on different grids.
- Files may be in any of the self-describing formats supported by CDMS, including netCDF, HDF, GrADS/GRIB, DRS, and UK Met Office PP format.

7.1.2 cdscan Syntax

The syntax of the cdscan command is

cdscan [*options*] *file1 file2* ...

or

cdscan [options] **-f** *file_list*

where

- *file1 file2* .. is a blank-separated list of files to scan
- *file_list* is the name of a file containing a list of files to scan, one pathname per line.

Output is written to standard output by default. Use the -x option to specify an output filename.

Table 7.1 cdscan command options

Option	Description
-a alias_file	Change variable names to the aliases defined in an alias file. Each line of the alias file consists of two blank separated fields: **`variable_id alias`**. **`variable_id`** is the ID of the variable in the file, and **`alias`** is the name that will be substituted for it in the output dataset. Only variables with entries in the alias_file are renamed.
-c *calendar*	Specify the dataset calendar attribute. One of "**`gregorian`**" (default), "**`julian`**", "**`noleap`**", **`“proleptic_gregorian”`**, **`“standard”`**, or "**`360_day`**".
-d *dataset_id*	String identifier of the dataset. Should not contain blanks or non-printing characters. Default: "**`none`**"
-e *newattr*	Add or modify attributes of a file, variable, or axis. The form of *newattr* is either: **`var.attr = value`** to modify a variable or attribute, or **`.attr = value`** to modify a global (file) attribute. In either case, **`value`** may be quoted to preserve spaces or force the attribute to be treated as a string. If **`value`** is not quoted and the first character is a digit, it is converted to integer or floating-point. This option does not modify the input datafiles. See notes and examples below.
--exclude *var,var,...*	Exclude specified variables. The argument is a comma-separated list of variables containing no blanks. Also see --include.

Table 7.1 cdscan command options

Option	Description
--exclude-file *pattern*	Exclude files with a basename matching the regular expression pattern. In contrast to --exclude, this skips the file entirely. Multiple patterns may be listed by separating with vertical bars (e.g. abc|def). Note that the match is to the initial part of the basename. For example, the pattern 'st' matches any basename starting with 'st'.
-f *file_list*	File containing a list of absolute data file names, one per line.
-h	Print a help message.
-i *time_delta*	Causes the time dimension to be represented as linear, producing a more compact representation. This is useful if the time dimension is very long. *time_delta* is a float or integer. For example, if the time delta is 6 hours, and the reference units are '**`hours since xxxx'`** , set the time delta to 6. See the -r option. See Note 2.
--ignore-open-error	Ignore open errors. Print a warning and continue.
--include *var,var,...*	Only include specified variables in the output. The argument is a comma-separated list of variables containing no blanks. Also see --exclude.
--include-file pattern	Only include files with a basename matching the regular expression pattern. In contrast to --include, this skips files entirely if they do not match the pattern. Multiple patterns may be listed by separating with vertical bars (e.g. abc|def). Note that the match is to the initial part of the basename. For example, the pattern 'st' matches any basename starting with 'st'.

Table 7.1 cdscan command options

Option	Description
-j	scan time as a vector dimension. Time values are listed individually. Turns off the -i option. The time dimension must be monotonic; the scanned time dimension will have no gaps.
-l *levels*	Specify that the files are partitioned by vertical level. That is, data for different vertical levels may appear in different files. *levels* is a comma-separated list of levels containing no blanks. See Note 3.
-m *levelid*	name of the vertical level dimension. The default is the vertical dimension as determined by CDMS. See Note 3.
--notrim-lat	Don't trim latitude values (in degrees) to the range [-90..90]. By default latitude values are trimmed.
-p *template*	Add a file template string, for compatibility with pre-V3.0 datasets. 'cdimport -h' describes template strings.
-q	Quiet mode.
-r *time_units*	time units of the form "**`units since yyyy-mm-dd hh:mi:ss`**", where *units* is one of **`"year", "month", "day", "hour", "minute", "second"`**.
-s *suffix_file*	Append a suffix to variable names, depending on the directory containing the data file. This can be used to distinguish variables having the same name but generated by different models or ensemble runs. 'suffix_file' is the name of a file describing a mapping between directories and suffixes. Each line consists of two blank-separated fields: **`directory suffix`**. Each file path is compared to the directories in the suffix file. If the file path is in that directory or a subdirectory, the corresponding suffix is appended to the variable IDs in the file. If more than one such directory is found, the first directory found is used. If no match is made, the variable ids are not altered. Regular expressions can be used: see the example in the Notes section.

