Scripting Guide
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Preface

This manual is intended for advanced users interested in developing scripts and tools within HIPE. It complements the cookbook approach, based mostly on graphical interfaces, followed by the Data Analysis Guide.
Chapter 1. Scripting and Jython basics

1.1. Getting started

1.1.1. Why scripting with HIPE?

HIPE comes with plenty of graphical tools for your data analysis (head to the Data Analysis Guide to find out more about them). While you can go a long way by using these point-and-click tools, scripting can dramatically improve your efficiency:

- You can automate tedious tasks and have HIPE do them for you, as many times as you like.
- You can record a procedure that worked particularly well and store it as a script for future reference, including the best values of any parameters.
- Some HIPE components, such as plotting, rely heavily on scripting.

Note that many graphical tools in HIPE echo all their actions to the command line in the Console view, so that effectively HIPE writes a script for you as you point and click.

1.1.2. Testing commands

If you are unsure about the syntax or the behaviour of a command, the best thing to do is to experiment with it. Just back up your data before trying anything potentially risky!

The Console view of HIPE is where you try commands for immediate execution. Write your command at the prompt and press Enter.

There are plenty of commands for you to try in the rest of this chapter. For more information about executing commands interactively, see Section 1.3.

If you are familiar with IDL and want to see what the most common commands look like in HIPE, see Section 1.41.

1.1.3. Writing your first script

The Editor view of HIPE is where you write your scripts. This is a full code editor with features such as syntax highlighting, automatic indentation, incremental search and many more.

In HIPE, choose File → New → Jython Script. A new blank document opens in the Editor view. Copy and paste the following script:

```jython
data = Int2d(100, 100, 10)
myImage = SimpleImage()
myImage.image = data
Display(myImage)
```

Example 1.1. Creating a simple image with fake data.

Tip

Jython is case sensitive. This means that SimpleImage is not the same as simpleImage or simpleimage.

This script does nothing too exciting: it defines an image of 100x100 pixels and a constant value of 10, then displays it with the default HIPE image viewer. Do not worry if you do not understand the syntax of the script. The point is for you to become comfortable with running scripts.
1.1.4. Running your first script

Now that you have your script ready, you can execute it in three ways:

- **Line by line.** Note the little arrow icon next to the first line of the script. That shows the line that is going to be execute when you click the icon in the HIPE toolbar. HIPE executes just that line, and the icon moves to the following line. Click the icon again, and HIPE executes that line, and so on. You can also click to the left of any line to have the icon point there, so that in theory you could execute single script lines in any order you want.

- **All at once.** If you click the icon in the toolbar, HIPE executes the whole script, from beginning to end. It does not matter where the icon on the left is, or whether you executed part of the script before.

- **Just one section.** Click and drag your mouse pointer to select part of the script, so that the text appears in white on blue background. If you click the icon, HIPE only runs what you have selected, all at once. Note that, if you have selected just part of a line, HIPE tries to execute just that part, whether it makes sense or not!

For more information about running scripts in HIPE, see again the HIPE Owner's Guide: Section 9 in HIPE Owner's Guide.

1.1.5. Where to go from here?

Now you know the basics of writing and running scripts in HIPE. You may want to explore the following topics next:

- **The scripting language.** Read the rest of this chapter to learn about Jython, the scripting language used in HIPE.

- **Example scripts.** You will find many examples in the rest of this chapter. Furthermore, you can look at the Scripts menu in HIPE. This menu lists useful scripts you can run, or just open and study. You can also look at the Pipeline menu, which gives you access to the pipeline scripts for the three instruments. All these scripts, usually well commented, are a good source to explore more advanced scripting techniques.

- **For IDL users.** If you are familiar with IDL, you will feel right at home after looking at the comparison tables in Section 1.41.

- **Sharing scripts.** Once you have written your scripts, you can easily share them with colleagues as HIPE plug-ins. Go to Section 1.40 to discover how.

1.2. Jython, Python and Java

The language you use to write scripts in HIPE is called Jython. Jython is an implementation of the Python (please open this link in a new window/tab) language, already heavily used for scientific purposes (see for example http://www.scipy.org).

Jython is written using the Java programming language, thus combining the power of Java and Python. HIPE currently uses version 2.5 of Jython. The original Python implementation is written in the C programming language, and for this reason is sometimes called CPython.
1.3. Writing commands interactively

You can write any Jython command in the Console view of HIPE to have it executed immediately.

For example you can use the Console view as a calculator. Use +, -, *, and / for the four basic operations, and parentheses for grouping, as in the following example. Note the use of the hash mark # for inserting comments:

```jython
HIPE> print 2+2
4
HIPE> # This is a comment and is ignored by the interpreter
HIPE> print 2+2
4
HIPE> print 2+2 # A comment on the same line as the code
4
HIPE> print (50-5*6)/4
5
HIPE> print 7/3 # Integer division returns the floor
2
HIPE> print 7/-3
-3
```

You can write a command spanning multiple lines by adding a backslash \ at the end of any intermediate line. When you add a backslash at the end of a line and press Enter, the prompt in the Console view changes from HIPE> to ......, indicating that you can add another line to the command. Write the last line without a backslash at the end and press Enter to execute the multiline command:
HIPE> print 5 + \\n......(3 * 4) - \\n......7
# 10

Multiline commands are useful to make long and complicated commands more legible, or to define multiline strings (see Section 1.7).

1.4. Writing a script

In the Editor view of HIPE you can write scripts, that is, series of Jython instructions that you can save and execute. You can execute a script all at once or line by line, or execute just a portion of a script.

You can turn most code examples in this chapter into scripts. Choose File → New → Jython Script. An empty window opens in the Editor view. Copy and paste a code example, then choose File → Save as to save it. HIPE saves scripts with a .py extension.

For more examples of Jython scripts, see entries in the Pipeline menu of HIPE.

For more information on opening and running scripts, see the HIPE Owner's Guide: Section 9 in HIPE Owner's Guide.

For more information on editing scripts, see again the HIPE Owner's Guide: Section 11 in HIPE Owner's Guide.

Non-ASCII characters. If you include non-ASCII characters in a Jython script, add the following line at the top of the file:

```python
# encoding=utf-8
```

Failing to do so could cause errors later.

Script length. Each Jython script cannot exceed a certain size limit, usually 65536 bytes. If your Jython script is very long (more than a few thousands lines) then it is advisable to split it into separate scripts.

1.5. Variables and variable types

A variable is a name corresponding to a value. A variable can refer to anything from a number to an entire Herschel observation.

To create a variable, or modify an existing value, use the = operator. You can create several variables at once. The following command creates three variables called x, y and z, holding the values 1, 2 and 3 respectively:

```python
x, y, z = 1, 2, 3
```

Example 1.2. Assigning multiple values to multiple variables in one line.

The following command creates two variables, a and b, both with the value 123.

```python
a = b = 123
```

Example 1.3. Assigning the same value to several variables at once.

To delete some of your variables, use the del command:

```python
del(x,y,z)  # Deletes three variables
```

Example 1.4. Deleting variables.
To delete all your variables, use the `clear` command:

```python
clear()  # Deletes all variables
```

**Example 1.5. Deleting all variables.**

Any variable has a `type` associated to it. To find out the type of a variable, use the `type` function:

```python
a = 5
print type(a)  # <type 'int'>
```

**Example 1.6. Printing the type (class) of a variable.**

Numeric variables (that is, variables representing numbers, can be of the following types in Jython:

- **Integer** (`int`): `a = 3`
- **Long integer** (`long`), denoted by the `l` or `L` suffix: `a = 3L`
- **Float** (`float`): `a = 3.0`
- **Complex** (`complex`): `a = (3 + 1j)`
- **Boolean** (`bool`): `a = True` or `a = False`

### 1.5.1. More on complex numbers

Imaginary numbers are written with a `j` or `J` suffix. Complex numbers with a nonzero real component are written as `real + imag j`, or can be created with the `complex(real, imag)` function:

```python
print 1j * 1J  # (-1+0j)
pint 1j * complex(0,1)  # (-1+0j)
pint 3+1j*3  # (3+3j)
pint (3+1j)*3  # (9+3j)
pint (1+2j)/(1+1j)  # (1.5+0.5j)
```

**Example 1.7. How to represent complex numbers in Jython.**

To extract the real and imaginary parts from a complex number `z`, use `z.real` and `z.imag`:

```python
z = 1.5+0.5j
print z.real  # 1.5
print z.imag  # 0.5
```

**Example 1.8. Printing complex numbers to the console.**

### 1.5.2. Java variable types

In addition to native Jython numeric variable types, the following Java numeric types are also available in HIPE:

- **Byte**: signed 8-bit integer. Values from -128 to 127.
- **Short**: signed 16-bit integer. Values from -32,768 to 32,767.
- **Integer**: signed 32-bit integer. Values from -2,147,483,648 to 2,147,483,647.
- **Float**: single-precision 32-bit floating point. Values from 1.40129846432481707e-45 to 3.40282346638528860e+38, either positive or negative.
• **Double**: double-precision 64-bit floating point. Values from 4.94065645841246544e-324 to 1.79769313486231570e+308, either positive or negative.

• **Boolean**: `true` or `false`.

You can use Java types are used as follows:

```python
a = Integer(3)  # Create an Integer with value 3
print a          # 3
b = Double(3)   # 3.0
print b

c = Boolean(0)  # false
print c
```

**Example 1.9. Printing numbers (with default formatting) to the console.**

---

**Warning**

Use only Jython primitive types in your scripts. If you use Java types like `Double` or `Integer`, Jython will silently and automatically convert back to native Jython types like `float` or `int` every time that an implicit cast is required (on assignment or comparison), which could result in strange errors when you try to operate on variables of incompatible types. See Section 1.9.1 for more information on these automatic conversions.

Another problem is apparently wrong results in comparisons between numbers. This may happen if you use Java number classes as in the following example:

```python
a = Integer(2)
b = Integer(3)
print a < b  # 0
```

**Example 1.10. Comparing variables from Java classes is different to Jython comparisons.**

It would seem that, according to HIPE (more precisely, to Jython), two is not smaller than three. This is because Jython is comparing the two objects `a` and `b`, using criteria that have nothing to do with the numeric values they represent.

---

### 1.5.3. The range of Jython numeric types

It is safe to apply the same ranges of Java numeric types to Jython numeric types, according to this list:

- Jython integer: same as Java `Integer`, from -2,147,483,648 to 2,147,483,647.
- Jython float: same as Java `Double`, from 4.94065645841246544e-324 to 1.79769313486231570e+308, either positive or negative.
- Jython complex: real and imaginary part have the same range of their variable type (integer, long or float).

If you go beyond the range of the integer type, a variable is automatically converted to long:

```python
i = 2147483647  # Integer range limit
print type(i)    # <type 'int'>
i = i + 1        # Adding 1 to the variable
print type(i)    # <type 'long'>
```

**Example 1.11. Checking the range limits of types.**
Note that Jython allows you to go beyond the range of the long type, but you won't be able to use the variable in HIPE-specific data structures such as Numeric arrays (see Section 2.2 for more information on Numeric arrays). Going beyond the range limit can cause errors like in the following example:

```python
i = 92233720368547758072147483647  # Long range limit
print type(i)
# <type 'long'>
i = i + 1  # Adding 1 to the variable
print i
# 9223372036854775808L
print type(i)
# <type 'long'>
a = Long1d([i]) # Trying to create a Numeric array
# java.lang.IllegalArgumentException: No implicit conversion for:
# 9223372036854775808L: too big for java.Long
```

Example 1.12. Demonstrating the ranges for built-in types in Jython.

### 1.5.4. Other variable types

This section deals with numeric variable types, but there are many more types you will encounter while working in HIPE. Some of the most important HIPE-specific variable types you are likely to encounter are the following:

- **Numeric arrays.** Numeric arrays are HIPE-specific data structures of up to five dimensions. They are described in Section 2.2.

- **Array, table and composite datasets.** These datasets are used to organise numeric arrays and add metadata to describe their contents. The table dataset is by far the most used. These datasets are described in Section 2.3, Section 2.4 and Section 2.5.

- **Products.** Products are the main building blocks of Herschel data. Products contain one or more datasets plus additional metadata. They are described in Section 2.8.

- **Contexts.** Context are special types of products that act as containers for other products. The most important type of context is the observation context. Contexts are described in Section 2.8.5 and observation contexts in Section 2.8.6.

- **Spectra and spectral cubes.** There are many variable types used to represent spectra and spectral cubes. These are described in Chapter 3.

- **Images.** The SimpleImage type is the most common variable type used to describe images. See the Data Analysis Guide for more information on images in HIPE: Chapter 4 in Data Analysis Guide.

### 1.6. Getting help on variables

While working in HIPE you come into contact with variables of many different types. Besides the primitive numeric types described in Section 1.5, there are many more variable types coming from the Java language, and other HIPE-specific variable types, such as those described in Chapter 2.

The following are some ways in which you can obtain help on a variable:

- **Right click on the variable name in the Variables view and choose, if available, Help in URM. This opens in your default browser the corresponding entry in the User's Reference Manual.**

  The equivalent command from the Console view is the following:

  ```python
  help(myVariable)
  ```

- **Right click on the variable name in the Variables view and choose, if available, Help in DRM. This opens in your default browser the corresponding entry in the Developer's Reference Manual.**
This manual is intended primarily for developers, but you can find information on the *methods* (functions) you can apply to your variable.

- Right click on the variable name in the *Variables* view and choose *Show methods*. This prints a list of available methods in the *Console* view.

The equivalent command from the *Console* view is the following:

```python
print dir(myVariable.__class__)
```

**Example 1.13. Printing the methods available for a variable in the console.**

- Issue the following command in the *Console* view:

```python
print myVariable.__doc__
```

This prints a short help text, when available.

The *User's Reference Manual* and *Developer's Reference Manual* include help for HIPE-specific variable types. For help on Jython types, see the online Jython standard library reference.

### 1.7. Defining and modifying strings

Strings in Jython can be within single or double quotes:

```python
print 'spam eggs'  # spam eggs
print "doesn't"  # doesn't
```

String literals can span multiple lines in several ways. A backslash as the last character of a line indicates that the next line is a logical continuation of the previous one:

```python
hello = "This is a rather long string containing
several lines of text just as you would do in C.
Note that whitespace at the beginning of the line is significant."
print hello
```

Note that newlines still need to be embedded in the string using `\n`; the newline following the trailing backslash is discarded. The previous example would print the following:

```
This is a rather long string containing
several lines of text just as you would do in C.
Note that whitespace at the beginning of the line is significant.
```

You can access individual characters like this:

```python
print hello[2]  # Third character: i
print hello[10:16]  # 11th to 16th character: rather
```

Note that numbering of the characters starts at 0.

**Counting the characters in a string.** To obtain the number of characters in a string, including any white spaces, use the following command:

```python
print len(hello)  # 158
```

**Concating strings.** Use the + operator to concatenate strings:

```python
a = "Blah Blah "
b = "Woof Woof"
```
print a + b  # Blah Blah Woof Woof

Example 1.14. Concatenating strings with + in Jython does not have the performance impact it has in Java.

Converting numbers to strings. Use backquotes (`) to convert a numeric variable to its string representation:

```
a = 42
print type (a)  # <type 'int'>
print type (`a`)  # <type 'str'>
```

Example 1.15. Converting numbers to string using the builtin `backquote` method.

### 1.7.1. Java string types

As with numeric types, you can use Java strings in addition to Jython native strings:

```
s1 = "Blah blah"  # Jython string
s2 = String("Woof woof")  # Java string
```

Example 1.16. Creating a Java string from a Jython string.

Java also has the `Character` type representing a single character. Note that it is not available by default within HIPE, but it has to be explicitly imported (see Section 1.33 for more information about importing):

```
c = Character("a")
# <type 'exceptions.NameError'>: name 'Character' is not defined
from java.lang import Character
c = Character("a")  # No error this time
print c  # a
```

Example 1.17. Creating Java Character variables.

Always use Jython strings in your scripting. If you come across a Java string, you will not be able to use it together with Jython strings:

```
a = "Blah Blah "  # Jython string
b = "Woof Woof"  # Jython string
c = String("Woof woof")  # Java string
print a + b  # Concatenating Jython strings
# Blah Blah Woof Woof
print a + c  # Jython and Java string
# <type 'exceptions.TypeError'>: cannot concatenate 'str' and 'java.lang.String' objects
print a + str(c)  # Convert Java string to Jython
# Blah Blah Woof Woof
```

Example 1.18. Jython and Java string incompatibilities.

### 1.8. Formatting strings

You can insert variable values in a string, either numeric values or other strings, with the `%` operator. The following example shows how to insert other strings in a string:

```
a = "Herschel"
b = "HIPE"
print "I like %s." % (a)
# I like Herschel.
print "I like %s and %s." % (a, b)
# I like Herschel and HIPE.
```

Example 1.19. Printing text to the console with variable substitution.
The `%s` means that the variable contents must be formatted as a string.

The following example shows how to insert numeric values:

```python
value = 4.0/3.0
print "Four thirds is approximately \%f" % (value)
# Four thirds is approximately 1.333333
print "Four thirds is approximately \%4.2f" % (value)
# Four thirds is approximately 1.33
```

**Example 1.20. How to change the floating-point precision when printing numbers.**

The `%f` means that the variable contents must be formatted as a floating point number. In the second command, `%4.2f` means that the number must be written with at least four characters, with two characters reserved for digits after the decimal point.

The following table shows other conversion types you can used in addition to `s` and `f`.

**Table 1.1. Conversion types for string formatting.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>signed integer decimal</td>
</tr>
<tr>
<td>o</td>
<td>unsigned octal</td>
</tr>
<tr>
<td>u</td>
<td>unsigned decimal</td>
</tr>
<tr>
<td>x</td>
<td>unsigned hexadecimal (lowercase)</td>
</tr>
<tr>
<td>X</td>
<td>unsigned hexadecimal (uppercase letters)</td>
</tr>
<tr>
<td>E</td>
<td>floating point exponential format (uppercase ‘E’)</td>
</tr>
<tr>
<td>e</td>
<td>floating point exponential format (lowercase ‘e’)</td>
</tr>
<tr>
<td>f</td>
<td>floating point decimal format (lowercase)</td>
</tr>
<tr>
<td>g</td>
<td>floating point exponential format if exponent &lt; -4, otherwise float</td>
</tr>
<tr>
<td>G</td>
<td>floating point exponential format (uppercase) if exponent &lt; -4, otherwise float</td>
</tr>
<tr>
<td>c</td>
<td>single character</td>
</tr>
<tr>
<td>s</td>
<td>string</td>
</tr>
</tbody>
</table>

### 1.9. Converting between variable types

Use the following functions to convert variables to different Jython types: `float()`, `int()`, `long()` and `complex()`.

```python
a = 1
print a  # 1
print float(a)  # 1.0
print long(a)  # 1 - No visible change
print complex(a)  # (1+0j)
```

**Example 1.21. Converting between Jython types.**

These conversions do not work with complex numbers, even if they have zero imaginary part:

```python
a = 1 + 0j
print float(a)  
# <type 'exceptions.TypeError'>: can’t convert complex to float; use e.g. abs(z)
```

**Example 1.22. Complex to float conversion is impossible.**

You can also convert from string to numeric values:
s = "01234.56"
print float(s)  # 1234.56

**Example 1.23. String to float conversion.**

Note that with this method when you try to convert a string representation of a floating point to integer you will get an error:

s = "01234.56"
print int(s)
# <type 'exceptions.ValueError'>: invalid literal for int() with base 10:
# 01234.56

**Example 1.24. Decimal to integer conversion is impossible.**

### 1.9.1. Converting between Java and Jython types

When it gets a Java numeric type, or a Java string, Jython automatically converts it into one of its primitive types. Take for example the following code, which generates a random number between 0 and 1 using a Java function.

```python
def print type(a)
# <type 'float'>
```

**Example 1.25. Implicit Java to Jython numeric conversion.**

The output of `nextDouble()` is a `Double`, but if you inspect the type using `print type(a)` you get something different:

```python
def print type(a)
# <type 'float'>
```

**Example 1.26. Printing the title of a variable.**

Another way to see whether a variable is a Java or Jython type is to check for the `.class` attribute. This is only available for Java types and gives an error for Jython types:

```python
def print a
# <type 'exceptions.AttributeError'>: 'int' object has no attribute 'class'
def print b
# <type 'java.lang.Integer'>
```

**Example 1.27. Printing the class of a Java variable.**

Java types are converted to Jython types according to the following table:

<table>
<thead>
<tr>
<th>Java type</th>
<th>Jython type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Byte</td>
<td>Integer</td>
</tr>
<tr>
<td>Short</td>
<td>Integer</td>
</tr>
<tr>
<td>Integer</td>
<td>Integer</td>
</tr>
<tr>
<td>Long</td>
<td>Long</td>
</tr>
<tr>
<td>Float</td>
<td>Float</td>
</tr>
<tr>
<td>Double</td>
<td>Float</td>
</tr>
<tr>
<td>Boolean</td>
<td>Integer (False = 0, True = 1)</td>
</tr>
</tbody>
</table>
### Incompatible types

Java and Jython numeric types do not mix well:

```python
a = 123.45
print type(a) # <type 'float'>
b = Float(123.45)
print type(b) # <type 'java.lang.Float'>
print a + b
# <type 'exceptions.TypeError'>: unsupported operand type(s) for +: 'float' and 'java.lang.Float'
```

**Example 1.28.** Another example of Java and Jython numeric type incompatibilities.

Although the two variables *look* the same, to HIPE they are just two different things for which no addition has been defined. For the addition to succeed, you have to convert the Java type to Jython (you may get a slightly different result because of rounding errors):

```python
print a + b.floatValue() # 246.9
```

**Example 1.29.** Converting the Java numeric variable to a Jython value.

Converting the Jython type to Java will not work:

```python
print Float(a) + b
# <type 'exceptions.TypeError'>: unsupported operand type(s) for +: 'java.lang.Float' and 'java.lang.Float'
```

**Example 1.30.** The Jython type to Java will not work.

To apply math operators to variables of Java numeric types, you always have to convert them to Jython types. This is another very good reason to use Jython primitive types in the first place.