Table 7.1 cdscan command options

Option	Description
-t *timeid*	id of the partitioned time dimension. The default is the name of the time dimension as determined by CDMS. See Note 1.
--time-linear *tzero,delta,units[,calendar]*	Override the time dimensions(s) with a linear time dimension. The arguments are comma-separated list: • zero is the initial time point, a floating-point value. • delta is the time delta, floating-point. • units are time units as specified in the [-r] option. • calendar is optional, and is specified as in the [-c] option. If omitted, it defaults to the value specified by [-c], otherwise as specified in the file. Example: `--time-linear '0,1,months since 1980,noleap'`
--var-locate '*var,file_pattern*'	Only scan a variable if the basename of the file matches the pattern. This may be used to resolve duplicate variable errors. var and file_pattern are separated by a comma, with no blanks. *var* is the name of the variable. *file_pattern* is a regular expression following the Python re module syntax. Example: to scan variable ps from files starting with the string 'ps_': --var-locate 'ps,ps_.*'
-x *xmlfile*	Output file name. By default, output is written to standard output.

Notes:

1. Files can be in netCDF, GrADS/GRIB, HDF, or DRS format, and can be listed in any order. Most commonly, the files are the result of a single experiment, and the ’partitioned’ dimension is time. The time dimension of a variable is the coordinate variable having a name that starts with ’time’ or having an attribute axis=’T’. If this is not the case, specify the time dimension with the -t option.

The time dimension should be in the form supported by cdtime. If this is not the case (or to override them) use the -r option.

2. By default, the time values are listed explicitly in the output XML. This can cause a problem if the time dimension is very long, say for 6-hourly data. To handle this the form 'cdscan -i delta <files>' may be used. This generates a compact time representation of the form <start, length, delta>. An exception is raised if the time dimension for a given file is not linear.
3. Another form of the command is 'cdscan -l lev1,lev2,..,levn <files>'. This asserts that the dataset is partitioned in both time and vertical level dimensions. The level dimension of a variable is the dimension having a name that starts with "lev", or having an attribute "axis=Z". If this is not the case, set the level name with the -m option.
4. An example of a suffix file:

```
/exp/pr/ncar-a  _ncar-a
/exp/pr/ecm-a   _ecm-a
/exp/ta/ncar-a  _ncar-a
/exp/ta/ecm-a   _ecm-a
```

For all files in directory /exp/pr/ncar-a or a subdirectory, the corresponding variable ids will be appended with the suffix '_ncar-a'. Regular expressions can be used, as defined in the Python 're' module. For example, The previous example can be replaced with the single line:

```
/exp/[^/]*/([^/]*) _\g<1>
```

Note the use of parentheses to delimit a group. The syntax \g<n> refers to the n-th group matched in the regular expression, with the first group being n=1. The string [^/]* matches any sequence of characters other than a forward slash.
5. Adding or modifying attributes with the -e option:

```
time.units = "days since 1979-1-1"
```

sets the units of all variables/axes to "days since 1979-1-1". Note that since this is done before any other processing is done, it allows overriding of non-COARDS time units.

```
.newattr=newvalue
```

Set the global file attribute 'newattr' to 'newvalue'.

6. The [--time-linear] option overrides the time values in the file(s). The resulting dimension does not have any gaps. In contrast, the [-i], [-r] options use the specified time units (from [-r]), and calendar from [-c] if specified, to convert the file times to the new units. The resulting linear dimension may have gaps.

   In either case, the files are ordered by the time values in the files.

   The [--time-linear] option should be used with caution, as it is applied to all the time dimensions found.

7.1.3 Examples

```
cdscan -c noleap -d test -x test.xml [uv]*.nc
cdscan -d pcmdi_6h -i 0.25 -r 'days since 1979-1-1' *6h*.ctl
```

7.1.4 File Formats

Data may be represented in a variety of self-describing binary file formats, including

- netCDF, the Unidata Network Common Data Format
- HDF, the NCSA Hierarchical Data Format
- GrADS/GRIB, WMO GRIB plus a GrADS control file (.ctl)
  The first non-comment line of the control file must be a **dset** specification.
- DRS, the PCMDI legacy format.
- UK Met Office PP format

7.1.5 Name Aliasing

A problem can occur if variables in different files are defined on different grids. What if the axis names are the same? CDMS requires that within a dataset, axis and variable IDs (names) be unique. What should the longitude axes be named in CDMS to ensure uniqueness? The answer is to allow CDMS IDs to differ from file names.

If a variable or axis has a CDMS ID which differs from its name in the file, it is said to have an *alias*. The actual name of the object in the file is stored in the attribute **name_in_file**. **cdscan** uses this mechanism (with the -a and -

s options) to resolve name conflicts; a new axis or variable ID is generated, and the **name_in_file** is set to the axis name in the file.

Name aliases also can be used to enforce naming standards. For data received from an outside organization, variable names may not be recognized by existing applications. Often it is simpler and safer to add an alias to the metafile rather than rewrite the data.

APPENDIX A

CDMS Classes

Figure 1, "CDMS Classes," on page 175 illustrates the class inheritance structure of CDMS. The classes may be categorized as abstract or concrete. Only concrete classes are meant to be used directly. In contrast an abstract class defines the common interface of its subclasses. For example, the class AbstractAxis2D defines the common interface for two-dimensional coordinate axes. It has concrete subclasses DatasetAxis2D, FileAxis2D, and TransientAxis2D, which are used in applications. Abstract classes are denoted in italics.

For many abstract classes there are three 'flavors' of subclass: dataset, file, and transient. Dataset-related objects are thought of as being contained in datasets in the sense that operations on those objects result in I/O operations on the corresponding dataset. The same is true of file-related objects. Objects in datasets and files are examples of persistent objects, whose state persists after the application exits. On the other hand, transient objects live in memory and are not persistent.

In general the concrete subclasses closely mirror the interface of the abstract parent class. For this reason this document defines the interfaces of the abstract classes, and only discusses a concrete class in the few cases where the interface has been extended. This allows applications to treat the behavior of, say a dataset axis and file axis, as identical.