### 1.10. Lists, dictionaries and tuples

Lists, dictionaries and tuples are important data structures available in Jython.

**Lists** are arrays of values written in a specific order.

```python
myList = ["one", "two", "three"]
```

**Tuples** are just like lists, but they cannot be modified once they are created.

```python
myTuple = ("one", "two", "three")
```

The only difference in syntax is round parentheses for tuples instead of square brackets for lists.

**Dictionaries** are lists of key-value pairs. To access each value you must specify the corresponding key.

```python
person = {"Alice": 111, "Boris": 112, "Clare": 113, "Doris": 114}
```

**Example 1.31.** Defining dictionaries.

In the previous example, Alice is a key and 111 the corresponding value.

### 1.11. Creating and modifying lists
You can mix different variable types and nest lists within other lists:

```python
name = ["Isaac", "Newton"]  # List of strings
a = [1, 2, "Herschel", 4.5]  # Mixing different types
y = z = 5
x = [[1,2,3],[y,z],[1,[2,[3,4]]]]  # Nested lists
print x
print x[0]
print x[2]
print x[2][1]
print x[2][1][1]
```

Example 1.32. Nesting lists does not require that all lists are of the same type.

To append values to the end of a list, you can use the `+=` operator or the `append` function.

```python
b = [1]  # List made of one element
b += [2] # Now b = [1, 2]. Note that the result is not b = [3]!
b.append(3) # Now b = [1, 2, 3]
```

Example 1.33. Appending values to the end of a list, using different methods.

You can use the `+=` operator or the `append` function to fill a list one element at a time through a `for` loop. See Section 1.19 for more information on loops.

```python
a = []  # Create empty list
for i in [0.1, 0.2, 0.3]:
a.append(SIN(i))
```

Example 1.34. Appending several values with the help of a `for` loop.

### 1.12. Concatenating lists and tuples

Use the `+` operator to concatenate (that is, join) lists or tuples to form a resultant third list or tuple:

```python
a = (1,2,3,4)
c = ("x","y","z")
b = a + c
print b  # (1, 2, 3, 4, 'x', 'y', 'z')
```

Example 1.35. Concatenating two lists or tuples.

You cannot concatenate a list and a tuple:

```python
a = (1,2,3)  # Tuple
b = ["x", "y"]  # List
print a + b
# <type 'exceptions.TypeError'>: can only concatenate tuple (not "list") to tuple
```

Example 1.36. Concatenating a list and a tuple will not work.

### 1.13. Accessing lists and tuples

You can access individual list and tuple elements or range of elements, as shown in the following example:

```python
a = [0, 1, 2, 3, 4, 5]
print a[0]  # Accessing first element
# 0
print a[1:3]  # Accessing second and third element
```
# [1, 2]
print a[:3]  # From beginning to third element
# [0, 1, 2]
print a[3:]  # From fourth to last element [3, 4, 5]

Example 1.37. Accessing elements or ranges using list slice notation.

Accessing list and tuple elements follow these rules:

- Each element is identified by an integer index starting from 0. For example, in a list or tuple of ten elements indexes go from 0 to 9 (list length minus one). So, a [0] returns the first element, a [1] the second element, and so on.

- a [:3] means "take every element from the beginning of the list or tuple up to the fourth element not included."

- a [3:] means "take every element from the fourth element included to the end."

- Negative numbers mean counting from the end of the list or tuple. a [-3] returns the third element from the end.

You can access elements of lists nested within other lists (or tuples nested within other tuples) as shown by the following example:

```python
x = [[1,2,3],[5,6],[1,[2,[3,4]]]]  # Nested lists (tuples work the same way)
print x  # Entire list
print x[0]  # [1, 2, 3]
print x[2]  # [1, [2, [3, 4]]]
print x[2][1]  # [2, [3, 4]]
print x[2][1][1]  # [3, 4]
```

Example 1.38. Accessing elements of nested lists or tuples.

1.14. Creating and modifying dictionaries

A dictionary has a set of key: value pairs. You can create a dictionary as follows:

```python
person = {"Alice": 111, "Boris": 112, "Clare": 113, "Doris": 114}
```

Example 1.39. Defining a dictionary.

The keys of this dictionary are Alice, Boris, Clare and Doris. The corresponding values are 111, 112, 113 and 114.

To change a value associated to a key:

```python
person["Alice"] = 222
```

Example 1.40. Accessing a dictionary value using a key.

The value associated with Alice in the dictionary called person has been changed to the number 222.

1.15. Accessing dictionaries

By providing a key to a dictionary, you can access the corresponding value:

```python
print person["Alice"]  # 111
```

Example 1.41. Accessing and printing a dictionary value using a key.
To obtain a list of all the keys and values in a dictionary:

```python
print person.keys()
# ['Clare', 'Alice', 'Boris', 'Doris']
print person.values()
# [113, 111, 112, 114]
```

**Example 1.42. Printing all the keys of a dictionary.**

### 1.16. Nesting dictionaries

Dictionaries can hold other dictionaries. You can use this feature to create advanced data structures.

The following example puts a dictionary called `abc` into another dictionary called `dict`:

```python
abc = {"John": 12345, "Jerry": 23456, "Joe": 34567}
dict = {"Alice": 111, "Boris": abc, "Charlie": "angel"}
```

**Example 1.43. Using a dictionary as a value of another dictionary.**

In this case the value corresponding to key `Boris` is not a number or a string, but an entire dictionary:

```python
print dict["Boris"]
# {'Joe': 34567, 'John': 12345, 'Jerry': 23456}
```

**Example 1.44. Accessing a dictionary value is the same as any other value.**

You can get a value from the nested dictionary as follows:

```python
print dict["Boris"]["John"]  # 12345
```

**Example 1.45. Accessing nested dictionaries is the same as with multidimensional arrays/lists.**

This is the same syntax you use for nested lists and tuples: see [Section 1.13](#).

### 1.17. Code blocks

A **code block** is a portion of your Jython script that is set apart from the rest of the code. You use code blocks to make your scripts more readable and maintainable. The following are examples of code blocks:

- Portions of code executed only if a specific condition is true. According to the condition, the execution of the script **branches** to different code blocks. See [Section 1.18](#).

- Portions of code executed many times. The execution of the script **loops** over the code block. See [Section 1.19](#).

- Functions, that is, portions of code that you can **call** and execute from other points of your script. See [Section 1.27](#).

- Classes, that is, bundles of variables and associated functions called **methods**. See [Section 1.29](#).

In Jython, code blocks are indicated only through line indentation. No begin/end braces or other special characters are required. See the following sections for examples.

**Warning**

Do not leave blank lines in your code, especially within code blocks. This could lead to errors or to different behaviours when executing the script line by line or in one go. If you want to leave blank space between statements, use a single comment character `#` with the correct indentation.
1.18. Writing branching code: if/elif/else

The `if/elif/else` statement executes blocks of commands depending on given conditions. The syntax is:

```python
if condition1:
    block1
elif condition2:
    block2
else:
    block3
```

The following example shows how to construct an `if/elif/else` statement, including the use of the `and` and `or` operators to combine logical conditions:

```python
x = 13
if x < 5 or (x > 10 and x < 20):
    print "The value is OK"
if x < 5 or 10 < x < 20:
    print "This value is OK"
if 0 <= x <= 10:
    print "The value is in the range [0,10]"
elif 10 < x < 20:
    print "The value is in the range [10,20]"
else:
    print "The value is not in the range [0,20]"
```

Example 1.46. Checking if a number belongs to several ranges using comparison operators.

1.19. Writing loops: for and while

The `for` loop. The `for` loop is used to execute a block of code a given number of times.

The syntax of the `for` loop is the following:

```python
for variable in list:
    block
```

where list can be an array of values, sequence of dictionary keywords, tuples, strings.

Some examples:

```python
for i in [1,2,3]:
    print i
```

Example 1.47. Basic loop printing the index values.

The above `for` loop goes through the values in the `[1,2,3]` list. A simpler way to create lists of increasing integer numbers is using the `range` function:

```python
for value in range(100):
    print value
```

Example 1.48. Constructing loops with the help of the `range` function.

In the previous example, `range(100)` creates a list with values increasing from 0 to 99.

The `for` loop can have an `else` clause, like in the following example:
for i in range(3):
    print i
    if i == 1:
        print 'YES!'
    else:
        print 'NO.'

Example 1.49. Adding an else code block to a for loop that is executed when the loop finishes.

The else block is executed after the for block has terminated normally. The else block is not executed if the for loop terminates prematurely with a break statement, like in the following example:

for i in range(3):
    print i
    if i == 2:
        break
    else:
        print 'NO.'

Example 1.50. Exiting the loop with break will not execute the else block.

The break statement is described in Section 1.20.

The following example uses a for loop and an if/elif/else block together. Note the indentation of the different blocks:

```python
person = {"Alice": 111, "Boris": 112, "Clare": 113, "Doris": 114}
# Get the list of people's names
list = person.keys()
# For each name in the list, get the associated value. This
# could be a test score, for example.
for i in list:
    pval = person.get(i)
    # Check if the person is on the cutoff, and print the name
    if pval == 112:
        print i, "is at the cutoff"
    # Below the cutoff
    elif pval < 112:
        print i, "is below the cutoff"
    # Or else, above the cutoff
    else:
        print i, "is above the cutoff"
```

Example 1.51. Branching and looping structures in Jython.

The while loop. The while loop executes a code block while a given condition is true. The syntax is the following:

```python
while condition:
    block
```

The condition can be any expression which returns a value: zero is treated as False, as are empty strings, tuples or lists. Any other value is True.

```python
x = 0
while x <= Math.PI:
    y = SIN(x)
    x += 0.1
```

Example 1.52. Writing a while loop block.

1.20. Controlling loops: break and continue
Use the `break` command to immediately exit from a loop, and `continue` to jump to the next iteration of the loop without executing the rest of the block.

An example for their usage is given below.

```python
x = 0
while 1:
    y = TAN(x)
    if y < 0:
        break
    print x, y
    x += 0.1
```

**Example 1.53. How to break out from a while loop.**

The above example shows an infinite `while` loop (the condition is always true). Inside the loop block a condition is checked to exit the loop at the first negative tangent.

```python
for i in range(100):
    if i % 2: continue
    print i
```

**Example 1.54. Exiting an infinite loop with the use of the continue keyword.**

The above example shows how you can skip the printing of the odd numbers (`i % 2` is `i` modulus 2 and it is zero for all even numbers).

### 1.21. Writing loops in the Console view

Multi-line code blocks are not only possible as part of a script, but you can also create and execute them in the `Console` view of HIPE.

Write the following in the `Console` view and press **Enter**:

```python
for i in (1,2,3):
    print i
```

This returns `......` instead of the usual `HIPE>` prompt. This means that the interpreter is waiting for the rest of the block. Input for instance a `print` `i` command `indented by at least one space`. A further `......` is returned. Press **Enter** once more to signal that the block is complete, and the interpreter executes the command.

The whole session should look like this (again, not that `print i` is indented by one space):

```
HIPE> for i in (1,2,3):
 ...... print i
 ...... 1
 ...... 2
 ...... 3
HIPE>
```

Of course you could have added more commands in the block after `print i`.

### 1.22. Printing to the screen

Use the `print` command to print values and variable contents to screen:

```python
print 1, 2, 1+2
```

Use the `print` command to print values and variable contents to screen:
# (1, 2, 3, 4)

The printout can be formatted in the same way as with the C `printf` format codes. Some examples:

```
print "When %s is %i years old then PI will be %8.10f" %("John",23,Math.PI)
# When John is 23 years old then PI will be 3.1415926536
print "When %8s is %04i years old then PI will be %016.12f" %("John",23,Math.PI)
# When     John is 0023 years old then PI will be 003.141592653590
```

To print lists or arrays it is necessary to make a loop:

```
a = [1,1,2,3,5,8,13,21,34]
for i in range(len(a)):
    print "Line: %3i" %(a[i])
```

Example 1.55. Using the range utility function to generate index values.

Another useful usage of formatted printout is with dictionaries as shown in the following example:

```
record = {"name": "John", "Room": 112, "class": "manager", "age": 27}
print "Extracted record\n Name: %(name)10s Room: %(Room)4i" % record
# Extracted record
#  Name:       John Room:  112
```

Example 1.56. Printing content from dictionaries.

### 1.23. Writing strings to file

You can print to file in the following way:

```
a = "example string" # A Jython string variable
file = open("output.txt", 'w') # 'w' allows write access overwriting
    # previous contents.
    # 'a' would append at the end of the file.
print >> file, 2 # Puts the number 2 into output.txt
print >> file, a # Puts the contents of the variable "a" into output.txt
```

Example 1.57. Printing text to file.

Note that it is not necessary to close access to a file within your HIPE session. To overwrite the original text file, reopen the file. Reopening the file will remove the contents.

**Tip**

*Why does Jython complain when I use the backslash (\) in a file name?* The backslash is the *escape character* in Java/Jython. For instance `\a` is interpreted as Control-A while `\t` is interpreted as the tab character. If you want to use a backslash, either escape it, that is, write it twice as `\\`, or replace it with a forward slash (`/`).

For example, change the expression `\Documents\demo_data.txt` to either `\Documents\demo_data.txt` or `/Documents/demo_data.txt`.

### 1.24. Reading strings from file

You can read strings of characters from a file as shown in the following example:

```
file = open("input.txt", 'r')
a = file.read() # Reads entire file into variable a
a = file.read(5) # Reads first five bytes of the file
a = file.readline() # Reads one line of the file
a = file.readlines() # Reads all the lines of the file into an array
```

Example 1.58. Reading text from files.
Note that everything will be read as a string, even numeric values. If you want to read numeric values in tabular form from a text file, see the Data Analysis Guide: Chapter 2 in Data Analysis Guide.

1.25. Writing numeric values to file

You can write numeric Jython data (single numbers, lists, tuples, dictionaries) to file with the pickle module. Use this method only if you want to write native Jython data and read it back with HIPE or with another Jython/Python interpreter. The pickle module has the following limitations:

- Data are written to the file in binary format, so you cannot read and change the file with a text editor.
- The pickle command can be used only with native Jython data. To save the HIPE-specific data described in Chapter 2, refer to the Data Analysis Guide: Chapter 2 in Data Analysis Guide.
- Do not use pickle if you want to exchange data with other applications. Instead, use table datasets, explained in Section 2.4, and save them to FITS or text files via a right click.

You can write data using pickle as in the following example:

```python
import pickle  # Importing module, you need to do it only once
a = [1,2,3]  # Creating two lists
b = [3,4,5]
file = open("output.txt", 'wb')
pickle.dump(a, file)  # Saving lists to file
pickle.dump(b, file)
```

Example 1.59. How to use the well-known pickle library.

See Section 1.26 for information on how to read back into HIPE data saved with pickle.

1.26. Reading numeric values from file

If you have written data to file using pickle (see Section 1.25) you can read them back as in the following example:

```python
import pickle  # Importing module, you need to do it only once
file = open("output.txt", 'rb')
a = pickle.load(file) # Read first record into a
b = pickle.load(file) # Read second record into b
# And so on until the end of the file
```

Example 1.60. Load data from file serialised using the pickle library.

Records can be simple numeric values or more complex Jython data structures such as lists, dictionaries or classes. The HIPE-specific data structures described in Chapter 2 cannot be read from file using pickle. For information on how to read data from text files into HIPE-specific data structures, see the Data Analysis Guide: Chapter 2 in Data Analysis Guide.

1.27. Functions

A function is a code block with a name. You use the function name to call the function, that is, to execute its code block.

A function may have a set of input parameters and one return parameter. Input parameters are values that the function needs to execute its code. The output parameter is the result of the code execution.

You create a function with the keyword def:

```python
def square (x):
```
Example 1.61. Defining functions in Jython.

The square function takes one input parameter, called x. The following line calls the function passing 2 as the value for the input parameter:

```python
print square(2)  # 4
```

The arguments of the functions are passed by value. This means that input arguments are not changed outside the function:

```python
def myfunc(a):
    a = a + 1
    return a

x = 4.0
print myfunc(x)  # Passing x as input parameter
# 5.0
print x  # The function returned 5.0, but x was not changed.
# 4.0
```

Example 1.62. Declaring functions for reuse.

Note that variables from the main HIPE session have global scope: they are accessible inside functions but cannot be changed. The example below gives an error:

```python
def myfunc(a):
    a = a + 1
    x = x + 5
    return a

x = 4.0
print myfunc(x)
# <type 'exceptions.UnboundLocalError'>: local variable 'x' referenced before assignment
```

Example 1.63. Global variables in Jython.

Using global variables. The following example shows a dangerous effect of relying on global variables:

```python
def myfunc(a):
    return a*z + 1

x = 4.0
z = 10.0
print myfunc(x)
# 41.0
```

Example 1.64. Declaring a global variable can be dangerous in an interpreted language like Jython.

The function works before the global variable z has been defined. However, there is no guarantee that z will be defined in future HIPE sessions, which could cause the function to give an error. The advice is to always pass global variables as function arguments, as in the following example:

```python
def myfunc(a, z):
    return a*z + 1

x = 4.0
z = 10.0
print myfunc(x, z)
```
# 41.0

Example 1.65. Passing global variables as function arguments.

**Default argument values.** Input arguments may have default values. This is illustrated by the following example:

```python
def myfunc(x,y=1.0,verbose=True):
    z = x*x + y
    if (verbose):
        print "The input is \%f \%f and the output is \%f \%(x,y,z)
    return z
```

```bash
# myfunc(5.0) # Using default values for y and verbose
# The input is 5.000000 1.000000 and the output is 26.000000
print myfunc(5.0, y=5.0, verbose=False)
# 30.0
print myfunc(5.0, 5.0, False) # The same as the previous
# 30.0.
print myfunc(5.0, 5.0)
# The input is 5.000000 5.000000 and the output is 30.000000
# 30.0
```

Example 1.66. Setting default values for function arguments.

**Functions as function arguments.** The arguments of a function can be functions themselves, like in the following example:

```python
def func1(x):
    return x*x

def func2(x):
    return x/2.0

def myfunc(f1,f2,x):
    return f1(x) + f2(x)
```

```bash
# x = 3.0
print myfunc(func1, func2, x)
# 10.5
# Even the user can input any available function of one argument
print myfunc(SIN, func1, x)
# 1.6411200080598671
```

Example 1.67. Passing functions as arguments is allowed in Jython.

**Functions without input arguments.** To define and call a function without input arguments, then the () brackets are still required:

```python
def myfunc(): # No arguments
    print "This function just prints a message."

# Calling the function
# This function just prints a message.
```

Example 1.68. Declaring a function without arguments.

### 1.28. Executing HIPE tasks from your scripts

HIPE tasks are prepackaged functions that take one or more input parameters and return results as output parameters. You can execute tasks from your scripts, thus taking advantage of HIPE advanced features.

All tasks have a graphical interface you can open from the Tasks view of HIPE. The graphical interface offers an easy way to find out the correct syntax to execute a task from a script:
1. Open the task graphical interface by double clicking on the task name in the Tasks view.

2. Fill the task parameters with values and press Accept to run the task.

3. The command corresponding to the task execution appears in the Console view. Copy the command to a new line of your script.

4. Make any changes to adapt the command to your script. For example, you may want to substitute a literal value with a variable name.

For more information on running tasks, see Chapter 6.

If you want to create a task from scratch, or to modify an existing task, see these tutorials on the HIPE community website:

- Creating your first Jython task
- Modifying an existing Jython task

1.29. Classes

A class is a bundle of variables and special functions called methods.

From a class you create, or instantiate, objects. You can think of a class as a blueprint from which you can create many objects.

Each object has a status and a behaviour. The status of an object is defined by its variables (also called instance variables), and its behaviour is defined by its methods.

See the following section for an example of creating and using a class in Jython.

1.30. Creating and using classes

The following code creates a class called Basket:

```python
class Basket:
    "A basket that can contain many items."  # <co id="Basket.doc-co"
linkends="Basket.doc" /></
    def __init__(self, contents=None):  # <co id="Basket.constr-co"
linkends="Basket.constr" />
        self.contents = contents or []  # <co id="Basket.__init__-co"
linkends="Basket.__init__" />
        def add(self, element):
            self.contents.append(element)  # <co id="Basket.add-co"
linkends="Basket.add" />
>
    def print_me(self):
        result = ""
        for element in self.contents:
            result = result + " " + `element`  # <co id="Basket.print_me-co"
linkends="Basket.print_me.add" />
        print "Basket contains: "+result
```

Example 1.69. How to create a Jython class.

Basket.doc-co: ???
This line is a documentation string, a short description of the class that you can see by invoking `print Basket.__doc__`(note the two underscore characters before and after doc).

Basket.constr-co: ???
This line declares a constructor, that is, a special method called __init__ that is called when ket.co you want to create an object from a class. Note the two underscore characters before and after str-constr, and the self parameter, which must always be present.

Basket.__init__-co: ???
This line defines the instance variable contents, which holds the contents of the basket. You ket.__init__pass-on contents when you create a Basket object, otherwise you get an empty basket.
Bas- The `add` methods adds an element to the contents of the basket (that is, to the `self.contents` variable).
Bas- This line, part of the `print_me` method, prints the contents of the basket. Note the use of the inverted commas around `element`.

The class has one variable `contents` and two methods, `add` and `print_me()` (following `def` in the above example).

You can put the above class definition in a script in the Editor view and run it all so that HIPE “knows” about the `Basket` class. Now you can instantiate the class, that is, create a particular basket from the `Basket` “blueprint”:

```python
a = Basket()  # ①
a.add("saw")  # ②
a.add("hammer")  # ③
a.print_me()  # ④
```

### Example 1.70. Instantiating and using methods from a class.

1. Sets up an empty basket called `a`.
2. Adds the item `saw` to the basket. It runs the `add` method on the object `a`.
3. Adds the item `hammer` to the basket.
4. Prints the contents of the basket called `a`, which should be `saw` and `hammer`. The command runs the `print_me` method on the object `a`.

You could equally have created your basket with one item:

```python
a = Basket(["saw"])
```

### Example 1.71. Passing parameters to the class constructor.

In the previous example `a` is the object, while `add` and `print_me` are the methods. Note that you do not explicitly call the `__init__` method when you construct an object. Instead, you call the class name, with or without arguments, depending on the class: in the previous examples, `a = Basket()` or `a = Basket(["saw"]).

### 1.30.1. Printing objects

You can use the special `__str__` method to define a string representation of an object, that is displayed when you use the `print` command on the object.

In the `Basket` class script, replace the `print_me` method with the following method:

```python
def __str__(self):
    result = ""
    for element in self.contents:
        result = result + " " + `element`
    result = "Basket contains: " + result
    return result
```

### Example 1.72. Overriding the default behaviour of the `__str__` method.

Now you can use `print str(a)` instead of `a.print_me()` to display the contents of the basket.
1.31. Naming conventions for classes and variables

The following rules are used to name classes and objects in HIPE. You are advised to follow the same rules when creating your own.

- **Classes**

  Class names consist of words with capitalised initials:

  - MyOwnClass
  - TableDataset
  - HifiProduct

- **Class instances (objects)**

  Objects (variables) of a particular class have names that start with the first letter in lower case. In general, this translates to the following:

    ```
    myOwnClass = MyOwnClass(...)
    table = TableDataset()
    a = 2
    ```

  **Example 1.73. Naming conventions for objects.**

- **Constants**

  Constants have names with all their letters capitalised and words separated by an underscore '_'. This rule also applies to so-called static instances. An example is SIN: it is the only allowed instance of class Sin, since it does not make sense to have multiple instances (they all would compute the sine of an angle in the same way). Some examples are the following:

  - VARIANCE
  - IS_FINITE
  - ALL_PRESENT

1.32. Creating aliases for class and function names

The names of classes and functions in HIPE are generally long and descriptive, such as TableDataset rather than TDset.

Longer, descriptive names tend to make scripts more readable. However, you can create shorter aliases to save typing as shown by the following example:

```
TDset = TableDataset
```

**Example 1.74. Creating aliases.**

You can now use TDset as you would use the original name TableDataset. For more information on what a TableDataset is, see Section 2.4.

1.33. Importing modules

Most useful classes and functions are put into Jython modules or Java packages. These are then imported into a given environment or program with the import statement.
In Python and Jython, source code is automatically organised in *modules* by means of each file being a module. Additionally, you can create *Jython packages*, which are directories with script files that also contain a special file called `__init__.py`. When importing other modules or packages, take special care in identifying the visibility of anything you have imported. For example, HCSS tasks usually have an alias (or short name, see the URM for reference), e.g.: `calcAttitude` is an alias for `CalcAttitudeTask`. If you want to use the alias of a task when using command-line `hipe` or when several packages are involved, the best way is to re-create the alias by instancing the task (see Section 1.31):

```python
from herschel.ia.toolbox.pointing import CalcAttitudeTask
calcAttitude = CalcAttitudeTask()
def function():
    calcAttitude(...)
```

**Example 1.75. Instantiating/aliasing an imported task.**

This instantiation statement will be imported along with your package or module and will be accessible when Jython executes `function` in the context of the caller module, avoiding a name not found error.

Try issuing the following command from within HIPE:

```
print localtime()
```

**Example 1.76. Executing methods from non-imported modules.**

You get an error:

```
<type 'exceptions.NameError'>: name 'localtime' is not defined
```

This is because, although the `localtime` function is part of the software distribution, it has not been imported into your session. The `localtime` function is part of the `time` Jython module, which you can import by issuing this command:

```python
import time
```

**Example 1.77. Import statement.**

This imports the entire module, but forces you to use the *qualified name* of the function (that is, including the module name):

```
print time.localtime()
# (2011, 9, 2, 12, 19, 46, 4, 245, 1)
```

**Example 1.78. Using names after importing a whole module.**

The following syntax allows you to use the `localtime` function without the qualified name:

```python
from time import localtime
print time.asctime(localtime())
# Fri Sep  2 12:20:31 2011
```

**Example 1.79.**

Note that `asctime`, which converts the time into a human-friendly format, still needs the qualified name. To import more than one name from a module, use a comma-separated list like in the following example:

```python
from time import localtime, asctime
print asctime(localtime())
```
Scripting and Jython basics

Example 1.80. Importing several names from a module.

Note that some of the names imported from the module could overwrite names you defined locally. To see all the names contained in a module, use the following command (here for the time module):

\[
\text{print dir(time)}
\]

To avoid name clashes, you can define a different name from what you import:

\[
\text{from time import localtime as ltime}
\]

\[
\text{print ltime()}
\]

# (2011, 9, 2, 12, 19, 46, 4, 245, 1)

Example 1.81. Aliasing imports to avoid name clashes.

Importing Java packages works in exactly the same way as importing Jython modules.

Most of the functions you are likely to need are imported automatically when HIPE starts, so you won’t need to use the import statement very often.

What modules can you import? The list of modules you can import into HIPE is virtually endless. Moreover, you will need only a small fraction of all the modules you can theoretically import. When a module is not imported automatically by HIPE, the code examples in the documentation show the necessary import statements.

If you want to have a look at what is available, these are some reference resources:

• HIPE-specific modules and packages. Chapter 8 has a list of the main packages that come with your HIPE installation. For a more comprehensive list see the Developer’s Reference Manual.

• Jython native modules. See the online Jython standard library reference.

• Java native packages. See the online Java reference documentation. This resources is likely to be useful only if you are familiar with Java and know what you are looking for.

Warning

Starting from HIPE 8, Jython was upgraded from version 2.1 to version 2.5. Some import rules have changed, which could cause old scripts to stop working. For more information see the Jython upgrade page on the Herschel public TWiki.

1.33.1. Importing, reloading and unimporting your own modules

Suppose you have written the module myModule.py and placed it into /home/user/some/ folder. The module file contains the following:

"""This module contains one simple function"

\[
\text{def simpleFunc():}
\]

\[
\text{print "Simple message."}
\]

Example 1.82. Self-contained module with documentation.

To have your module imported automatically when HIPE starts, you can modify the property hc-ss.interpreter.imports. To do so, follow these steps:

1. Choose Edit → Preferences. The Preferences window opens.
2. Click the Advanced button and answer Yes to the warning. The Properties window opens.

3. In the Filter by property name text field, write hcss.interpreter.imports. This property is the only one left in the list. If you have not modified it previously, its value should be `{}`.

4. Double click the Value cell to modify it. List all the files you want to import automatically, like in the following example (but all on the same line):

```
{ /home/user/some/folder/myModule.py,
  /home/user/another/folder/anotherModule.py }
```

5. Click Save and then Close. Click OK to close the Preferences window.

6. Restart HIPE. Your modules are now imported. In the case of the simpleFunc() example, the function will be immediately available in the Console view:

```
simpleFunc()
# Simple message.
```

**Example 1.83. Demonstrating that modules imported at start-up are available in HIPE.**

With this property you can also execute a list of custom import statements when HIPE starts. Just add them to a file, for instance imports.py:

```
from some.module import Foo
from another.module import Bar
```

**Example 1.84. Creating a file with just imports for HIPE start-up.**

Then add the imports.py file to the hcss.interpreter.imports property:

```
{ /home/user/some/folder/myModule.py,
  /home/user/another/folder/anotherModule.py,
  /home/user/yet/another/folder/imports.py }
```

If your module is not imported automatically, you can import it on the fly within HIPE. First you have to add the directory containing the module to the list of paths searched by Jython:

```
import sys
sys.path.append('/home/user/some/folder')
import myModule
myModule.simpleFunc()
# Simple message.
```

**Example 1.85. How to modify the Jython classpath at runtime.**

**Reloading a module.** If you modify your module and want to apply the changes to your current HIPE session, use the reload command:

```
reload(myModule)
```

**Example 1.86. Reloading updates the module loaded in memory with the latest changes from the source files.**

**Unimporting a module.** To unimport a module so that it is no longer available in your HIPE session, use the del command:

```
del(myModule)
```

**Example 1.87. Removing a module from memory using del.**
Of course this command does not delete the `myModule.py` file.

### 1.34. Understanding pipeline scripts

Rather than writing scripts from scratch, you may have to understand and possibly modify scripts written by others. This is especially true for pipeline scripts, available from the Pipelines menu in HIPE. These are the scripts you run when you want to reprocess your data.

Pipeline scripts are essentially a series of task calls. For specific details on running and understanding pipeline scripts for a given instrument and observing mode, see the instrument manuals:

- HIFI
- PACS photometry
- PACS spectroscopy
- SPIRE photometry
- SPIRE spectroscopy

To fully understand a pipeline script you must also understand the tasks it calls. You can see the documentation and the source code of each task by following these steps:

1. Find the task in the Tasks view and double click on it. The task dialogue window opens in the Editor view of HIPE.

2. Click Help to open the task entry in the User's Reference Manual.

3. Click Source to open the source code of the task in the Editor view. For this to work you must have chosen to include the source code when installing HIPE.

Note that most HIPE tasks are written in Java, so you will need some familiarity with this language to understand their source code.

### 1.35. Accessing files and directories

It is possible to print the file contents of the current working directory using the following in a console window.

```python
import os

# Print the working directory
print os.getcwd()
# Print the names of the files in the working directory
print os.listdir(os.getcwd())
# Any directory name can be placed in the brackets
print os.listdir('anotherDirectory')
```

**Example 1.88. How to list the contents of the current directory.**

The `listdir` provides an unsorted listing of all the files and subdirectories within a directory. Use the `glob` module to filter the file list. You can use wildcards such as `*`, `?`, `[]` and so on:

```python
import glob
fitsfiles = glob.glob("/my/directory/*.fits")
# fitsfiles is a list of the files that were found.
print fitsfiles  # Print the list
```

**Example 1.89. Using the glob module to recursively list files with wildcard matching.**
1.36. Adding simple dialogue windows

This section explains how you can make your scripts more interactive, having them asking the user for input and reacting accordingly.

The scripts in the following subsections use Swing, a Java library used to create graphical interfaces. For more information about using Swing in Jython scripts, a possible source is the first chapter of the *Jython Book*.

1.36.1. Dialogue box with message

The following example shows how to display a message in a window, together with an OK button:

```python
from javax.swing import JOptionPane
print "Let's stop for a while"
JOptionPane.showMessageDialog(None, "Press OK to continue")
print "Well done."
```

Example 1.90. Using pure Java to display dialogues to the user.

The first line imports the swing package (note that it is `javax` rather than `java`). Then we have the line creating the window, embedded between two lines printing text messages to demonstrate that the script will not advance until we press the OK button.

![Figure 1.1. The window that appears calling the Swing showMessageDialog method.](image)

In the above example, the first parameter of `showMessageDialog` is set to `None`. This parameter indicates the "parent" element of the dialogue box. For creating single dialogue boxes, you do not need to set this parameter to anything else.

You can add two more parameters to customise the window title and the icon:

```python
JOptionPane.showMessageDialog(None, "Press OK to continue", "Title bar text", \
JOptionPane.ERROR_MESSAGE)
```

Example 1.91. Configuring the style of Java dialogues.

Note that the third and four parameters must both be present. You cannot specify only the title or the icon.

![Figure 1.2. Customising the icon and the window title.](image)
Besides `ERROR_MESSAGE`, other available icons are `INFORMATION_MESSAGE`, `WARNING_MESSAGE`, `QUESTION_MESSAGE` and `PLAIN_MESSAGE`.

### 1.36.2. Dialogue box with text input field

The following command creates a window for entering text, just like the `raw_input` function:

```python
myAnswer = JOptionPane.showInputDialog(None, "Please write something, anything")
```

**Example 1.92. Using input dialogues to retrieve data from the user.**

![Image of input dialog window]

**Figure 1.3. The window that appears calling the Swing `JOptionPane.showInputDialog` method.**

Additional options are available for this method as well:

```python
myAnswer = JOptionPane.showInputDialog(None, "Please write something, anything", "Big question", JOptionPane.QUESTION_MESSAGE)
```

**Example 1.93. Customising the style of input dialogues.**

You can also put a default string of text in the box, like this:

```python
myAnswer = JOptionPane.showInputDialog(None, "Please write something, anything", "Default text")
```

**Example 1.94. Providing a default value for input dialogues.**

If you want the user to choose from a predefined set of options, you can use `JOptionPane.showInputDialog`, as the following script demonstrates:

```python
from javax.swing import JOptionPane
myAnswer = 
possibleAnswers = ["HIFI", "PACS", "SPIRE", "No clue", "All three"]
while myAnswer == 
    myAnswer = JOptionPane.showInputDialog(None, "Favourite Herschel instrument?", "Test", JOptionPane.QUESTION_MESSAGE, None, possibleAnswers, possibleAnswers[4])
if myAnswer == None:
    myAnswer = 
print "Your answer is: " + myAnswer
```

**Example 1.95. Using lists to restrict the values to use in an input dialogue.**

![Image of input dialog window with combo box]

**Figure 1.4. A more complex window with a combo box.**
Let us go through the parameters one by one:

1. None: the "parent" element.
2. "Favourite Herschel instrument?": the window text.
3. "Test": the window title text.
4. JOptionPane.QUESTION_MESSAGE: the type of window.
5. None: the custom icon. We choose to provide no one and stick with the default one.
6. possibleAnswers: the array of possible answers.
7. possibleAnswers[4]: the default answer.

### 1.36.3. Dialogue box asking yes/no question

The `showConfirmDialog` method can be used to display a window asking the user to confirm or block a certain action:

```python
from javax.swing import JOptionPane
myAnswer = JOptionPane.showConfirmDialog(None, "Yes or no?")
if myAnswer == 0:           # Now myAnswer is an integer variable
    print "You agree"
elif myAnswer == 1:
    print "You disagree"
else:
    print "You have no opinion on this"
```

**Example 1.96. Displaying a confirmation dialogue.**

![Image of a confirmation dialogue box](image)

**Figure 1.5. Using the Swing `showConfirmDialog` method.**

You can use predefined constants to make the code easier to understand:

```python
from javax.swing import JOptionPane
myAnswer = JOptionPane.showConfirmDialog(None, "Yes or no?")
if myAnswer == JOptionPane.YES_OPTION:
    print "You agree"
elif myAnswer == JOptionPane.NO_OPTION:
    print "You disagree"
elif myAnswer == JOptionPane.CANCEL_OPTION:
    print "You have no opinion on this"
elif myAnswer == JOptionPane.CLOSED_OPTION:
    print "You closed the window. How rude!"
```

**Example 1.97. Using constants instead of the automatic indexes to improve readability.**

You can add another two parameters to provide a title for the window and the type of buttons you want:

```python
myAnswer = JOptionPane.showConfirmDialog(None, "Yes or no?", "Question", \
```
Example 1.98. Adding title and button type to the confirmation dialogue.

Other possible options are YES_NO_CANCEL_OPTION, OK_CANCEL_OPTION, both self-explanatory, and DEFAULT_OPTION, which just displays an OK button.

1.37. Pausing and debugging scripts

You can pause a script at any point using the pause() command. This allows you to inspect and change variable values while the script is paused, and to resume execution with the new values. This is especially useful to diagnose problems in a script.

Run the following example script:

```python
a = 10
pause() # Pause here. You can change the value of a in the debugger.
print a
pause() # Pause again.
pause() # Pause again.
```

Example 1.99. Pausing a script to allow debugging or printing text to console.

When the first pause() statement is reached, the following window appears:

![Debug window](image)

Click on a variable name to display a summary in the right-hand area of the window. You can also change the value of a variable at the DEBUG> prompt. For example, try changing the value of `a` by writing `a = 100` at the DEBUG> prompt and pressing Enter. Then resume the script execution by choosing Console → Resume, and see the new value for `a` reflected in the print statements.

Another way to resume the execution of the script is to issue the resume() command at the DEBUG> prompt. Note that using resume() elsewhere, for instance in a script or in the Console view, has no effect.

1.38. Interoperating with external software

HIPE offers a complete solution for reducing, visualising and analysing your data. However, for a variety of reasons you may want to do some processing with other astronomical or data analysis software, such as IDL or IRAF. This section explains how to do that.

Any data processing, whether done through an official pipeline or a custom script, is a series of tasks applied on products, like in the code fragment below. For more information on tasks, see Chapter 6; for more information on products, see Section 2.8.
Example 1.100. Outline on how to create a pipeline executing tasks sequentially.

Any task can output a product representing the state of processing up to that point. For example, `product_2` is the result of processing by `TaskA`, before `TaskB` is applied.

To continue processing outside HIPE, you only have to export a product to FITS format, as explained in the *Data Analysis Guide*. See also the `simpleFitsWriter` entry in the *User's Reference Manual*: Section 1.383 in *HCSS User's Reference Manual*.

You can start processing outside HIPE with the `system` instruction. For example, to launch the `my-Command` command insert the following in your script:

```python
os.system('myCommand')
```

Example 1.101. Executing platform binaries from within HIPE.

For this to work you need to import the `os` module first:

```python
import os
```

Example 1.102. Importing the Jython module that allows communication with the operating system.

**Note**

With `os.system` you execute external software *outside* HIPE, which means that you will not get feedback from the external command in the *Console* view of HIPE. For example, if you are working on Linux and try to list files in the current directory with the following command, you will not get any result:

```python
os.system('ls')
```

However, if you started HIPE from a command line window, you will see the output of the `ls` command in that window.