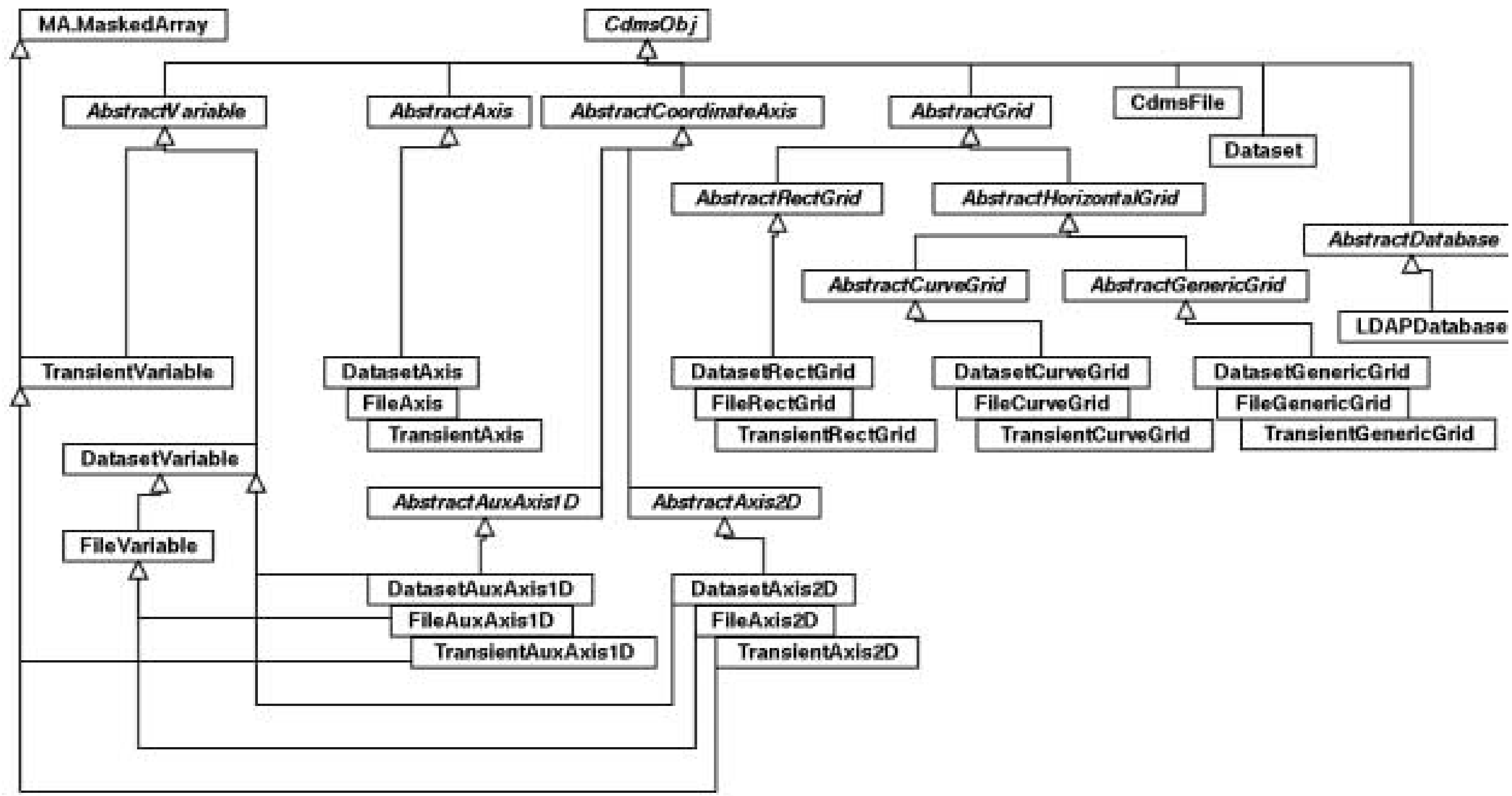


FIGURE 1. CDMS Classes

APPENDIX B

Version Notes

B.1 Version 5.0

CDMS Version 5.0 is based on the NumPy scientific computing package. See the transition guide for information on converting scripts to this version.

1. The modules cdms2, regrid2, and MV2 are based on NumPy.
2. The modules cdms, regrid, and MV are deprecated. They will be retained in CDMS for an interim period to facilitate conversion, on 32-bit architectures only.
3. The NumPy-based modules work correctly on the 64-bit x86_64 and ia64 architectures.

B.2 Version 4.0

CDMS version 4.0 adds support for nonrectangular grids:

1. The following grid classes were added: AbstractHorizontalGrid, AbstractCurveGrid, AbstractGenericGrid, DatasetCurveGrid, FileCurveGrid, TransientCurveGrid, DatasetGenericGrid, FileGenericGrid, and TransientGenericGrid.

2. The following axis classes were added: AbstractCoordinateAxis, AbstractAuxAxis1D, AbstractAxis2D, DatasetAuxAxis1D, FileAuxAxis1D, TransientAuxAxis1D, DatasetAxis2D, FileAxis2D, and TransientAxis2D.
3. The getMesh and clone methods were added for grids.
4. An interface to the SCRIP package was added.

B.3 Version 3.0 Overview

CDMS version 3.0 is a significant enhancement of previous versions. The major changes were:

1. CDAT/CDMS was integrated with the Numerical Python masked array class MA.MaskedVariable. The MV submodule was added as a wrapper around MA.
2. Methods that read data, such as subRegion, subSlice, and the slice operations, return instances of class TransientVariable. The plot and regrid modules were modified to handle masked array input. The specifiers time=..., latitude=..., etc. were added to the I/O routines.
3. The class TransientVariable was added.
4. A number of new functions were added, notably subRegion and subSlice, which return instances of TransientVariable.
5. When a masked array is returned from a method, it is “squeezed”: singleton dimensions are removed. In contrast, transient variables are not squeezed. I/O functions have a *squeeze* option. The method setAutoReshapeMode was removed.
6. Internal attributes are handled in the InternalAttributes class. This allows CDMS classes to be subclassed more readily.
7. The class Variable was renamed DatasetVariable.
8. The cu module was emulated in cdms. cu and cdms methods can be mixed.
9. The code was modularized, so that Python, CDMS, and Numerical Python can be built and installed separately. This significantly enhances the portability of the code.