By the way, you can use this command to obtain a list of files in the current directory from within HIPE:

```python
print os.listdir('.')
```

Example 1.103. Listing the contents of a directory.

The `myCommand` executable could be, for instance, a shell script with further processing instructions. Whatever your external processing, it *must* accept as input the FITS file produced by HIPE, and *must* output another FITS file that can then be loaded into HIPE again. For more information on how to load a FITS file into HIPE, see the `fitsReader` entry in the *User's Reference Manual*: Section 1.147 in *HCSS User's Reference Manual*.

A script with part of the processing carried out outside HIPE would look something like this:

```python
import os
aProduct = aTask()(inputProduct)
simpleFitsWriter(product = aProduct, file = "aProduct.fits")
os.system('myCommand')  # Reads aProduct.fits, produces output.fits
outputProduct = fitsReader(file = "output.fits")
```

Example 1.104. Mixed processing with external commands and HIPE tasks.

### 1.39. Developing version-aware scripts
There are times when you require your scripts to check for the current HIPE version in order to use features that were introduced in a particular version or build. To do that you have two options, depending on the type of HIPE release that you want to check.

- **User releases:** These releases are downloaded from the HIPE official page and use a Java-based installer that sets some properties in several configuration files. One of these properties is `hcss.release.user` and can be retrieved in Jython using the standard Java method:

  ```java
  version = java.lang.System.getProperty("hcss.release.user")
  ```

  **Example 1.105. Getting the version number of a user release (method 1).**

  Note that you can also use the `Configuration` class to retrieve this property:

  ```java
  version = Configuration.getProperty("hcss.release.user")
  ```

  **Example 1.106. Getting the version number of a user release (method 2).**

  The string returned by both methods contains the version number in "major.minor" format.

- **Developer builds (also known as CIB builds):** These releases are generated each time a new change in HIPE is integrated and can be downloaded from the Continuous Integration Build (CIB) system pages.

  These builds do not set any property in the configuration system, but there are static methods (in the `Configuration` class) to obtain the version of a particular developer build. You can see an example using these methods below:

  ```java
  pi = Configuration.getProjectInfo()
  pi.getBuild() # Retrieves the build number
  pi.getTrack() # Retrieves the version (in "major.minor" format)
  pi.getVersion() # Retrieves the complete version string (in "major.minor.build" format)
  ```

  **Example 1.107. Getting the build number of a developer build.**

### 1.40. Sharing scripts

If you have a small number of files you want to share with your colleagues, you can just send the `.py` files by whatever means you prefer, for example by email.

If you have larger collections of scripts, you may want to pack them into a HIPE plug-in. This allows other users to easily install, update and remove all your scripts at once.

To share Jython scripts as a HIPE plug-in, follow these steps:

1. Put all the scripts you want to share into a directory and rename this directory `scripts`.
2. Compress the directory into a zip file. The zip file must contain the `scripts` directory with the scripts, not just the scripts.
3. Rename the zip file as follows: plug-in name, followed by an underscore, followed by a version number. The version number can be any number of digits separated by dots. An example of a valid file name is `MyScripts_0.1.zip`.
4. The zip file is the plug-in itself. You can now share it, for example by linking to it from a web page.
1.41. IDL to HIPE command mapping

1.41.1. Idl to Jython mapping

The following tables contain the HIPE equivalents of the most common IDL commands and functions.

**Warning**

HIPE uses \([row, column]\) as notation for two-dimensional arrays, while IDL uses \([column, row]\). In addition, HIPE uses row major ordering when allocating array elements into memory: elements in the first row are allocated first, followed by elements in the second row, and so on. IDL uses column major ordering instead. This difference also holds for arrays of more than two dimensions.

This means that IDL scripts involving loops on large arrays will suffer big performance penalties unless they are adapted to row major ordering. Write your loops so that elements are accessed in the same order they are located in memory:

```python
x = [[1,2,3], [4,5,6]]  # Two rows, three columns
# Order of elements in memory:  1  2  3  4  5  6
# Correct way of looping:
for i in range (2):  # Loop on rows
    for j in range (3):  # Loop on columns
        print x[i][j]
```

You should also use array operations instead of loops whenever possible. Look here for more information: [Section 2.2.10](#).

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</tr>
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</tr>
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<td><code>0</code></td>
<td><code>0</code></td>
</tr>
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<td><code>wait</code></td>
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</tr>
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<td>Execute script</td>
<td><code>execute()</code></td>
<td><code>exec()</code></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plot commands</th>
<th>IDL</th>
<th>HIPE equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open a plotting window</td>
<td><code>window.retain = 2</code></td>
<td><code>p = \text{PlotXY}()</code></td>
</tr>
<tr>
<td>Plot two numeric arrays a &amp; b</td>
<td><code>plot,a,b</code></td>
<td><code>p = \text{PlotXY}(a,b)</code></td>
</tr>
</tbody>
</table>
### Plot commands

<table>
<thead>
<tr>
<th>IDL</th>
<th>HIPE equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>plot,a,b,[xy]range = [0.,10.], [xy]title = &quot;lambda&quot;</td>
<td>PlotXY(a,b,[xy]range = [0.,10.], [xy]title = &quot;$\lambda$&quot;)</td>
</tr>
<tr>
<td>plot,a,b,linestyle = 1</td>
<td>p.style.line = 2</td>
</tr>
<tr>
<td>plot,a,b,psym = 2</td>
<td>p.style.symbol = 5</td>
</tr>
<tr>
<td>plot,a,b,title TEXT = 'title'</td>
<td>PlotXY(a,b,titleText = 'title')</td>
</tr>
<tr>
<td>oplot,a,c</td>
<td>p[1] = LayerXY(a,c)</td>
</tr>
<tr>
<td>xyouts,0.2,0.7,Label</td>
<td>d.addAnnotation(&quot;Label&quot;, 0.2, 0.7)</td>
</tr>
<tr>
<td>set_plot,'ps'</td>
<td>p.saveAsEPS(&quot;file.ps&quot;)</td>
</tr>
<tr>
<td>device, filename = &quot;file.ps&quot;</td>
<td></td>
</tr>
<tr>
<td>device, close</td>
<td></td>
</tr>
<tr>
<td>p.saveAsJPG(&quot;file.jpg&quot;)</td>
<td></td>
</tr>
<tr>
<td>p.saveAsPNG(&quot;file.png&quot;)</td>
<td></td>
</tr>
<tr>
<td>p.saveAsPDF(&quot;file.pdf&quot;)</td>
<td></td>
</tr>
<tr>
<td>(right-click on plot and select Properties)</td>
<td></td>
</tr>
</tbody>
</table>

### Data import/export commands

<table>
<thead>
<tr>
<th>IDL</th>
<th>HIPE equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>readcol,'file.dat',a,b,c</td>
<td>t = simpleAsciiTableReader(file = &quot;file.dat&quot;)</td>
</tr>
<tr>
<td>plot,a,b</td>
<td>p = PlotXY(t[&quot;c0&quot;].getData(), t[&quot;c1&quot;].getData())</td>
</tr>
<tr>
<td>readcol,'file.csv', DELIMITER = ','</td>
<td>t = asciiTableReader(file = &quot;file.csv&quot;)</td>
</tr>
<tr>
<td>im = mrdfits(&quot;image.fits&quot;)</td>
<td>im = fitsReader(file = &quot;image.fits&quot;)</td>
</tr>
<tr>
<td>tvcsl,im</td>
<td>right-click on &quot;im&quot; and Open with &quot;ImageViewer&quot;</td>
</tr>
<tr>
<td>cube = mrdfits(&quot;cube.fits&quot;)</td>
<td>im = fitsReader(file = &quot;cube.fits&quot;)</td>
</tr>
<tr>
<td>sp = mrdfits(&quot;spec.fits&quot;)</td>
<td>sp = fitsReader(file = &quot;spec.fits&quot;)</td>
</tr>
<tr>
<td>plot, wave, flux</td>
<td>right-click on &quot;sp&quot; and Open with &quot;SpectrumExplorer&quot;</td>
</tr>
<tr>
<td>mwrfits,image,'image.fits'</td>
<td>simpleFitsWriter(product = image, file = &quot;image.fits&quot;)</td>
</tr>
<tr>
<td>asciiTableWriter(table = t, file = &quot;file.csv&quot;)</td>
<td></td>
</tr>
</tbody>
</table>
### Data import/export commands

<table>
<thead>
<tr>
<th>Data import/export commands</th>
<th>IDL</th>
<th>HIPE equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>openw,u,'file.csv'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>printf,u,a,b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>close,u</td>
<td></td>
<td></td>
</tr>
<tr>
<td>free_lun,u</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Arithmetics commands

<table>
<thead>
<tr>
<th>Arithmetics commands</th>
<th>IDL</th>
<th>HIPE equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add</td>
<td>3 + 4</td>
<td>3 + 4</td>
</tr>
<tr>
<td>Powers</td>
<td>3^4</td>
<td>3**4</td>
</tr>
<tr>
<td>Absolute value</td>
<td>abs()</td>
<td>absolute(), fabs()</td>
</tr>
<tr>
<td>Arc cosine</td>
<td>acos()</td>
<td>arccos()</td>
</tr>
<tr>
<td>Natural logarithm</td>
<td>alog()</td>
<td>log()</td>
</tr>
<tr>
<td>Base 10 logarithm</td>
<td>alog10()</td>
<td>log10()</td>
</tr>
<tr>
<td>Arc sine</td>
<td>asin()</td>
<td>arcsin()</td>
</tr>
<tr>
<td>Arc tangent</td>
<td>atan()</td>
<td>arctan()</td>
</tr>
<tr>
<td>Ceil</td>
<td>ceil()</td>
<td>ceil()</td>
</tr>
<tr>
<td>Conjugate</td>
<td>conj()</td>
<td>conjugate()</td>
</tr>
<tr>
<td>Cosine</td>
<td>cos()</td>
<td>cos()</td>
</tr>
<tr>
<td>Hyperbolic cosine</td>
<td>cosh()</td>
<td>cosh()</td>
</tr>
<tr>
<td>Exponential</td>
<td>exp()</td>
<td>exp()</td>
</tr>
<tr>
<td>Floor</td>
<td>floor()</td>
<td>floor()</td>
</tr>
<tr>
<td>Invert (matrix)</td>
<td>invert()</td>
<td>Matrix (module)</td>
</tr>
<tr>
<td>Bit shift operations</td>
<td>ishft()</td>
<td>right_shift(),left_shift()</td>
</tr>
<tr>
<td>Sine</td>
<td>sin()</td>
<td>sin()</td>
</tr>
<tr>
<td>Hyperbolic sine</td>
<td>sinh()</td>
<td>sinh()</td>
</tr>
<tr>
<td>Square root</td>
<td>sqrt()</td>
<td>sqrt()</td>
</tr>
<tr>
<td>Tangent</td>
<td>tan()</td>
<td>tan()</td>
</tr>
<tr>
<td>Hyperbolic tangent</td>
<td>tanh()</td>
<td>tanh()</td>
</tr>
<tr>
<td>Random 0-1 generator</td>
<td>randomu()</td>
<td>random()</td>
</tr>
<tr>
<td>Reverse array 'a'</td>
<td>reverse(a)</td>
<td>a[:::-1]</td>
</tr>
<tr>
<td>Collapse array</td>
<td>total(a)</td>
<td>sum(a)</td>
</tr>
<tr>
<td>Number of elements</td>
<td>n_elements()</td>
<td>len(), size()</td>
</tr>
<tr>
<td>Number of parameters</td>
<td>n_params()</td>
<td>len(*args)</td>
</tr>
<tr>
<td>Extra parameters</td>
<td>_extra</td>
<td>**kwargs</td>
</tr>
<tr>
<td>Array size</td>
<td>size()</td>
<td>shape(), arrayvar.type()</td>
</tr>
</tbody>
</table>

These are external resources that you may find useful:

- [IDL to Python](#)
- [Jython homepage](#)
HIPE is based on Jython 2.5. External examples for different Jython/Python versions might not always work.
Chapter 2. Arrays, datasets and products

2.1. HIPE-specific data structures

The previous chapter described some data structures available in Jython, such as tuples and dictionaries. This chapter introduces other data structures available in HIPE, but that are not part of Jython:

- **Numeric arrays**: arrays of boolean, integer, floating point or complex values, from one to five dimensions. One of their major advantages with respect to Jython lists is the ability to do array arithmetic in single line commands rather than having to loop through arrays.

- **Datasets**: sets of arrays with additional information, such as a description of the content of each array, measurement units, and other metadata. Metadata consist of keyword-value pairs and have the same role as keywords and their values in the header of a FITS file.

There are three types of datasets:

- **Array datasets**: an array dataset contains a single numeric array.

- **Table datasets**: a table dataset contains one or more numeric arrays organised in columns. The arrays can be of different types and sizes.

- **Composite datasets**: a composite dataset is a container for other datasets, including other composite datasets.

- **Products**: sets of one or more datasets with additional metadata.

- **Contexts**: special products acting as containers for other products, including other contexts.

2.2. Numeric arrays

Numeric arrays available in HIPE are shown in the following table. A numeric array can have from one to five dimensions.

For completeness the following table also shows the String1d array type, which is not a numeric array. String arrays can only be one-dimensional.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>BoolNd</td>
<td>boolean</td>
</tr>
<tr>
<td>ByteNd</td>
<td>byte</td>
</tr>
<tr>
<td>ShortNd</td>
<td>short</td>
</tr>
<tr>
<td>IntNd</td>
<td>integer</td>
</tr>
<tr>
<td>LongNd</td>
<td>long</td>
</tr>
<tr>
<td>FloatNd</td>
<td>float</td>
</tr>
<tr>
<td>DoubleNd</td>
<td>double</td>
</tr>
<tr>
<td>ComplexNd</td>
<td>complex</td>
</tr>
<tr>
<td>String1d</td>
<td>string</td>
</tr>
</tbody>
</table>
Arrays, datasets and products

Differences with Jython native arrays. Numeric arrays are optimised for holding Herschel data and for working with HIPE tasks and tools. Many tasks and functions accept Numeric arrays as their input, but not native Jython arrays. You are advised to use Numeric arrays when manipulating Herschel data.

2.2.1. Creating an array

See the following example for various ways in which you can create a one-dimensional array:

```python
y = Double1d() # Create an empty array
y = Double1d([3.0, 5.5, 2.1, 6.0]) # Create from a Jython array
y = Double1d(4) # [0.0, 0.0, 0.0, 0.0]
```  

Example 2.1. Declaring an array of doubles.

You can create a complex array, with the same commands. In addition, you can specify real and imaginary parts separately:

```python
y = Complex1d() # Create an empty array
y = Complex1d([1+4j, 2+3j, 5+8j]) # Create from a Jython array
y = Complex1d([1, 2, 5], [4, 3, 8]) # Same result as previous command
y = Complex1d(4) # [0j, 0j, 0j, 0j]
```  

The following example shows how to create a two-dimensional array. You can create arrays of more dimensions in the same way:

```python
y = Double2d() # Create an empty array
y = Double2d([[3.0, 5.5], [2.1, 6.0]]) # Create from a Jython array
y = Double2d(4, 4) # Creates a 4x4 array whose values are all zero.
y = Double2d(4, 4, 42.0) # Creates a 4x4 array whose values are all 42.
```  

Example 2.2. Declaring a two-dimensional array of doubles.

Rectangular and jagged arrays. Rectangular arrays are multidimensional arrays which always have the same number of elements in each row or column. Jython and Java allow you to create jagged arrays. Jagged arrays are multidimensional arrays where each row can have a different number of elements. The following example creates a two-dimensional jagged array, with two rows of two and three elements, respectively:

```python
x = [[1,2], [3,4,5]]
```  

Example 2.3. Creating Jython jagged arrays.

However, you cannot create Numeric jagged arrays:

```python
x = Double2d([[1,2], [3,4,5]]) # Gives an error
```  

Example 2.4. It is impossible to create Numeric jagged arrays.

2.2.2. Inspecting an array

Array elements along each dimension are defined by an index running from zero to the array length, minus one:

```python
x = Double1d([3.0, 5.0, 9.0, 4.3]) # Four elements
print x[0] # Prints the first element, 3.0
```
Example 2.5. Accessing array elements using the indices.

To access ranges of elements, or slices, use a notation like `[i:j]`:

```python
print x[3]  # Prints the fourth element, 4.3
```

```python
print x[1:3]  # From index 1, included, to 3, excluded
# [5.0,9.0]
print x[2:]  # From index 2, included, to end of array
# [9.0,4.3]
print x[:3]  # From start of array to index 3, excluded
# [3.0,5.0,9.0]
```

Example 2.6. Using array slices to access ranges from Jython lists.

To access elements in multi-dimensional arrays, separate indices or ranges along each dimension with commas:

```python
x = Int2d([[1,2,3],[4,5,6]])
#   1 2 3
#   4 5 6
print x[1]                # 2 (second element of the first row)
print x[0,:]              # Row 0: [1,2,3]
print x[1,1]              # Individual element: 5
print x[:,:]              # Print entire array. Same as print x
print x[:,1]              # Column 1: [2,5]
```

Example 2.7. Accessing ranges of indices using slices.

Multi-dimensional arrays are conceptually arrays of lower-dimensional arrays. For a two-dimensional array, the first subscript selects a row and the second subscript selects an element within that row (the column).

```
Note
This is the opposite order to some other computer languages, but it is the same behaviour as in the Java programming language.
```

Note the difference in syntax when inspecting native Jython arrays and numeric arrays:

```
# Jython array:
x = [[1,2,3,4],[5,6,7,8]]
print x[1][2]       # 7
print x[1][1:3]     # 6, 7

# Numeric array:
y = Int2d([[1,2,3,4],[5,6,7,8]])
print y[1,2]        # 7
print y[1,1:3]      # 6, 7
```

Example 2.8. Checking the differences between Jython arrays and numeric arrays.

### 2.2.3. Inspecting a complex array

Complex arrays offer the following additional commands:

```python
z = Complex1d([1,2,3,4],[4,3,2,1]) # Set up complex array
print z.real # [1.0,2.0,3.0,4.0]
print z.imag # [4.0,3.0,2.0,1.0]
print z.conjugate() # [(1.0-4.0j),(2.0-3.0j),(3.0-2.0j),(4.0-1.0j)]
```

Example 2.9. Inspecting and manipulating a Complex Numeric array.

### 2.2.4. Modifying an array
You can append single values or entire arrays to an existing array:

```python
y = Double1d()
y.append(2.0)  # Append a single value
y.append(Double1d([3.0, 7.5, 2.8]))  # Append a whole array
```

**Example 2.10.** Appending values to an array.

Individual elements or slices can be set as follows:

```python
x[1,2] = 22  # Set an element in place
x[0,1:3] = 42
print x  # 
    # [2.0,42.0,42.0],
    # [1.0,3.0,22.0]
```

**Example 2.11.** Assigning values with the use of indices and slice notation.

It is possible to set a row to a copy of a 1d array of the same length:

```python
x[0,:] = [5,6,7,8]        # Set a row to (a copy of) a Jython array
y[1,:] = Int1d([9,7,6,5]) # Set a row to a Double1d array
```

**Example 2.12.** Assign arrays to arrays using slice notation.

### 2.2.5. Ordering of array elements

The following line of code creates an array of two rows and three columns:

```python
x = Double2d([[2,4,6],[1,3,5]])
```

**Example 2.13.** Declaring multidimensional Numeric array.

You can access the element corresponding to the \(i\)-th row and \(j\)-th column like this:

```python
x[i, j]
```

**Example 2.14.** Accessing elements in multidimensional arrays.

The values are stored sequentially in memory as follows:

```plaintext
[2 4 6 1 3 5]
```

This means that, if you go through the array elements as they are stored in memory, their indices would vary as follows:

```plaintext
x[0,0] x[0,1] x[0,2] x[1,0] x[1,1] x[1,2]
```

That is, index \(j\) varies more rapidly than index \(i\). This can be generalised to more than two dimensions by saying that the rightmost index varies most rapidly. This is called row-major ordering, and is the convention followed by languages such as Java and C, but not Fortran.

This has an implication on performance. When looping through a multidimensional array, it is more efficient to read its elements in the order they are stored in memory.

Confusion may arise when dealing with images, which are stored as two-dimensional arrays. If you visualise the array with horizontal rows and vertical columns, then the number of rows and columns represents the size of the vertical \((y)\) and horizontal \((x)\) side of the image, respectively. When accessing a particular pixel (array element), you have to specify the \(y\) coordinate before the \(x\) coordinate:

```python
myImage(y, x)
```
2.2.6. Numeric array arithmetic

HIPE numeric arrays support arithmetic operations that are applied element-by-element. For example:

```python
y = Double1d.range(5)                  # [0.0,1.0,2.0,3.0,4.0]
print y * y * 2 + 1                    # [1.0,3.0,9.0,19.0,33.0]
```

Example 2.15. Applying multiplication and addition to all elements of an array.

This is much simpler (and runs much faster) than writing an explicit loop in Jython. The `+` operator does not concatenate arrays, as it does with Jython arrays. For example:

```python
# Adding Jython arrays
print [0,1,2,3] + [4,5,6,7]                  # [0, 1, 2, 3, 4, 5, 6, 7]

# Adding numeric arrays
print Double1d([0,1,2,3]) + Double1d([4,5,6,7])       # [4.0,6.0,8.0,10.0]

# Concatenate two numeric arrays
print Double1d([0,1,2,3]).append(Double1d([4,5,6,7])) # [0.0,1.0,2.0,3.0,4.0,5.0,6.0,7.0]

# Adding Jython arrays to numeric arrays
print [0,1,2,3] + Double1d([4,5,6,7])        # [4.0,6.0,8.0,10.0]
print Double1d([0,1,2,3]) + [4,5,6,7]        # [4.0,6.0,8.0,10.0]
```

Example 2.16. Concatenating numeric arrays.

All arrays support the following arithmetic operators:

```
+, -, *, /, %, **
```

Note that the 'modulo' operator `%` provides the normal Jython semantics for this operation, which is not the same as that of the Java '%' operator. The Jython definition is more consistent with the mathematical notion of congruence for negative values.

The following relational operators return a `Bool1d` array:

```
<, >, <=, >=, ==, !=
```

For example:

```python
y = Double1d([0,1,2,3,4])
print y > 2                         # [false,false,false,true,true]
```

Example 2.17. Applying relational operators to a Numeric array.

2.2.7. Selecting and filtering array values

Use the `where` function to select the elements of an array that satisfy a given condition:

```python
y = Double1d([2,6,3,8,1,9])
print y.where(y > 4) # [1,3,5] Indices of elements greater than four
```

Example 2.18. Filtering array elements with the where method.

Note that the result contains the indices of the elements that satisfy the condition, not the elements themselves. You can combine more conditions with the & (and), | (or) and ~ (not) operators:

```python
print y.where((y > 4) & (y < 9)) # [1,3]
print y.where((y > 8) | (y < 2)) # [4,5]
```
Arrays, datasets and products

Example 2.19. More complex filtering using the where method.

You can obtain the actual array elements instead of the indices as follows:

```python
print y where(~(y > 4))  # [0, 2, 4]
```

```python
print y[y where(y > 4)]  # [6.0, 8.0, 9.0]
print y.get(y > 4)  # [6.0, 8.0, 9.0]
```

Example 2.20. Accessing the array values with a filter.

Obtaining the indices rather than the actual values can be useful, for instance, when you want to select the same elements from different arrays:

```python
x = Double1d([5, 6, 7, 8, 9, 10])
s = y where(y > 4)
print x[s] + y[s]  # [12.0, 16.0, 19.0]
```

Example 2.21. Accessing the array values with a filter.

You can also use the where function to set values:

```python
s = y where(y > 4)
y[s] = 0  # Set all matching elements to 0
print y  # [2.0, 0.0, 3.0, 0.0, 1.0, 0.0]
y[s] = [9, 8, 7]  # Set matching elements using an array
print y  # [2.0, 9.0, 3.0, 8.0, 1.0, 7.0]
```

Example 2.22. Assigning values with the results of the where method.

You cannot use the where function like this:

```python
a = Double1d.range(10)
b = a where(a < 3)
print b[0]  # AttributeError: __getitem__
print b[0:2]  # AttributeError: __getitem__
print a[b[0]]  # AttributeError: __getitem__
```

Example 2.23. The output list of where is not accessible by index.

The commands fail because `b` is a Selection object rather than a Jython or Numeric array. For the above to work you need to convert it to Int1d:

```python
c = b.toInt1d()
print c[0]  # 0
print c[0:2]  # [0, 1]
print a[c[0]]  # 0.0
```

Example 2.24. Converting the output of where to a normal array that you can manipulate.

By converting to Int1d you can also loop over all the selected elements:

```python
for i in c:
    print a[i]
```

Example 2.25. Converting the output of where makes the resulting object iterable.

Another useful function is `get`, with which you can extract individual elements or a subset of element values from an array. There are four ways to use it:

- Get a single value:

```python
HIPE> print y.get(0)
```
This is the same as `print y[0]`.

- Retrieve elements based on a `Bool1d` array (in other words, a mask):

  ```python
  HIPE> mask = Bool1d([0,0,1,0,1,1])
  HIPE> print y.get(mask)
  [3.0,1.0,9.0]
  ```

  The mask array can be shorter than the target array (in which case the remaining elements in the target array will be ignored), but not longer.

- Retrieve elements based on a `Selection` object:

  ```python
  HIPE> indices = Selection([1,2,4])
  HIPE> print y.get(indices)
  [6.0,3.0,1.0]
  ```

  An out of bounds index will cause an error.

- Retrieve elements based on a `Range` object:

  ```python
  HIPE> range = Range(2,4)
  print y.get(range)
  [3.0,8.0]
  ```

  Note how the lower boundary (second element) is included, while the upper boundary (fourth element) is excluded. An out of bounds value will cause an error.

You can combine `get` calls to perform the same operation as a compound IDL `WHERE` execution such as the one shown in this example:

```idl
IDL> a = [1, 2, 3, 4, 5, 6]
IDL> b = [2, 3, 4, 5, 6, 7]
IDL> c = [3, 4, 5, 6, 7, 8]
IDL> q = WHERE(a ge 2 and b lt 6 and c gt 5)
IDL> x = [a[q],b[q],c[q]]
IDL> print, x
4       5       6
```

This is the equivalent in HIPE:

```python
q = (a >= 2) & (b < 6) & (c > 5)
x = a.get(q),b.get(q),c.get(q) # x == ([4.0], [5.0], [6.0])
```

- Using logical operators with arrays

The Jython logical operators `and`, `or` and `not` work like normal Boolean operators (see Appendix A for more details), but using them with arrays (both the native Jython arrays and HIPE numeric arrays) can give unexpected results. The reason is that these operators do not work on an element-by-element basis when applied to arrays, but they evaluate the entire array at once.

The Jython bitwise operators, represented by the symbols `&`, `|` and `^` (see Appendix A for more details) can be used with numeric arrays (Int1d, Bool3d and so on), but what you get is not a
Arrays, datasets and products

bitwise comparison. Instead, these operators perform the usual boolean comparisons, but this time working element by element. Precisely what and, or and not do not do.

Finally, Numeric array classes have the and, or and xor methods acting like boolean operators working element by element. An example will clarify the differences among all these operators:

```python
jythonOne = [1, 0, 0, 1]
jythonTwo = [0, 0, 1, 1]
numericOne = Bool1d(jythonOne)
numericTwo = Bool1d(jythonTwo)
print jythonOne and jythonTwo
## [0, 0, 1, 1] # jythonOne is not empty so it is treated as true, which means that
## jythonTwo is evaluated and returned
print numericOne and numericTwo
## [false,false,true,true] # Same thing as with the Jython native arrays
print jythonOne & jythonTwo
## Here an error is returned
print numericOne & numericTwo
## [false,false,false,true] # Here the operator works element by element
print numericOne.and(numericTwo)
## [false,false,false,true] # Same thing as the & operator
```

Example 2.26. Differences between Jython and Numeric arrays.

### 2.2.9. Removing infinite and NaN values from arrays

To remove infinite and NaN values from an array, use the IS_FINITE, IS_INFINITE and IS_NAN functions as shown in the following examples.

First example:

```python
# Set up an array with non-finite elements
x = Double1d.range(5)+1
x[0] = Double.NaN
x[3] = Double.POSITIVE_INFINITY
print x     # [NaN,2.0,3.0,Infinity,5.0]
# Keeping finite values
q = x.where(IS_FINITE)
print q     # [1,2,4]
print x[q]  # [2.0,3.0,5.0]
```

Example 2.27. Removing infinite and NaN values from an array.

Second example:

```python
# Creating a mask
mask = IS_FINITE(x)
print mask     # [false,true,true,false,true]
q = x.where(mask)
print q      # [1,2,4]      (as before)
print x[q]   # [2.0,3.0,5.0]  (as before)
# Asking to filter the non-finite numbers:
q = x.where(~mask)
print q     # [0,3]
print x[q]  # [NaN,Infinity]
# Replacing selected values
x[q] = 0
print x     # [0.0,2.0,3.0,0.0,5.0]
```

Example 2.28. Creating a filter (mask) with a function to remove NaNs.

### 2.2.10. Advanced tips for improved performance

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The underlying array operations and functions are very fast, as they are implemented in Java. The overhead of invoking them from Jython is relatively small for large arrays. However, the advanced user may find the following tips useful to improve performance in cases where it becomes a problem.

The arithmetic operations, such as `+`, have versions that allow in-place modification of an array without copying. For example:

```python
y = Double1d.range(10000)
y = y + 1  # The array is copied
y += 1    # The array is modified in place
```

**Example 2.29. Avoiding unnecessary array allocation for the addition operation.**

Copying an array is slow as it involves allocating memory (and subsequently garbage collecting it). For simple operations, such as addition, the copying can take longer than the actual addition.

Function application also involves copying the array. This can be avoided by using the Java API instead of the simple prefix function notation. For example:

```python
x = Double1d.range(10000)
x = SIN(x) * COS(x)  # This operation involves three copies
x = x.apply(SIN).multiply(x.apply(COS))  # Only one copy
```

**Example 2.30. Using Java array utility methods to avoid wasteful array allocation.**

When writing array expressions, it is better to group scalar operations together to avoid unnecessary array operations. For example:

```python
y = Double1d([1,2,3,4])
print y * 2 * 3  # 2 array multiplications
print y * (2 * 3)  # 1 array multiplication
print 2 * 3 * y  # 1 array multiplication
```

**Example 2.31. Grouping scalar multiplication avoids costly array multiplication.**

It is better to avoid explicit loops over the elements of an array. It is often possible to achieve the same effect using existing array operations and functions. For example:

```python
sum = 0.0
for i in y:
    sum = sum + i * i  # Explicit iteration
sum = SUM(y * y)  # Array operations
```

**Example 2.32. Using arithmetic operations on arrays to avoid loops.**

### 2.2.11. Type conversions

Since the numeric library supports different types it would be very convenient to be able to convert an array from one type to another. The numeric library supports both implicit conversion from within Jython for all supported dimensions and explicit conversion from one data type to another.

#### 2.2.11.1. Explicit conversion

Explicit conversion is supported for all data types by constructing a numeric array from another numeric array of the same or a different type. Note however that some explicit conversions may result in rounding and/or truncation of the values e.g. an explicit conversion from Long1d to Double1d will reduce the number of significant digits.

```python
i = Int1d([1,2,3])  # [1,2,3]
r = Double1d(i)     # [1.0,2.0,3.0]
```
2.2.11.2. Implicit conversion

Implicit conversions are conversions that can be done automatically, provided that such a conversion is a widening operation, for example, from Int1d to Double1d. Implicit narrowing conversions are not allowed and result in an error message.

A widening operation is when the result is stored in more bits than the source, thus not losing any accuracy. A narrowing operation is the opposite and data loss is possible as the result is stored using fewer bits than the source.

The library supports implicit conversions in the following cases:

- access: [...]  
- operators: +, -, *, /, ^ and %  
- in-line operators: +, -, *, /, ^ and %

The examples below show allowed implicit conversions.

d = Double1d(5)        # [0.0,0.0,0.0,0.0,0.0]  
d[1] = 3               # [0.0,3.0,0.0,0.0,0.0]  
d[1:4] = [-5, 0, 5]    # [0.0,-5.0,0.0,5.0,0.0]

Example 2.34. Converting types implicitly in Jython.

HIPE considers the conversion from int to float and from long to float/double as an automatic widening operation, but some of the least significant digits of the value may be lost during the conversion. You will not be notified of this loss of significant digits.

Another thing to notice is that floating point operations will never throw an exception or error. As shown in the following example, a division by zero results in NaN or Infinity.

d = Double1d.range(5)  
l = Long1d.range(5)    
print d/l              # [NaN,1.0,1.0,1.0,1.0]  
print d/SHIFT(l, 1)    # [0.0,Infinity,2.0,1.5,1.3333333333333333]

Example 2.35. Dividing by zero will generate NaN or Infinity as appropriate.

2.3. Array datasets

2.3.1. Creating an array dataset

The following example shows the available commands to create an array dataset:

```python
x = ArrayDataset()    # Create an empty dataset  
array = Double1d([1.0, 5.3, 2.1])  # Create the array first  
x = ArrayDataset(array)  # Create the array dataset  
# Create an array dataset with measurement units and a description from herschel.share.unit import *  
x = ArrayDataset(array, Power.WATTS, "My measurements")
```

Example 2.36. Declaring an array dataset.
See Section 2.6 for more information about measurement units.

2.3.2. Modifying an array dataset

The following example shows various ways of modifying an array dataset:

```python
# Change the description
x.description = "New description"
# Change the measurement unit
from herschel.share.unit import *
x.unit = Mass.GRAMS
# Change the data
x.data = Int1d([2, 5, 6, 4])
# Change one element of the data
x.data[1] = 7
```

Example 2.37. How to modify an array dataset.

See Section 2.7.1 for how to change the array dataset metadata.

2.3.3. Inspecting an array dataset

The following example shows various ways of inspecting an array dataset:

```python
print x.description # Print the description
print x.unit  # Print the measurement unit
print x.hasData() # Check if the array dataset contains data (returns 1 if yes)
print x.data # Print only the data contained in the dataset
print x.data[2] # Print a single element of the data
```

Example 2.38. Accessing relevant data of an array dataset.

2.4. Table datasets

A table dataset is made up of a number of columns. Each column contains an array (data), a description and a measurement unit.

Note
For reasons of flexibility, memory consumption and performance, this class is not checking whether all columns are of the same length: this is your responsibility.

2.4.1. Creating a table dataset

The following example shows how to create a table dataset:

```python
t = TableDataset()  # Empty table dataset, no description
t = TableDataset(description = "My dataset")  # Empty table dataset, with description
```

Example 2.39. Creating a table dataset.

You can only create empty table datasets and fill them later with columns.

Creating columns is very similar to creating array datasets:

```python
c = Column()  # Create an empty dataset
# Create a column with an embedded array
array = Double1d([1.0, 5.3, 2.1])  # Create the array first
c = Column(array)  # Create the array dataset
# Create a column with measurement units and a description
```
Example 2.40. Creating isolated columns.

See Section 2.6 for more information about measurement units.

The following example shows how to add columns to a table dataset:

```python
from herschel.share.unit import *
c = Column(array, Power.WATTS, "My measurements")
```

Example 2.41. Adding data columns to table datasets.

```
# Add column c with name Measurements
t["Measurements"] = c
# You can create and add a column in one step
t["secondColumn"] = Column(Int1d([1,2,3,4,5]))
```

Example 2.42. Avoiding references to the same data from two different columns.

```
# Changing the description
t.description = "New description"
# Substituting a column (same as adding a column)
t["Measurements"] = Column(myOtherArray)
# Changing column data
t["Measurements"].data[0] = 2 # First element set to 2
# Changing a specific data element
t.setValueAt(12, 0, 1) # Set the value 12 at row = 0, column = 1
# Removing a column by name
t.removeColumn("myColumn") # Remove column called myColumn
# Removing a column by index
t.removeColumn(0) # Remove the first column
```

2.4.2. Modifying a table dataset

The following example shows how to modify a table dataset:
## Adding a row, assuming the table dataset has two integer and one floating point column

t.addRow([5, 9, 3.2])

## Removing a row

t.removeRow(1) # Remove the second row

Example 2.45. Exercising some of the most useful methods of a table dataset.

### Copying a table dataset into another

You can append data from one table dataset to another, provided that they have the same number of columns and each column in either dataset is of the same type. The following example adds `t2` as rows to table `t1`.

```plaintext
# Create two compatible table datasets

# Append the data in t2 to the data in t1

t1.addRowByIndex(t2)
```

Example 2.46. Copying table datasets.

### Inspecting a table dataset

The following example shows various ways of inspecting an array dataset:

```plaintext
print t.description # Print the description
print t.columnCount # Print the number of columns
print t.rowCount # Print the number of rows
print t.getColumnName(i) # Print the name of the column at integer position i
print t.columnNames # Print a vector with the names of all the columns
print t[i] # Print the column at integer position i
print t['name'] # Print the column called name
print t['name'].data # Print only the data inside the column called name
print t['name'].data[2] # Print a specific value of the data
print t['name'].unit # Print the unit of the column called name
print t['name'].description # Print the description of the column called name
print t.getRow(i) # Print a vector containing the values of the row at integer position i
print t.getValueAt(0,1) # Print the value contained in row = 0, column = 1
```

Example 2.47. Exercising the most useful methods of an array dataset.

If the table dataset has columns of different lengths, `getRow` gives an error if some of the row values are undefined.

## Composite datasets

A composite dataset is a container in which you can place other datasets (array or table), including other composite datasets.

### Creating a composite dataset

This example shows how to create a composite dataset:

```plaintext
# Create an empty composite dataset

c = CompositeDataset()
# Create an empty composite dataset with a description
```
c = CompositeDataset("My dataset")

Example 2.48. Creating a composite dataset.

Adding datasets to a composite dataset follows the same syntax as adding columns to a table dataset:

```python
# Assume that t is a table dataset and c is a composite dataset
c["measurements"] = t  # Adding t to c with the name measurements
```

Example 2.49. Adding a table dataset to a composite dataset.

2.5.2. Modifying a composite dataset

This example shows how to modify a composite dataset:

```python
# Set the description
c.description = "My composite dataset"
# Replace the dataset called coordinates with the one held in variable t
c["coordinates"] = t
# Remove a dataset
c.remove("coordinates")
# Extract a copy of a dataset to a variable
c["measurements"] = myData  # Dataset called measurements now held in myData
# Changes to myData will also affect the composite dataset
```

Example 2.50. Manipulating a composite dataset.

To change a dataset name, remove it and add it again with the new name.

2.5.3. Inspecting a composite dataset

This example shows how to inspect a composite dataset:

```python
print c.description # Print the description
print c.keySet() # Print a vector with the names of all the datasets
print c["name"] # Print the dataset called name
print c["name"].data # Print only the data inside the dataset called name
print c["name"].description # Print the description of the dataset called name
```

Example 2.51. Exercising the most useful methods of a composite dataset.

2.6. Measurement units

You can assign measurement units to array datasets and columns in a table dataset. Different columns in the same table dataset may have different units.

To use units in your scripts, you have to manually import the unit package with the following command:

```python
from herschel.share.unit import *
```

The following table shows the measurement units available in HIPE.

<table>
<thead>
<tr>
<th>Type</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>METERS_PER_SECOND_SQUARED</td>
</tr>
<tr>
<td>Angle</td>
<td>RADIANS, DEGREES, MINUTES_ARC, SECONDS_ARC</td>
</tr>
</tbody>
</table>

Note: Constants describing the units are given in American English spelling (e.g.: meter versus metre) because that is the way they are stored within the software.
## 2.6.1. Creating and assigning units

To create a variable representing a unit, specify the type and value of the unit, separated by a dot, as shown in the following example:

```
a = Angle.DEGREES  # Type Angle, value DEGREES
b = Temperature.KELVIN
```

**Example 2.52. Assigning units to variables.**
You can then assign the unit to an array dataset or to a column of a table dataset. You can use a variable representing the unit, or specify the unit definition:

```python
myTableDataset["x"].unit = Angle.DEGREES  # Assign to a column, specify unit definition
myArrayDataset.unit = b  # Assign to array dataset, use existing variable
```

Example 2.53. Assigning units to columns or datasets.

**Warning**

If you change the unit assigned to a dataset, this will have no effect on its values. For example, changing a unit from metres to centimetres will not result in the values being multiplied by 100. For a discussion on how to properly convert the units of a quantity, affecting the values, see this chapter in the Data Analysis Guide in Data Analysis Guide.

### 2.6.2. Obtaining derived units

You can obtain derived units with simple expressions, as shown in the following example:

```python
N = Force.NEWTONS
m = Length.METERS
m2 = m**2  # Square meters
Pa = N / m2  # Pascals
J = N * m  # Joules
```

Example 2.54. Creating a new, derived unit.