B.4 V3.0 Details

B.4.1 AbstractVariable

- Functions getDomain, getSlice, rank, regrid, setMissing, size, subRegion, and subSlice were added.
- The functions getRegion, getSlice, getValue, and the slice operators all return an instance of MA, a masked array. Singleton dimensions are squeezed.
- The functions subRegion and subSlice return an instance of TransientVariable. Singleton dimensions are not squeezed.
- The xxSlice and xxRegion functions have keywords *time, level, latitude, and longitude*.
- The input functions have the keyword *squeeze*.
- AbstractVariable inherits from class Slab. The following functions previously available in module cu are Slab methods: getattribute, setattribute, listdimattributes, getdimattribute, listall, and info.
- AbstractVariable implements arithmetic functions, astype.
- The write function was added.

B.4.2 AbstractAxis

- The functions asComponentTime, asRelativeTime, clone, getAxisIds, getAxisIndex, getAxisList, getAxisListIndex, mapIntervalExt were added.
- subaxis was renamed subAxis for consistency.
- Generalized wraparound was implemented, to handle multiple cycles, reversing, and negative strides. By default, coordinate intervals are closed. The intersection options 'n','e','b',and 's' were added to the interval indicator - see mapIntervalExt.

B.4.3 AbstractDatabase

- The function open is synonymous with openDataset.

B.4.4 Dataset

- The function open is synonymous with openDataset.

B.4.5 cdms module

- The functions asVariable, isVariable, and createVariable were added.
- The function setAutoReshapeMode was removed. It is replaced by the squeeze option for all I/O functions.

B.4.6 CdmsFile

- The function createVariable has a keyword fill_value. The datatype may be a Numeric/MA typecode.
- The function write was added.

B.4.7 CDMSError

- All errors are an instance of the class CDMSError.

B.4.8 AbstractRectGrid

- The function createGaussianGrid was added.

B.4.9 InternalAttributes

- The class InternalAttributes was added. It has methods add_internal_attribute, is_internal_attribute, and replace_external_attributes.

B.4.10 TransientVariable

- The class TransientVariable was added. It inherits from both AbstractVariable and MA.
- The cdms module function createVariable returns a transient variable.
- This class does not implement the functions getPaths or getTemplate.

B.4.11 MV

- The MV submodule of cdms was added.

APPENDIX C

cu Module

The cu module is the original CDAT I/O interface. As of version 3 it is emulated in the cdms module. It is maintained for backward compatibility.

The cu classes are Slab, corresponding to TransientVariable in CDMS, and cuDataset, corresponding to Dataset in CDMS.

C.1 Slab

Table C.1 **Slab Methods**

Type	Definition
Various	**getattribute(name)** Get the value of an attribute. *name* is the string name of the attribute. The following special names can always be used: ‘filename’, ‘comments’, ‘grid_name’, ‘grid_type’, ‘time_statistic’, ‘long_name’, ‘units’.
Various	**getdimattribute(dim, field)** Get the value of a dimension attribute. *dim* is the dimension number, an integer in the range 0..rank-1. *field* is a string, one of: "name", "values", "length", "units", "weights", "bounds".
None	**info(flag=None, device=sys.stdout)** Print slab information. If *flag* is nonzero, dimension values, weights, and bounds are also printed. Output is sent to *device*.
List	**listall(all=None)** Print slab information. If *all* is nonzero, dimension values, weights, and bounds are also printed.

Table C.1 Slab Methods

Type	Definition
List	**listdimattributes(dim, field)** List dimension attributes. Returns a list of string attribute names which can be input to **getdimattribute**. dim is the dimension number, an integer in the range 0..rank-1. field is a string, one of: "name", "values", "length", "units", "weights", "bounds".
None	**setattribute(name, value)** Set an attribute. *name* is the string name of the attribute. *value* is the value of the attribute.

C.2 cuDataset

Table C.2 cuDataset Methods

Type	Definition
None	**cleardefault()** Clear the default variable name.
None	**default_variable(vname)** Set the default variable name. *vname* is the string variable name.