You can also obtain multiples and fractions of units by using functions such as `.milli()`, `.mega()`, `.kilo()`:

```python
s = Duration.SECONDS
us = s.micro()  # microseconds
ns = s.nano()   # nanoseconds
```

Example 2.55. Converting units between standard SI prefixes.

All SI prefixes from `atto` ($10^{-18}$) to `exa` ($10^{18}$) are available. For a list of SI prefixes, see for example [http://www.bipm.org/en/measurement-units/prefixes.html](http://www.bipm.org/en/measurement-units/prefixes.html).

### 2.6.3. Converting units to and from strings

You can convert a unit variable to various string representations:

```python
A = Length.ANGSTROMS
print A.name         # angstrom. ASCII characters only.
print A.dialogName   # Å.
um = Length.MICROMETERS
print um             # micrometer [1.0E-6 m]. Includes factor
                    # with respect to SI unit
print um.name        # micrometer. ASCII characters only.
print um.dialogName  # µm.
```

Example 2.56. Printing unit names for ASCII output or dialog output that includes symbols and Greek characters.

You can also convert a string to a unit variable:

```python
myUnit = Unit.parse("km s-1")
myUnit = (Unit.parse("km") / Unit.parse("s"))
myUnit = Unit.parse("km s-1")
myUnit = Unit.parse("arcsec")
myUnit = Unit.parse("eV")
```
myUnit = Unit.parse("cm")
myUnit = Unit.parse("mm")
myUnit = Unit.parse("microm")

Example 2.57. Parsing the string representation of the unit to assign it to a variable.

If you give an invalid string to the parse method, a unit is created anyway, but it will give an error if you try any operation on it.

2.6.4. Converting units to other units

To obtain the SI equivalent of a unit, use .asSI:

a = Angle.DEGREES # a is an angle in degrees
b = a.asSI       # b is an angle in radians
v1 = Speed.KILOMETERS_PER_HOUR # v1 is a speed in km/h
v2 = v1.asSI     # v2 is a speed in m/s

Example 2.58. Assigning units to variables.

Example 2.59. Retrieving the conversion factor to SI units.

To obtain the conversion factor between a unit and its SI equivalent, use .toSI:

a = Length.ANGSTROMS  # a is a length in angstroms
print a.toSI            # 1e-10
print Duration.HOURS.toSI  # 3600.0
print FluxDensity.MILLIJANSKYS.toSI  # 1.0E-29
print Unit.parse("g cm s-2").toSI  # 1.0E-5

Example 2.60. Using the to method to explicitly convert units.

2.6.5. Comparing units for compatibility

You can compare units to see if they are of compatible types.

Example 2.61. Checking if two different units refer to the same physical quantity.

2.6.6. Comparing units for equivalence

You can use the .isEquivalent method to determine if two unit types are the same.
Example 2.62. Checking if two units are the same but expressed differently.

2.6.7. Obtaining physical and mathematical constants

You can obtain the following physical constants, complete with units:

```python
h = Constant.H_PLANCK
print h.value # 6.62606896E-34
print h.unit   # J s
print h        # 6.62606896E-34 J s
k = Constant.K_BOLTZMANN
c = Constant.SPEED_OF_LIGHT
e = Constant.ELECTRON_CHARGE
```

Example 2.63. Using physical constants provided within the Constant class.

The following mathematical constants are also available:

```python
from java.lang.Math import PI
print PI # 3.141592653589793
from java.lang.Math import E
print E # 2.718281828459045
```

2.7. Metadata

_Metadata_ contain additional information about a dataset. Metadata consist of couples of _keys_ and _values_. A key describes a piece of information, while the value is the actual piece of information. For example, in the metadata entry _instrument_ = _HIFI_, the key is _instrument_ and the value is _HIFI_.

Metadata are automatically created whenever you create a dataset. For products, the metadata set is filled with a few compulsory entries. For other datasets, the metadata set is initially empty.

Metadata entries, or _parameters_, can be of the following types:

- **StringParameter**: strings of text.
- **BooleanParameter**: true/false values.
- **LongParameter**: integer numbers.
- **DoubleParameter**: floating point numbers.
- **DateParameter**: date values.

2.7.1. Modifying metadata

The following example shows how to add or modify the metadata of a dataset called _s_. If a metadata entry with a given key value already exists in the dataset, it is modified. If not, it is added.

```python
s.meta["observation"] = StringParameter("NGC 4151")
s.meta["principal investigator"] = StringParameter("William Herschel")
# Set "date" as the current date and time
s.meta["date"] = DateParameter(FineTime(java.util.Date()))
s.meta["ra"] = DoubleParameter(182.836)
# Add a description
s.meta["dec"] = DoubleParameter(39.405, "Declination")
# Add a description and a unit
```

# Units are only available to DoubleParameter and LongParameter
from herschel.share.unit import *
```
s.meta["ra"] = DoubleParameter(182.836, "Right Ascension", Angle.DEGREES)
# Remove a key-value pair
s.meta.remove("dec")

Example 2.64. Adding and modifying metadata associated to a table dataset.

Date parameters are expressed as FineTime objects. For more information see Chapter 9.

### 2.7.2. Inspecting metadata

The following example shows how to inspect the metadata of a dataset called *s*:

```python
# Print all the metadata
print s.meta
# Print a list of all the parameters in the metadata
print s.meta.keySet()
# Print a specific parameter.
print s.meta["observation"]
# Print the value of a specific parameter
print s.meta["observation"].value
# Print the description of a specific parameter
print s.meta["observation"].description
# Print the unit of a specific parameter (numeric parameters only).
print s.meta["wavelength"].unit
# Check if a key value is present. Returns True or False.
print s.meta.containsKey("obsid")
# Check if the metadata is empty. Returns True or False.
print s.meta.empty
```

Example 2.65. Inspecting the metadata of a dataset.

If you want to search the metadata of datasets held in a pool, use the Product Browser perspective. See the [Data Analysis Guide](#) for more information: Section 1.7 in Data Analysis Guide.

For more information on searching metadata from the command line, see Section 7.3.

### 2.8. Products

A product is an object containing a set of metadata entries and one or more datasets.

With respect to composite datasets, products offer more features, such as a history recording all the changes (see Section 2.8.7) and a set of metadata parameters added automatically whenever a product is created.

The automatic metadata values are `type`, `creator`, `creationDate`, `description`, `instrument`, `modelName`, `startDate`, `endDate` and `formatVersion`.

#### 2.8.1. Creating a product

The following example shows how to create a product:

```python
# Create an empty product
myProduct = Product()
# Create a product with a given description
myProduct = Product("This is my product")
# Create a product by specifying some of the compulsory metadata values
myProduct = Product(creator="Myself", instrument="SPIRE", 
description="An empty product", modelName="PFM", type="ABC")
```

Example 2.66. Creating an empty product with some metadata.

Adding datasets or other products to a product follows the same syntax as adding datasets to a composite dataset:
# Assume that t is a table dataset and p is a product
p["measurements"] = t  # Adding t to p with the name measurements

## 2.8.2. Modifying a product

The following example shows how to modify a product:

```python
# Substituting an array/product (same as adding an array/product)
p["Measurements"] = myOtherDataset
# Removing an array/product
p.remove("Measurements")
```

Example 2.67. Overwriting an array within a dataset.

To change a dataset name, remove it and add it again with the new name.

There is a simplified syntax to set the compulsory metadata values:

```python
myProduct.type = "ABC"
myProduct.creator = "Myself"
myProduct.description = "An empty product"
myProduct.instrument = "SPIRE"
myProduct modelName = "PFM"  # And so on
```

Example 2.68. The most common metadata have attributes defined.

## 2.8.3. Setting date and time in product metadata

The `startDate`, `endDate` and `creationDate` are mandatory metadata parameters and are set to the current date and time when the product is created. To set any of these parameters to the system date and time, use these commands:

```python
myProduct.creationDate = FineTime(java.util.Date())
myProduct.startDate = FineTime(java.util.Date())
myProduct.endDate = FineTime(java.util.Date())
```

Example 2.69. Some of the time attributes are instances of FineTime.

To set these parameters to an arbitrary date and time, expressed as UTC or TAI, use the following commands:

```python
formatter = SimpleTimeFormat(TimeScale.UTC)  # or just SimpleTimeFormat()
timeUtc = formatter.parse("2008-01-31T12:35:00.0Z")    # Z at the end is mandatory for UTC
formatter = SimpleTimeFormat(TimeScale.TAI)            # or just SimpleTimeFormat()
timeTai = formatter.parse("2008-01-31T12:35:00.0TAI")  # TAI at the end is mandatory for TAI

myProduct.creationDate = timeUtc or
myProduct.creationDate = timeTai
```

Example 2.70. Creating TAI or UTC time strings to set time metadata.

Note that the two previous dates, represented as `FineTime`, are different:

```bash
HIPE> print timeUtc
2008-01-31T12:35:33.000000 TAI (1580474133000000)
HIPE> print timeTai
2008-01-31T12:35:00.000000 TAI (1580474100000000)
```

See Section 9.1 for more information on representing time in the Herschel software.
2.8.4. Inspecting a product

The following example shows how to inspect a product:

```java
print myProduct.description  # Print the description of a product
# You can use the above syntax for any of the compulsory metadata. For example:
print myProduct.type
print myProduct.creationDate  # And so on
print myProduct.isEmpty()  # Check whether a product is empty. Returns True or False.
print myProduct.sets.size()  # Print the number of dataset/products in the product.
print myProduct.keySet()  # Print a vector with the names of all the datasets and products in this product
print myProduct.default  # Print the first inserted dataset.
print myProduct["anotherDataset"]  # Print the dataset called anotherDataset.
```

Example 2.71. Inspecting an object from a subclass of Product.

Instead of just printing out the datasets you get, you can assign them to variables and execute other operations on them. To see how to explore the contents of datasets please refer to the previous sections of this chapter.


2.8.5. Product contexts

Contexts are special types of products that contain references to other products. Contexts are used to organise related products into a coherent structure. For example, the observation context in HCSS User's Reference Manual contains all the data related to an observation.

There are two standard types of context products provided: ListContext in HCSS User's Reference Manual, for grouping products into sequences or lists, and MapContext in HCSS User's Reference Manual, for grouping products into containers with access to each by key. The observation context is a map context.

Most likely you will not have to create your own contexts, but just access those you retrieve from the Herschel Science Archive.

2.8.6. Observation contexts

Every observation you download from the Herschel Science Archive is an observation context. An observation context contains other contexts and many data products. While the high-level structure of observation contexts is broadly the same, the detailed structure and product types vary according to the observation type. See the following resources for more information on observation contexts:

- For a brief introduction to observation contexts see the Products Definitions Document: Section 2.9 in Product Definition Document.
- For more information on HIFI observation contexts, see the HIFI Data Reduction Guide.
- For more information on PACS observation contexts, see the PACS Products Explained.
- For more information on SPIRE observation contexts, see the SPIRE Data Reduction Guide.

2.8.7. Product history

The Product history is generated or updated whenever a task is run on a product. It contains the tasks which have been run to generate the product (including used parameters), as well as the used calibration files and the track and build number of the used build.
You can retrieve the history of a product in Jython as follows:

```python
history = product.history
```

A simple `print` shows which tasks, build numbers and calibration files have been used:

```
HIPE> print history
```

Additional interesting functionalities of the history list are the following:

- Get the history as a Jython script:

```python
script = product.history.script
product.history.saveScript("script.py")
```

**Example 2.72. Saving the product history to a script file.**

- Find out if a certain task has been run (useful in a task which depends on another task):

```python
if not product.history.isTaskPerformed("someTask"):
    print "You have to run someTask first!"
    exit
```

**Example 2.73. Checking if a task has been executed on a product (either locally or as part of standard processing).**

Calibration file appear in the history with identifiers constructed from meta keywords. How this is done depends on the instrument:

- For PACS the identifier is constructed from the meta keywords `calFileId`, `modelName` and `calFileVersion` as follows:

```
Common|Photometer|Spectrometer_calFileId_modelName_calFileVersion
```

Also, if you want to introduce your own handcrafted PACS calibration file you should change especially the `calFileId` keyword to make sure that this is visible in the history.

- For SPIRE the `fileName` meta keyword is used to identify calibration files.

- For HIFI no standard has been implemented yet.
Chapter 3. Spectra and spectral cubes

3.1. Spectrum containers and segments

Within HIPE there are several types of datasets and products that are used to contain spectra. These consist of the data and metadata that are necessary for correct handling of spectral display and combination (e.g. spectral arithmetic).

The available spectral datasets are Spectrum1d and Spectrum2d. These are extensions of the generic Herschel TableDataset, and are made up of columns containing arrays of numbers. A Product is a wrapper which can contain one or more Datasets collected together with metadata (header) - see Section 2.1 for more details on datasets and products. Examples of spectral Products are SimpleSpectrum and SpectralSimpleCube.

In general, most of the datasets and products dealing with spectra inside HIPE make use of the "SpectrumContainer" interface. This interface specifies the way that the spectral data are accessed so that the same tasks (e.g. those in the Spectrum Toolbox) can operate on all of the different types of spectral datasets and products.

A "SpectrumContainer" is built up of several layers. It can contain one or several "PointSpectrum" objects, with each PointSpectrum consisting of one or several "SpectralSegments".

- The SpectralSegment is the most basic unit of spectral data, with a frequency, wavelength or velocity array, a flux array and, optionally, weights, errors, flags and masks.
- The PointSpectrum contains individual segments, and may also contain additional parameters that hold for all of its segments. Examples are integration time, observation time, position on sky or other instrument specific information (e.g. house-keeping data).

In general, the full complexity of SpectrumContainers, PointSpectra and SpectralSegments is only used by HIFI, where a SpectralSegment physically corresponds to a single HIFI subband. For PACS and SPIRE, a SpectrumContainer usually contains a single PointSpectrum with one SpectralSegment.

The most basic SpectrumContainers for Herschel data are the Spectrum1d (see Section 3.2) and Spectrum2d (see Section 3.3) datasets and the SpectralSimpleCube product (see Section 3.5). They form the basic building blocks and can be wrapped into various kinds of other products (i.e. with added metadata) or extended to form instrument-specific products.

3.2. Spectrum1d

A Spectrum1d is a one-dimensional representation of a spectrum. It is a TableDataset (see Section 2.4) that has columns for wave, flux, flag, weights and segment number. In this case, the column called wave can contain any of wavelength, frequency, wavenumber, or velocity information. If the dataset has more than one segment, they are contained within the same columns, and distinguished by the segment number. For PACS and SPIRE, an error column is used instead of weights. A SPIRE example is shown in Figure 3.1. Details of the Spectrum1d can also be found in the User Reference Manual in HCSS User's Reference Manual.
Spectra and spectral cubes

Figure 3.1. An example of a Spectrum1d product from SPIRE (in the HIPE Dataset Viewer). In this case, the wave column contains wavenumbers in cm\(^{-1}\), there is no segment number column (as only one segment is contained) and there are additional columns for error and mask.

In addition to the actual data, each column can also contain the units and a description, which is used to label the axes in plots generated by spectral tools within HIPE. Metadata can also be added to a Spectrum1d to describe the target, RA, Dec. etc. (see Section 2.7.1).

Several related spectra, or sub-spectra, can be kept together in a single Spectrum1d dataset by storing them as different spectral segments. Different spectral segments can be stored in the same dataset even if they do not have the same number of datapoints or an identical wave array (but they must have the same units). The spectral tools in HIPE operate on all of the segments - in general applying the selected function to all segments separately. However, the spectrumFitterGUI works on one specified segment at a time.

### 3.2.1. Creating a Spectrum1d

To make a Spectrum1d from scratch the data for each column must be created as an array and added to the dataset - the following is a simple example with a single segment:

```python
# Define the spectrum
# (in this case in frequency and brightness temperature)
wave = Double1d([1000.0, 1000.2, 1000.4, 1000.6, 1000.8, 1001.0, 1001.2, 1001.4, 1001.6, 1001.8])
flux = Double1d([12.2, 12.5, 13.0, 11.8, 11.9, 12.6, 12.2, 12.8, 12.2, 15.2])
flag = Int1d(10)
weight = Double1d(10) + 1
segs = Int1d(10)
# Create the Spectrum1d
mySpectrum1d = Spectrum1d(flux, wave, weight, flag, segs)
```

Example 3.1. Adding data arrays as columns to a spectrum dataset.

This simple example can now be viewed and operated upon by spectral tools in HIPE. More information can be added to define the units (see Section 2.6) and descriptions of the axes:

```python
# Import the Herschel unit classes from herschel.share.unit import *
# Set the wave and flux units and descriptions
mySpectrum1d.waveUnit = Frequency.GIGAHERTZ
mySpectrum1d.waveDescription = "Frequency"
```
mySpectrum1d.fluxUnit = Temperature.KELVIN
mySpectrum1d.fluxDescription = "Brightness Temperature"

Example 3.2. Setting the units of various spectral metadata.

Multiple spectral segments can be added by changing the segment ID in the segments column (note that if several segments are present, they do not necessarily need to have the same number of data points, or the same wave array):

```python
# Define the spectrum
# (in this case in frequency and brightness temperature)
wavel1 = Double1d([1000.0, 1000.2, 1000.4, 1000.6, 1000.8, 
                   1001.0, 1001.2, 1001.4, 1001.6, 1001.8])
wavel2 = Double1d([453.0, 453.2, 453.4, 453.6, 453.8, 
                   454.0, 454.2, 454.4])
flux1 = Double1d([12.2, 12.5, 13.0, 11.8, 11.9, 
                  12.6, 12.2, 12.8, 12.2, 15.2])
flux2 = Double1d([6.2, 6.5, 5.0, 6.8, 7.9, 
                  6.6, 5.2, 5.8])
# Flags all set to zero (by default)
flag1 = Int1d(10)
flag2 = Int1d(8)
# Weights all set to one
# (note that weight of zero means the sample is irrelevant)
weight1 = Double1d(10) + 1
weight2 = Double1d(8) + 1
# Set the segment IDs
seg1 = Int1d(10)
seg2 = Int1d(8) + 1
# Create the Spectrum1d
flux = flux1.append(flux2)
wavel = wavel1.append(wavel2)
weight = weight1.append(weight2)
flag = flag1.append(flag2)
segs = seg1.append(seg2)
mySpectrum1d = Spectrum1d(flux, wavel, weight, flag, segs)
```

Example 3.3. Adding spectral segments to a one-dimensional spectrum dataset.

### 3.2.2. Accessing data from a Spectrum1d

The following table defines the standard Spectrum1d columns and how these are accessed on the command line in HIPE.

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Contents</th>
<th>Direct data access</th>
<th>Java access method</th>
<th>Jython shortcut</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>wave</td>
<td>Wavelength, frequency, wavenumber, or velocity</td>
<td>['wave'].data</td>
<td>.getWave()</td>
<td>.wave</td>
<td>Double1d</td>
</tr>
<tr>
<td>flux</td>
<td>Flux density, brightness temperature, brightness, etc.</td>
<td>['flux'].data</td>
<td>.getFlux()</td>
<td>.flux</td>
<td>Double1d</td>
</tr>
<tr>
<td>weight</td>
<td>Weight for each datapoint</td>
<td>['weight'].data</td>
<td>.getWeight()</td>
<td>.weight</td>
<td>Double1d</td>
</tr>
<tr>
<td>flag</td>
<td>Flag for each datapoint</td>
<td>['flag'].data</td>
<td>.getFlag()</td>
<td>.flag</td>
<td>Int1d</td>
</tr>
<tr>
<td>segments</td>
<td>Spectral segment number</td>
<td>['segment'].data</td>
<td>.getSegment()</td>
<td>.segment</td>
<td>Int1d</td>
</tr>
</tbody>
</table>
The direct data access (using square brackets) is the generic way to access columns inside Herschel datasets (see Section 2.1). The Java access method and related Jython shortcut provide shorter ways to access specific columns of data, and so are preferred by some people in their scripts. These methods are explicitly coded into the class definition of the Spectrum1d dataset and so only exist for the columns included in that definition (this is one of the things that can be added in instrument-specific extensions of the Spectrum1d).

As an example, the following code plots the spectrum from a Spectrum1d in PlotXY (see the chapter on plotting in the Data Analysis Guide in Data Analysis Guide) using the Jython shortcut access:

```python
pl = PlotXY()
pl.addLayer(LayerXY(mySpectrum1d.wave, mySpectrum1d.flux))
```

**Example 3.4. Plotting the spectrum with the wave and the flux as axes.**

The weights column is used by HIFI, and by default, these are computed based on receiver temperature. A weight of zero means that sample was irrelevant.

For PACS and SPIRE, errors are (or will be, for PACS) used rather than weights. Therefore, PACS and SPIRE products contain an error column instead of the weights column. The errors are converted into weights on-the-fly when either .getWeight() or .weight are called. The conversion follows this formula:

\[ \text{weight} = \frac{1}{\text{error}^2} \]

The HIPE Spectrum Toolbox tasks work solely with weights, and so they apply the above conversion automatically if only errors are present. The task then uses/propagates the weights and automatically converts them back to errors in the output. This automatic conversion in the Spectrum Toolbox tasks can be turned off by setting a Boolean parameter in the Spectrum1d:

```python
# Turn off automatic conversion of errors to weights
# (default is True)
mySpectrum1d.setAutoConversion(False)
```

**Example 3.5. Turning off automatic conversion of errors to weight.**

The conversion can be carried out explicitly by calling the following methods:

```python
error = mySpectrum1d.weight2Error(mySpectrum1d.weight)
weight = mySpectrum1d.error2Weight(mySpectrum1d.error)
```

**Example 3.6. Converting weights to errors and errors to weights.**

The flag column contains an integer flag per sample. These are used by HIFI to show which data samples are affected by particular issues such as saturation (see the HIFI Data Reduction Guide: Flags in HIFI data). The flags are used by some of the Spectrum Toolbox tasks to mask out bad samples.

More details of the Spectrum Toolbox tasks can be found in the Data Analysis Guide and in the User Reference Manual.

Some useful commands related to manipulating spectral segments in a script are:

```python
# The total number of segments in this spectrum1d
segmentCount = mySpectrum1d.segmentCount
# The valid segment indices in the spectrum1d
segmentIndices = mySpectrum1d.segmentIndices
# Extract the segment using the segment ID
# (as given in the segment column)
segment0 = mySpectrum1d.getSegment(0)
# Access the wave and flux data of this segment
wave0 = segment0.wave
flux0 = segment0.flux
# Extract the segment using a counter over segment IDs
# (i.e. the number given refers to the order of
# the IDs in the segment column, starting at zero)
```
Example 3.7. Manipulating spectral segments.

### 3.3. Spectrum2d

For multiple spectra taken in an observation, a two-dimensional structure is required. The components of a Spectrum2d dataset are similar to the Spectrum1d dataset (see Section 3.2), except for the provision of a second dimension where each spectrum is stored horizontally in a new row of the table. The same column names exist as in the Spectrum1d, but each element in the column is an array containing a spectrum. Details of the Spectrum2d can also be found in the User Reference Manual in HCSS User’s Reference Manual.

The Spectrum2d dataset is used by HIFI to store all of the data from different data frames from a single observation (see Figure 3.2). For SPIRE, it is used to collect together the spectra from different sky positions before gridding them into a spectral cube (see Figure 3.3). The advantage of this structure over many separate Spectrum1d datasets is that a group of related spectra can be contained in a single dataset that is easier to display and manipulate than a bunch of individual datasets.

**Figure 3.2. Example of a HIFI Spectrum2d viewed in the SpectrumExplorer in HIPE. Different spectra appear as different rows, and in this case each spectrum has 4 subbands. Each subband is plotted in the colour shown in the boxes on the lower left. The other columns give further information about each spectrum.**

**Figure 3.3. Example of a SPIRE Spectrum2d viewed in the SpectrumExplorer in HIPE. Different spectra appear as different rows, but in this case each spectrum only has one subband. There are fewer columns for additional information than in the HIFI example in Figure 3.2.**

An additional component of the Spectrum2d, which is important for HIFI data, is the ability to split each spectral row into sub-spectra (analogous to the segments in the Spectrum1d - see Section 3.2).
The output from the HIFI spectrometers contains subbands, where several CCD or autocorrelator readouts lead to several "chunks" (subbands) of spectra in one data frame. This functionality is only used by HIFI, and so these chunks, or segments, in the Spectrum2d are (officially) referred to as "subbands".

Inside the Spectrum2d, subbands are vertical splits in the flux (and weight, flag etc.) columns, equivalent to the functionality of the segment column in the Spectrum1d. The flux etc. columns are replaced with flux_1, flux_2, ... columns, depending on how many subbands were defined. The definition of the subbands in terms of the starting index (e.g. the channel number in the HIFI CCD) and the length (the number of datapoints in the subband) are stored in metadata items called subbandstart and subbandlength (see Figure 3.4). The subbandstart refers to the index in the original spectrum before it was split into subbands, and for HIFI this refers to the physical channel inside the instrument. It is an important parameter because some data samples might have been discarded from the beginning/end of the spectrum when it was split into subbands (i.e. the first subbandstart is not necessarily equal to zero).

![Figure 3.4. Example of a HIFI Spectrum2d viewed in the SpectrumExplorer in HIPE, showing the metadata describing the different subbands (to display the metadata, right click in the plot and select Dialogs - Metadata). In this dataset, there is one spectrum with 4 subbands.](image)

### 3.3.1. Creating a Spectrum2d

An example of creating a simple Spectrum2d containing 4 spectra, from scratch, is given below. The inputs to create the Spectrum2d are 2D arrays of wave, flux etc., and so every spectrum must have the same number of datapoints.

```python
wave2d = Double2d([[1000.0,1000.2,1000.4,1000.6],
                   [1000.0,1000.2,1000.4,1000.6],
                   [1000.0,1000.2,1000.4,1000.6],
                   [1000.0,1000.2,1000.4,1000.6]])
flux2d = Double2d([[12.2,12.5,13.6,12.8],
                   [12.8,12.2,13.3,12.9],
                   [10.2,14.5,12.5,11.4],
                   [12.2,12.5,13.6,12.8]])
flag2d = Int2d([[1,1,1,1],[1,1,1,1],[1,1,1,1],[1,1,1,1]])
weight2d = Double2d([[1,1,1,1],[1,1,1,1],[1,1,1,1],[1,1,1,1]])

mySpectrum2d = Spectrum2d(flux2d, weight2d, flag2d)
mySpectrum2d.setWave(wave2d)
```

**Example 3.8. Creating a two-dimensional dataset containing four spectra.**

A further example to set up a basic Spectrum2d with associated subbands is given below. This example sets up a dataset which holds 2 spectra, each with 2 subbands. Each subband can cover a different wavelength range if necessary (e.g., as for the individual subbands of the HRS spectrometer of HIFI). This forms the basis of how HIFI observations, which are typically made up of many frames, are stored in HIPE.

```python
# This example creates a Spectrum2d that contains
# two rows of spectra, each containing two subbands
```
Example 3.9. Creating a multiband spectrum dataset.

3.3.2. Accessing data from a Spectrum2d

The following table defines the standard Spectrum2d columns and how these are accessed on the command line in HIPE.

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Contents</th>
<th>Direct data access</th>
<th>Java access method</th>
<th>Jython shortcut</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>wave</td>
<td>Wavelength, frequency,</td>
<td>['wave'].data</td>
<td>.getWave()</td>
<td>.wave</td>
<td>Double2d</td>
</tr>
<tr>
<td></td>
<td>wavenumber, or velocity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>flux</td>
<td>Flux density, brightness</td>
<td>['flux'].data</td>
<td>.getFlux()</td>
<td>.flux</td>
<td>Double2d</td>
</tr>
<tr>
<td></td>
<td>temperature, brightness, etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>Weight for each datapoint</td>
<td>['weight'].data</td>
<td>.getWeight()</td>
<td>.weight</td>
<td>Double2d</td>
</tr>
<tr>
<td>flag</td>
<td>Flag for each datapoint</td>
<td>['flag'].data</td>
<td>.getFlag()</td>
<td>.flag</td>
<td>Int2d</td>
</tr>
</tbody>
</table>

The direct data access (using square brackets) is the generic way to access columns inside Herschel datasets (see Section 2.1). The Java access method and related Jython shortcut provide shorter ways to access specific columns of data, and so are preferred by some people in their scripts. These methods are explicitly coded into the class definition of the Spectrum2d dataset and so only exist for the columns included in that definition (this is one of the things that can be added in instrument-specific extensions of the Spectrum2d).

If subbands are not used (e.g. for SPIRE data), all the access methods above work to return 2D arrays. For example, to plot (see the chapter on plotting in the Data Analysis Guide in Data Analysis Guide) the first spectrum using the Jython syntax:
Example 3.10. Plotting some columns selected using slice notation.

For HIFI, where different subbands can be specified, each column is split into sub-columns (appended with the subband number - e.g. flux_1, flux_2...), and only the Java-like access methods (getFlux() etc.) work, with the subband number specified inside the brackets. For example:

```python
# To access (e.g.) subband number 3
subbandNum = 3
subbandWave = mySpectrum2d.getWave(subbandNum)
subbandFlux = mySpectrum2d.getFlux(subbandNum)
```

Example 3.11. Accessing subbands using specific methods

In the above example, subbandWave and subbandFlux are 2D arrays. There are two (equivalent) ways to access the individual spectra - either specifying the indices (the first index is for the subband number), as in the previous plot example above:

```python
# Plot the first spectrum for the subband
pl.addLayer(LayerXY(subbandWave[0, :], subbandFlux[0, :]))
```

Example 3.12. Plotting the first spectrum of a subband using indices.

Or by using a "get()" method, specifying the subband index number:

```python
# Plot the first spectrum for the subband
pl.addLayer(LayerXY(subbandWave.get(0), subbandFlux.get(0)))
```

Example 3.13. Plotting the first spectrum of a subband using the get method.

Some other useful commands to investigate subbands are:

```python
# To determine how many subbands there are
print mySpectrum2d.subbandCount
print mySpectrum2d.numberOfSubbands
# To determine the start element and length of each subband
# (returns an array of indices/lengths taken from the metadata)
print mySpectrum2d.subbandStart
print mySpectrum2d.subbandLength
```


### 3.4. SimpleSpectrum

The SimpleSpectrum is a product containing a single Spectrum1d (see Section 3.2) dataset and metadata describing the associated observation. It is designed to allow a Spectrum1d to be written out to a FITS file and easily shared between collaborators, and also to allow simple spectra from other instruments to be read into HIPE with meaningful metadata preserved. Details of the SimpleSpectrum can also be found in the User Reference Manual in HCSS User's Reference Manual. Note that also, a Spectrum1d object can be written directly to a FITS file without the SimpleSpectrum product wrapper.

There are tasks for each instrument to extract a SimpleSpectrum product from any of the more complicated instrument products:

```python
simpleSpectrum = convertSingleHifiSpectrum()
simpleSpectrum = spireProduct2SimpleSpectrum()
simpleSpectrum = convertPacsProduct2SimpleSpectrum()
```

Example 3.15. Converting instrument specific spectral datasets to SimpleSpectrum.
Details of how to run these tasks can be found in the User Reference Manual for HIFI, SPIRE and PACS.

### 3.5. SpectralSimpleCube

The SpectralSimpleCube is a product containing three-dimensional datasets with axes denoting the longitude, latitude and spectral dimension of the data. The three dimensions are interpreted as spectral stacks of images, each with the same spatial grid - i.e. the SpectralSimpleCube contains data that has been projected (gridded) onto a regular square grid. It is the format used by all three instruments as the output of their gridding/projection tasks for spectral mapping observations.

The spatial grid of the cube is specified in the World Coordinate System with a WCS object defining cdelt, crpix, crval etc. in the same way as Herschel images (see Chapter 4). The individual spatial grid squares are referred to either as "pixels" (e.g. by HIFI) or as "spaxels" (e.g. by PACS).

The spectral axis values are provided as a Double1d array. It is assumed that the spectral axis applies to each spatial position.

The product can contain cubes for the flux, weight, error, flag, coverage, depending on the gridding algorithm used (SpectralSimpleCubes need not contain all of these datasets).

#### 3.5.1. Creating a SpectralSimpleCube

You can create a SpectralSimpleCube out of a three-dimensional array, like in the following example:

```python
# Create a 100x100x100 cube with all values equal to 1.0
data = Double3d(100, 100, 100, 1.0)
# Create a SpectralSimpleCube
myCube = SpectralSimpleCube(image=data)
```

Example 3.16. Creating cubes from Numeric arrays.

You can then set other cube components among the ones shown in Table 3.3, For instance, you can set the weight for each data point as in the following example:

```python
# Create a dummy weights cube with all weights equal to 1.0
weight = Double3d(100, 100, 100, 1.0)
# Assign weights to cube
myCube.weight = weight
```

Example 3.17. Creating a weight cube.

You can set components in any order, with one exception: before assigning a wavelength array to the cube (wave component) you must have assigned a valid WCS (wcs component). For information on how to assign a WCS to a cube, see Section 4.1.

#### 3.5.2. Accessing data from a SpectralSimpleCube

The standard datasets that can be contained in a SpectralSimpleCube are described in the following table (not all of them must be present) with how they are accessed on the command line in HIPE.

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Contents</th>
<th>Direct data access</th>
<th>Java access method</th>
<th>Jython shortcut</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>wave</td>
<td>Wavelength,</td>
<td>['ImageIndex'] [DepthIndex'] data</td>
<td>.getWave()</td>
<td>.wave</td>
<td>Double1d</td>
</tr>
</tbody>
</table>
## Spectra and spectral cubes

### Column Name | Contents | Direct data access | Java access method | Jython shortcut | Type
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>wavenumber, or velocity</td>
<td>(Remove space between ( ) and ( ) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>image</td>
<td>Flux density, brightness temperature, brightness, etc.</td>
<td>['image'].data</td>
<td>getImage() .image</td>
<td>Double3d</td>
<td></td>
</tr>
<tr>
<td>wcs</td>
<td>World Coordinate System parameters</td>
<td>*</td>
<td>getWcs() .wcs</td>
<td>Wcs</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>Weight for each datapoint</td>
<td>['weight'].data</td>
<td>getWeight() .weight</td>
<td>Double3d</td>
<td></td>
</tr>
<tr>
<td>error</td>
<td>Error for each datapoint</td>
<td>['error'].data</td>
<td>getError() .error</td>
<td>Double3d</td>
<td></td>
</tr>
<tr>
<td>flag</td>
<td>Flag for each datapoint</td>
<td>['flag'].data</td>
<td>getFlag() .flag</td>
<td>Short3d</td>
<td></td>
</tr>
<tr>
<td>coverage</td>
<td>Coverage for each datapoint from gridding task</td>
<td>['coverage'].data</td>
<td>getCoverage() .coverage</td>
<td>Double3d</td>
<td></td>
</tr>
</tbody>
</table>

* the WCS information is stored in the "image" metadata. The values can be accessed in the form of metadata items with the square bracket notation as follows:

```python
# Extract the "image" metadata
wcsMeta = cube['image'].meta
# Wrap this into a Wcs object
wcs = Wcs(wcsMeta)
```

**Example 3.18. Extracting the image metadata (including Wcs information).**

The direct data access (using square brackets) is the generic way to access columns inside Herschel datasets (see Section 2.1). The Java access method and related Jython shortcut provide shorter ways to access specific columns of data, and so are preferred by some people in their scripts. These methods are explicitly coded into the class definition of the SpectralSimpleCube and so only exist for the data included in that definition (this is one of the things that can be added in instrument specific extensions of the SpectralSimpleCube).

An example of extracting the 3D array of fluxes from a cube is:

```python
flux3d = cube.image
```

**Example 3.19. Accessing the image (flux) data from a cube.**

The most basic operations that might be useful for scripting with a cube are to extract a spectrum from a particular location (one spaxel/pixel), or to extract a single image plane as a SimpleImage (see the chapter on image analysis in the Data Analysis Guide). More complicated operations can be achieved using the Cube Spectral Analysis Toolbox (see the Data Analysis Guide) or with the basic Spectrum Toolbox (see the Data Analysis Guide).