Table C.2 cuDataset Methods

Type	Definition
Array	**dimensionarray(dname, vname=None)** Values of the axis named dname. *dname* is the string axis name. *vname* is the string variable name. The default is the variable name set by **default_variable**.
Axis	**dimensionobject(dname, vname=None)** Get an axis. *dname* is the string name of an axis. *vname* is a string variable name. The default is the variable name set by **default_variable**.
Various	**getattribute (vname, attribute)** Get an attribute value. *vname* is a string variable name. *attribute* is the string attribute name.
String	**getdimensionunits (dname,vname=None)** Get the units for the given dimension. *dname* is the string name of an axis. *vname* is a string variable name. The default is the variable name set by **default_variable**.
Various	**getglobal (attribute)** Get the value of the global attribute. *attribute* is the string attribute name.

Table C.2 cuDataset Methods

Type	Definition
Variable	**getslab (vname, *args)** Read data for a variable. *vname* is the string name of the variable. *args* is an argument list corresponding to the dimensions of the variable. Arguments for each dimension can be: (1) ':' or None -- select the entire dimension (2) Ellipsis -- select entire dimensions between the ones given. (3) a pair of successive arguments giving an interval in world coordinates. (4) a CDMS-style tuple of world coordinates e.g. (start, stop, 'cc')
List	**listall (vname=None, all=None)** Get info about data from the file. *vname* is the string name of the variable. If *all* is non-zero, dimension values, weights, and bounds are returned as well.
List	**listattribute (vname=None)** Return a list of attribute names. *vname* is the name of the variable. The default is the variable name set by **default_variable**.
List	**listdimension (vname=None)** Return a list of the dimension names associated with a variable. *vname* is the name of the variable. The default is the variable name set by **default_variable**.
List	**listglobal ()** Return a list of the global attribute names.

Table C.2 cuDataset Methods

Type	Definition
List	**listvariable ()** Return a list of the variables in the file.
None	**showall (vname=None, all=None, device=sys.stdout)** Print a description of the variable. *vname* is the string name of the variable. If *all* is non-zero, dimension values, weights, and bounds are returned as well. Output is sent to *device*.
None	**showattribute (vname=None, device=sys.stdout)** Print the attributes of a variable. *vname* is the string name of the variable. Output is sent to *device*.
None	**showdimension (vname=None, device=sys.stdout)** Print the dimension names associated with a variable. *vname* is the string name of the variable. Output is sent to *device*.
None	**showglobal (device=sys.stdout)** Print the global file attributes. Output is sent to *device*.
None	**showvariable (device=sys.stdout)** Print the list of variables in the file.

APPENDIX D

Version 5 Transition Guide

The major change in version 5 is the transition from the Numeric scientific computing package to the NumPy package (http://numpy.scipy.org). NumPy is a full replacement and enhancement of Numeric, which is no longer supported. Since many of the CDMS array objects, such as Variables and Axes, are extensions of the Numeric array, this transition is nontrivial. Fortunately NumPy is very similar to Numeric. In many cases a simple change of module name will be sufficient to update a script. This section details the differences between versions 4 and 5 and the steps necessary to take advantage of the new package.

D.1 Namespace changes

In CDMS Version 5 the **cdms2** module interfaces to **numpy** and **numpy.core.ma** (the replacement for **MA**). For an interim period, the **cdms, MA** and **Numeric** modules will be retained for backward compatibility, but are deprecated. The change of namespace reflects the fact that the array objects are fundamentally different, and in certain instances behave differently. Also, **MV** is now **MV2**, **cdms2.MV** is an alias for **cdms2.MV2**, and **regrid** is changed to **regrid2**. The following table summarizes these namespace changes for the affected CDAT modules:

Table D.1

Version 4	Version 5	Compatibility module
cdms	**cdms2**	**cdms**
MV	**MV2**	**MV**
regrid	**regrid2**	**regrid**
Numeric	**numpy**	**numpy.oldnumeric**
MA	**numpy.core.ma**	**numpy.oldnumeric.ma**
vcs	**vcs**	**-**
cdutil	**cdutil**	**-**
genutil	**genutil**	**-**

4.2 Converting scripts with convertcdms.py

Fortunately the changes needed to convert from cdms/Numeric to cdms2/NumPy are relatively few and can mostly be automated. The script convertcdms.py is installed in the bin directory. It scans a Python script or directory and makes the following changes:

1. import cdms => import cdms2 as cdms
2. import regrid => import regrid2 as regrid
3. import MV => import MV2 as MV
4. import Numeric => import numpy.oldnumeric as Numeric
5. import MA => import numpy.oldnumeric.ma as MA
6. import cdms.MV => import cdms2.MV2
7. from cdms import XX => from cdms2 import XX (similarly for regrid, MV, MA, and Numeric)

8. from cdms.XX import YY => from cdms2.XX import YY (similarly for regrid, MV, MA, and Numeric)
9. import cdms as XX => import cdms2 as XX (similarly for regrid, MV, MA, and Numeric)
10. import cdms.XX => import cdms2.XX (similarly for regrid, MV, MA, and Numeric)

import XX, cdms, YY => import XX, cdms2 as cdms, YY (similarly for regrid, MV, MA, and Numeric)

11. MA.Float => Numeric.Float, similarly for MA.Int, MA.NewAxis
12. MA.Numeric => Numeric
13. The 'typecode=' argument in MA and MV functions is changed to 'dtype='
14. XX.mask() => XX.mask
15. XX.mask is None => ((XX.mask is None) or (XX.mask is MV2.nomask))
16. A keyword argument 'axis=0' is added to MA.sum, MA.average, MA.product, and MA.repeat
17. The translations in **numpy.oldnumeric.alter_code1**. This module is used for most Numeric and MA-related translations. **alter_code1** methods do not have to be executed separately. See the sample chapters of "Guide to NumPy" at http://numpy.scipy.org .
18. *array*.typecode() => arr.dtype.char
19. *array*.size() => arr.size
20. *array*.mask() => arr.mask
21. Some typecode characters haved changed. For example, 's' => 'h'.

To run convertcdms.py:

```
convertcdms.py foo.py
```

saves the original file in **foo.orig** (if translations are made) and converts the script.

```
convertcdms.py -r directory
```

converts all Python and C source code in the directory, and recursively in subdirectories.

```
convertcdms.py -h
```

shows all options.

Some of the changes in NumPy must be made by hand:

1. Slicing a singleton value from an array returns a scalar, not a 0-D array. Such scalars have a shape but no length.
2. To test for the type of a scalar extracted from an array, use isinstance instead of type().
3. Masked arrays return a special **nomask** object instead of None when there is no mask on the array. This applies to **getmask()** and the ***array*.mask** attribute.
4. Masked array functions have a default axis of None, meaning ravel. The default in previous versions was axis=0.
5. The default datatype in **numpy/ma/cdms2** is **float**. In **Numeric/MA/cdms** it was int.

These differences are illustrated in the following table:

Table D.2

Note	Numeric/MA/cdms	numpy/ma/cdms2
1	>>> import MV	>>> import MV2
	>>> x = MV.arange(12.)	>>> y = MV2.arange(12.)
	>>> x[0]	>>> y[0]
	array(0.0)	0.0
		>>> type(y[0])
		<type 'float'>
		>>> cdms2.setNumericCompatibility(True)
		>>> y[0]
		array(0.0)

Table D.2

Note	Numeric/MA/cdms	numpy/ma/cdms2

2	>>> xnum = Numeric.arange(12.)
	>>> type(xnum[0])
	<type 'float'>
	>>> type(xnum[0]) is FloatType
	True
		>>> ynum = numpy.arange(12.)
		>>> type(ynum[0])
		<type 'numpy.float64'>
		>>> type(ynum[0]) is FloatType
		False
		>>> isinstance(ynum[0], FloatType)
		True

3	>>> import MA
	>>> xma = MA.arange(12.)
	>>> xma.mask() is None
	True
		>>> import numpy.core.ma as ma
		>>> yma = ma.arange(12.)
		>>> yma.mask is None
		False
		>>> yma.mask is ma.nomask
		True

4	>>> x = MV.ones((3,4))
	>>> MV.sum(x)
	variable_6
	array([3,3,3,3,])
		>>> y = MV2.ones((3,4))
		>>> MV2.sum(y)
		array(12)
		>>> MV2.sum(y, axis=0)
		array([3 3 3 3])
		>>> cdms2.setNumericCompatibility(True)
		>>> MV2.sum(y)
		array([3 3 3 3])

5	>>> MV.ones(12).typecode() 'l'	>>> MV2.ones(12).typecode() 'd'

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