```python
# To extract a single spectrum
# Define the RA and Dec of the position to extract
# e.g. taking the nominal (commanded) source position from the metadata
ra = cube.meta['raNominal'].value
dec = cube.meta['decNominal'].value
# First find the pixel/spaxel closest to the desired RA/Dec
```
Spectra and spectral cubes

pixCoord = cube.nearestPixels(ra, dec)
#
# Extract the flux as a Double1d specifying RA, Dec
# in decimal degrees
extractedFlux = cube.getFlux(ra, dec)
# or, specifying pixel/spaxel position (row, column)
extractedFlux = cube.getFlux(pixCoord[0], pixCoord[1])
#
# Extract the flux as a Spectrum1d at pixel/spaxel position
extractedSpectrum = cube.getSpectrum1d(pixCoord[0], pixCoord[1])

Example 3.20. Extracting a single spectrum from a cube.

Note: the nearestPixels and getFlux(ra, dec) methods work by calculating the exact position in fractions of a pixel from the WCS (using wcs.getPixelCoordinates(ra, dec) and then rounding this to the nearest integer with Math.round()).

To extract an image plane
#
# Find the nearest plane to a particular
# wave-scale value (e.g. 1000.0 GHz)
freq = 1000.0
planeIndex = cube.nearestPlane(freq)
#
# Extract a single plane as a Double2d specifying the frequency
extractedFlux = cube.getFlux(freq)
# or, specifying the plane index
extractedFlux = cube.getFlux(planeIndex)
#
# Wrap the extracted Double2d dataset into a
# SimpleImage so that it can be displayed in HIPE
extractedImage = SimpleImage()
extractedImage.image = extractedFlux
extractedImage.wcs = cube.wcs

Example 3.21. Extracting a single image plane for a specific frequency.

Note: the nearestPlane and getFlux(freq) work by starting at the zero element in the wave array and looping through all planes in the cube to find the smallest separation with the entered value. This applies even if the entered value is outside of the cube range.

Displaying cube dimensions. You can display the dimensions of the cube with the following command:

print myCube.dimensions
#array('i', [100, 70, 30])

Example 3.22. Printing the cube dimensions.

The first number (100 in the example above) is the size in the wavelength dimension, while the second and third number are the y and x dimensions, respectively, or in other words the number of rows and columns. For more information about cube dimensions see the Data Analysis Guide: Section 6.3 in Data Analysis Guide.

3.6. Instrument-specific spectral products

The following table summarises the spectral products used by each instrument and how these relate to the basic building blocks defined in the previous sections.

Table 3.4. Instrument-specific spectral products

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Product/Dataset</th>
<th>Basic building block</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPIRE (Level-1)</td>
<td>SpectrometerDetectorSpectrum</td>
<td>Spectrum1d</td>
<td>Composite dataset containing spectra from all detectors and scans from one</td>
</tr>
<tr>
<td>Instrument</td>
<td>Product/Dataset</td>
<td>Basic building block</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------</td>
<td>----------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>observation. Uses SpireSpectrum1d datasets which are extensions of Spectrum1d for SPIRE containing an error column and ra, dec and channelName metadata.</td>
</tr>
<tr>
<td>SPIRE (Level-2)</td>
<td>Spectrometer-PointSourceSpectrum</td>
<td>Spectrum1d</td>
<td>Composite dataset containing point source calibrated spectra from the central detectors. Uses SpireSpectrum1d datasets.</td>
</tr>
<tr>
<td>SPIRE</td>
<td>SpirePreprocessed-Cube</td>
<td>Spectrum2d</td>
<td>Data from all sky positions prepared for gridding into a cube.</td>
</tr>
<tr>
<td>SPIRE (Level-2 maps)</td>
<td>SpectralSimple-Cube</td>
<td>SpectralSimple-Cube</td>
<td>SpectralSimpleCube used directly without SPIRE specific extension.</td>
</tr>
<tr>
<td>HIFI</td>
<td>HifiSpectrum-Dataset</td>
<td>Spectrum2d</td>
<td>Extension of Spectrum2d for HIFI - contains additional data specific to HIFI (e.g. housekeeping, flags).</td>
</tr>
<tr>
<td>HIFI</td>
<td>HrsSpectrum-Dataset</td>
<td>Spectrum2d</td>
<td>Extension of a HifiSpectrumDataset - contains additional information for the HRS (e.g. correlation functions).</td>
</tr>
<tr>
<td>HIFI</td>
<td>WbsSpectrum-Dataset</td>
<td>Spectrum2d</td>
<td>Extension of a HifiSpectrumDataset - contains additional information for the WBS.</td>
</tr>
<tr>
<td>PACS (Level 1)</td>
<td>PacsCube</td>
<td>-</td>
<td>PACS specific format - it is a Spectrum-Container, but does not extend any of the basic building blocks described in this chapter. Does not contain flag or weight information, rather it has PACS-specific Masks.</td>
</tr>
<tr>
<td>PACS (Level 2)</td>
<td>SpectralSimple-Cube</td>
<td>SpectralSimple-Cube</td>
<td>The so-called PACS &quot;projectedCube&quot;. Currently does not contain flag or weight information. This uses the SpectralSimpleCube without PACS specific extension.</td>
</tr>
<tr>
<td>PACS (Level 2)</td>
<td>PacsRebinnedCube</td>
<td>SpectralSimple-Cube</td>
<td>PACS extension of the SpectralSimpleCube. Currently does not contain flag or weight information.</td>
</tr>
</tbody>
</table>
Chapter 4. The World Coordinate System

4.1. Assigning a World Coordinate System to images and cubes

You can assign WCS information to images and cubes. The World Coordinates System (WCS) describes the coordinates of a SimpleImage or SimpleCube. It makes it possible to convert image coordinates to world coordinates and the other way around. The WCS can have a lot of parameters, as defined in the FITS standard:

• naxis: the number of axes
• crval1: First coordinate of the centre
• crval2: Second coordinate of the centre
• crpix1: Reference pixel X coordinate
• crpix2: Reference pixel Y coordinate
• cdelt1: Pixel scale of axis 1. Step per pixel or number of degrees per pixel along x-axis when converting to Sky Coordinates. These parameters are no longer used in modern Wcs definition, but are included in the CDi_j matrix.
• cdelt2: Pixel scale axis 2. Step per pixel or number of degrees per pixel along y-axis when converting to Sky Coordinates. These parameters are no longer used in modern Wcs definition, but are included in the CDi_j matrix.
• ctype1, ctype2: Projection type name. This can be "LINEAR", "PIXEL" or the FITS convention. The default value for ctype1 and ctype2 is "LINEAR". When using the FITS convention, the first four characters are:
  • RA-- and DEC- for equatorial coordinates
  • GLON and GLAT for galactic coordinates
  • ELON and ELAT for ecliptic coordinates
The next four characters describe the projection. Possibilities are:
  • -AZP: Zenithal (Azimuthal) Perspective
  • -SZP: Slant Zenithal Perspective
  • -TAN: Gnomonic = Tangent Plane
  • -SIN: Orthographic/synthesis
  • -STG: Stereographic
  • -ARC: Zenithal/azimuthal equidistant
  • -ZPN: Zenithal/azimuthal PolyNomial
  • -ZEA: Zenithal/azimuthal Equal Area
• -AIR: Airy
• -CYP: CYlindrical Perspective
• -CAR: Cartesian
• -MER: Mercator
• -CEA: Cylindrical Equal Area
• -COP: COnic Perspective
• -COD: COnic equiDistant
• -COE: COnic Equal area
• -COO: COnic Orthomorphic
• -BON: Bonne
• -PCO: Polyconic
• -SFL: Sanson-Flamsteed
• -PAR: Parabolic
• -AIT: Hammer-Aitoff equal area all-sky
• -MOL: Mollweide
• -CSC: COBE quadrilateralized Spherical Cube
• -QSC: Quadrilateralized Spherical Cube
• -TSC: Tangential Spherical Cube
• -NCP: North celestial pole (special case of SIN)
• -GLS: GLobal Sinusoidal (Similar to SFL)

• Other types are also possible (for example TEMP for temperature.)
  
  • cunit1: The Unit of Axis 1.
  • cunit2: The Unit of Axis 2.
  • epoch: Epoch of coordinates.
  • Radesys: The reference frame, default value is "ICRS".
  
  • pc1_1: Element (1,1) of the linear transformation matrix. The pc1 and pc2 parameters are no longer used in modern Wcs definition, but are together with CDELT1 and CDELT2 included in the CDi_j matrix.
  
  • pc1_2: Element (1,2) of the linear transformation matrix.
  • pc2_1: Element (2,1) of the linear transformation matrix.
  • pc2_2: Element (2,2) of the linear transformation matrix.
  • cd1_1: Element (1,1) of the corrected linear transformation matrix.
• cd1_2: Element (1,2) of the corrected linear transformation matrix.
• cd2_1: Element (2,1) of the corrected linear transformation matrix.
• cd2_2: Element (2,2) of the corrected linear transformation matrix.

With a third dimension the following also applies:

• ctype3: Description of what the 3rd axis represents, for instance Wavelength, Time, M1 Temperature, and so on.
• cunit3: The Unit of Axis 3.
• crval3: [Optional - in case of equidistant 3rd dimension]. Wavelength, time, ... of reference layer; unit : length, time, ...
• crpix3: [Optional - in case of equidistant 3rd dimension] Reference layer index
• cdelt3: [Optional - in case of equidistant 3rd dimension] Scale in 3rd dimension - unit: length, time, ...

• PC elements:
  • pc1_3: Element (1,3) of the linear transformation matrix.
  • pc2_3: Element (2,3) of the linear transformation matrix.
  • pc3_1: Element (3,1) of the linear transformation matrix.
  • pc3_2: Element (3,2) of the linear transformation matrix.
  • pc3_3: Element (3,3) of the linear transformation matrix.

To create a WCS object that can be assigned to an image you can use something like the following.

```python
# Create the WCS object, units in degrees by default
myWcs = Wcs(crpix1 = 29, crpix2 = 29, crval1 = 30.0, crval2 = -22.5, 
             cdelt1 = 0.0004, cdelt2 = 0.0004, cunit1 = "DEGREES", 
             cunit2 = "DEGREES", ctype1 = "RA---TAN", ctype2 = "DEC--TAN")
# Check whether the WCS is valid
print myWcs.valid
# Assign the world coordinates to our image
myImage = SimpleImage(description = "Mock image", wcs = myWcs)
# You can then obtain the world coordinates at any pixel
print myImage.getWcs().getWorldCoordinates(31,31)
# This provides an array of sky coordinates in degrees.
# You can get the intensity at a given WCS position
# Assign a mock image with all intensity values set to 1.0
myImage.image = Double2d(100, 100, 1.0)
# Get the intensity at a given WCS position.
print myImage.getIntensityWorldCoordinates(30.0012, -22.498)
```

Example 4.1. Creating a WCS object from scratch.

For the SimpleCube and SpectralSimpleCube objects you can do this almost identically. Using the `d3` cube defined in a previous example:

```python
# Create WCS object, units in degrees by default
myWcs = Wcs(crpix1 = 29, crpix2 = 29, crval1 = 30.0, crval2 = -22.5, 
             cdelt1 = 0.0004, cdelt2 = 0.0004, cunit1 = "DEGREES", 
             cunit2 = "DEGREES", ctype1 = "RA---TAN", ctype2 = "DEC--TAN")
# Create a mock cube with all intensity values set to 1.0
myCube = SimpleCube(description="Mock cube", image=Double3d(100, 100, 100, 1.0), 
                     wcs=myWcs)
# Add third axis (WCS is created with two axes by default)
```
The World Coordinate System

myWcs.NAxis = 3

# Add quantities related to the third axis
myWcs.crval3 = 300.0
myWcs.crpix3 = 0
myWcs.cdelt3 = 0.001
myWcs.ctype3 = "Wavelength"
myWcs.cunit3 = "MICROMETERS"

# You can obtain the world coordinates at any pixel on the image.
print myCube.getWcs().getWorldCoordinates(31,31)

# Get the intensity at a given WCS position. We need three arguments now, with the first argument being the layer number (depth)
# from which we want the intensity measure. Count starts from 0.
print myCube.getIntensityWorldCoordinates(0, 30.0012, -22.498)

---

Example 4.2. Getting the world coordinates from a screen pixel position.

If the third axis of the cube is irregularly sampled, you can define an `imageIndex` array with the sampling values of each layer along the axis. Such array would replace the values of the `crval3`, `crpix3` and `cdelt3` parameters:

```python
# Create WCS object, units in degrees by default
myWcs = Wcs(crpix1 = 29, crpix2 = 29, crval1 = 30.0, crval2 = -22.5, 
    cdelt1 = 0.0004, cdelt2 = 0.0004, cunit1 = "DEGREES", 
    cunit2 = "DEGREES", ctype1 = "RA---TAN", ctype2 = "DEC--TAN")

# Create a mock cube
myCube = SimpleCube(description="Mock cube", image=Double3d(100, 100, 100, 1.0), wcs=myWcs)

# Add third axis (WCS is created with two axes by default)
myWcs.NAxis = 3

# Add quantities related to the third axis
myWcs.ctype3 = "Wavelength"
myWcs.cunit3 = "MICROMETERS"

# Add the imageIndex array
from herschel.share.unit.Length import MICROMETERS
wavelengths = Double1d([20.0, 45.0, 100.0])
myWcs.setImageIndex(wavelengths, MICROMETERS)
```

Example 4.3. Adding a third axis to a WCS structure to define an image index.

To check whether the third axis is regularly sampled, the following will return 1 if true, 0 if false:

```python
print myWcs.equidistantInZ
```

Example 4.4. Printing if the third axis is regularly sampled.

A summary of queries on the wcs of the cube (replace the specific numbers here with those appropriate for your cube):

```python
# You can obtain the world coordinates at any spaxes/pixel
print myCube.getWcs().getWorldCoordinates(31,31)

# You can obtain the spectral coordinate at any index position
print myCube.wcs.getPixelCoordinates(30.0012, -22.498)

# Or the spaxel/pixel and wavelenth/frequency coordinate
# for a world coordinate position
print myCube.wcs.getPixelCoordinates(30.0012, -22.498)
print myCube.wcs.getPixelCoordinateZ(300.023)

# Get the intensity at a given WCS position. We need three arguments now, with the first argument being the layer number (depth)
# from which we want the intensity measure. Count starts from 0.
print myCube.getIntensityWorldCoordinates(0, 30.0012, -22.498)
```

Example 4.5. Transforming between world coordinates and

4.2. Correcting the astrometry of your data
With the `astrometryFix` task you can correct the astrometry of your data to make it consistent with the astrometry of some other data. To learn more about the `astrometryFix` task, see the corresponding entry in the *User's Reference Manual: Section 1.29* in *HCSS User's Reference Manual*.

If you are a SPIRE user, there is a helper script to correct the astrometry of your observations. In HIPE, choose *Scripts → SPIRE Useful scripts → Photometer Astrometry Correction*. 
Chapter 5. The Numeric library

This chapter describes the numeric functions available within HIPE. For information on numeric arrays and other datasets, see Chapter 2. For reference information about all the numeric functions in HIPE, see the User’s Reference manual in HCSS User’s Reference Manual.

5.1. Numeric functions and lambda expressions

You can apply functions as follows:

```python
print SQRT(16) # 4.0 (applied to a scalar)
y = DoubleId([1,4,9,16])
print SQRT(y) # [1.0,2.0,3.0,4.0] (applied to a DP numeric array)
```

Example 5.1. Taking the square root of a numeric array of doubles.

As shown by this example, functions on scalars (such as SQRT) are implicitly mapped over each element of an array. You can combine functions with arithmetic operators to perform complex operations on each element of an array:

```python
t = DoubleId([1,2,3,4])
print SIN(1000 * t * (1 + .0003 * COS(3 * t)))
# [0.6260976237441638,0.5797470124743422,0.8629107307631398, -0.9811675382238753]
```

Example 5.2. Numeric functions are applied to each element of an array.

The names of functions in the numeric library have ALL LETTERS capitalised. This is to avoid ambiguity, as Jython already defines certain functions, such as 'abs', which are not applicable to our DP numeric arrays.

There are various types of functions in the numeric library:

```python
y = DoubleId([1,2,3,4])
print SQRT(4) # double->double
print SQRT(y) # double->double (mapped)
print REVERSE(y) # Doubleld->DoubleId
print MEAN(y) # DoubleId->double
```

Example 5.3. Converting values to double as it is the type of the numeric arrays.

You can define new functions as lambda expressions in Jython and apply them to numeric arrays. For example:

```python
y = DoubleId([1,2,3,4])
f = lambda x: x**2 + 1 #take the given array, call it 'x' and return the value x**2 +1 to an array called f.
print f(y) #[2.0,5.0,10.0,17.0]. Each element of y was taken -> x then each element was squared #plus 1 added.
```

Example 5.4. Using lambda expression to apply new functions to arrays in the same way as Numeric functions.

However, in this case, it is much easier and faster to do this with array operations.
print y * y + 1

Example 5.5. For simple functions it is much more readable to use the built-in operators.

Lambda expressions are not as fast as the standard Java functions provided by the numeric library, but this is often not a problem.

More complex functions (equivalent to subroutines) can be created using the def command, which is discussed in Section 1.27.

5.2. Basic functions

Basic functions applicable to scalars or arrays, and returning scalars or arrays of the same size:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Absolute value</td>
</tr>
<tr>
<td>ARCCOS</td>
<td>Inverse cosine</td>
</tr>
<tr>
<td>ARCSIN</td>
<td>Inverse sine</td>
</tr>
<tr>
<td>ARCTAN</td>
<td>Inverse tangent</td>
</tr>
<tr>
<td>CEIL</td>
<td>Ceiling</td>
</tr>
<tr>
<td>COS</td>
<td>Cosine</td>
</tr>
<tr>
<td>EXP</td>
<td>Exponential</td>
</tr>
<tr>
<td>FIX</td>
<td>Integer</td>
</tr>
<tr>
<td>FLOOR</td>
<td>Floor</td>
</tr>
<tr>
<td>LOG</td>
<td>Logarithm</td>
</tr>
<tr>
<td>LOG10</td>
<td>Common logarithm</td>
</tr>
<tr>
<td>ROUND</td>
<td>Round</td>
</tr>
<tr>
<td>SIGNUM</td>
<td>Signum</td>
</tr>
<tr>
<td>SIN</td>
<td>Sine</td>
</tr>
<tr>
<td>SQRT</td>
<td>Square root</td>
</tr>
<tr>
<td>SQUARE</td>
<td>Square</td>
</tr>
<tr>
<td>TAN</td>
<td>Tangent</td>
</tr>
</tbody>
</table>

These are applied in the form

\[ b = \text{SIN}(a) \]

Example 5.6. The SIN function works for arrays and scalars.

\[ b \] will be an array of the same dimension as \( a \), or a scalar if \( a \) is a scalar.

Array functions on Double\(<n>d\) returning a double:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>Minimum</td>
</tr>
<tr>
<td>MAX</td>
<td>Maximum</td>
</tr>
<tr>
<td>SUM</td>
<td>Sum</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Product</td>
</tr>
<tr>
<td>MEAN</td>
<td>Mean</td>
</tr>
<tr>
<td>MEDIAN</td>
<td>Median</td>
</tr>
<tr>
<td>STDDEV</td>
<td>Standard deviation</td>
</tr>
</tbody>
</table>

\[ b = \text{MIN}(a) \] # 'b' is the minimum value of the array 'a'.

Warning

Remember to strip your arrays of any NaN (Not a Number) values before using these functions, or the result will always be a NaN. See Section 2.2.9 for more information.

Example 5.7. Finding the minimum value of an array.

These functions can also be used to reduce the dimensionality of an array (for instance, three- to two-dimensional).

Functions applicable to one-dimensional arrays and returning an array of the same size:

Functions applicable to arrays and returning an array of increased rank (number of dimensions):

- **REPEAT** in *HCSS User's Reference Manual*

**Warning**

Many of these functions have lower case equivalents built-in in Jython. Be aware of which one you are using, because their behaviour could differ in some cases, as shown by the example below which creates a table with NaN values in it.

```python
tt=Double1d.range(10)
tt[0]=Double.NaN
print max(tt) # NaN
print min(tt) # NaN
```

```python
tt[1]=Double.NaN
print max(tt) # By using the built-in Jython functions
# 9.0
print min(tt) # 1.0
```

```python
print MAX(tt) # By using the DP Numeric functions
# NaN
print MIN(tt) # NaN
```

Example 5.8. Differences between the lower-case Jython functions and the upper-case Numeric functions.

### 5.3. Integral transforms

HIPE has two options for performing fast Fourier transforms: FFT and FFT_PACK. These two classes are comparable in terms of their accuracy. Both FFT and FFT_PACK transform data from a complex array to a complex array. They differ in execution time. Additional classes, which are related to FFT_PACK, add the options of transforming real data and of taking advantage of symmetry for shorter execution run-times. Table 5.1 gives an overview of the available transformation options:

<table>
<thead>
<tr>
<th>Name</th>
<th>Input type</th>
<th>Output type</th>
<th>Output length</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FFT</strong></td>
<td>Complex1d</td>
<td>Complex1d</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FFT_PACK</strong></td>
<td>Complex1d</td>
<td>Complex1d</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RealDoubleFFT#ft</strong></td>
<td>double[]</td>
<td>Complex1D</td>
<td>floor(N/2) +1</td>
<td>Calculates FFT of real input.</td>
</tr>
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</tr>
</tbody>
</table>

\[ X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi \ i n k}{N}}, \quad k = 0, \ldots, N - 1. \]

\[ a_k = \sum_{n=0}^{N-1} x_n \cos \left( \frac{2\pi \ i n k}{N} \right), \quad k = 0, \ldots, \lfloor N/2 \rfloor. \]

\[ b_k = -\sum_{n=1}^{N-1} x_n \sin \left( \frac{2\pi \ i n k}{N} \right), \quad k = 1, \ldots, \lfloor N/2 \rfloor. \]
The Numeric library

<table>
<thead>
<tr>
<th>Name</th>
<th>Input type</th>
<th>Output type</th>
<th>Output length</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT_PACK_EVEN</td>
<td>Double1d</td>
<td>Double1d</td>
<td>N</td>
<td>Discrete cosine transform.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFT_PACK_ODD</td>
<td>Double1d</td>
<td>Double1d</td>
<td>N</td>
<td>Discrete sine transform.</td>
</tr>
</tbody>
</table>

\[ c_k = x_0 + 2 \sum_{n=1}^{N-1} x_n \cos \frac{k\pi n}{N} + (-1)^k x_{N-1}, \quad k = 0, \ldots, N - 1 \]

5.3.1. FFT

The FFT class offers a Discrete Fourier Transform for Complex1d arrays. It uses a radix-2 FFT algorithm for array lengths that are powers of 2 and a Chirp-Z transform for other lengths.

Example 5.9 shows the generation of a frequency modulated signal, followed by a FFT both with and without windowing:

```java
ts = 1E-6          // Sampling period (sec)
f_c = 200000       // Carrier frequency (Hz)
f_m = 2000         // Modulation frequency (Hz)
beta = 0.0003      // Modulation index (Hz)
n = 5000           // Number of samples
pi = java.lang.Math.PI   // define pi

t = Double1d.range(n) * ts
    // t is a 5000 element array holding time values

signal = SIN(2 * pi * f_c * t * (1 + beta * COS(2 * pi * f_m * t)));
    //create the modulated signal with modulation frequency f_m and carrier
    //frequency f_c, t is the array we created above for the time elements.

spectrum = ABS(FFT(Complex1d(signal)));
    //spectrum holds the absolute value (ABS) of the FFT of the signal.
    //We need to handle these arrays as Complex1d rather than Double1d.

t_freq = Double1d.range(n) / (n * ts)
    //The frequency values for the spectrum.

// Repeat with apodizing
spectrum2 = ABS(FFT(Complex1d(HAMMING(signal))));
```

Example 5.9. FFT of a modulated signal, with and without HAMMING smoothing

5.3.2. FFT_PACK

HIPE offers a Java implementation of FFT_PACK for the fast calculation of the Discrete Fourier Transform for Complex1d arrays and for Double1d arrays. Specialized classes are available to operate on Double1d arrays that contain data of even or odd symmetry. FFT_PACK aims to make use of the data properties (real only, symmetry) in order to reduce execution run-time.


FFT_PACK transforms complex input into complex output. For the numbers from 2 to 10,000, FFT_PACK is faster than FFT in more than 55% of all cases. FFT_PACK is slower than FFT if the length of the input array is a power of 2. FFT_PACK is also slower than FFT if the prime factor decomposition of the length of the input array contains a large value.

```java
# Handle these arrays as Complex1d rather than Double1d.
```
spectrum = ABS(FFT_PACK(Complex1d(signal)))
# spectrum now holds the absolute value (ABS) of the FFT of signal.

Example 5.10. Transforming a signal into the modulus of its spectrum.

RealDoubleFFT#ft (Discrete Fourier Transform for real data) in HCSS User's Reference Manual

RealDoubleFFT#ft transforms real input into complex output. It makes no assumption about the symmetry of the input data. To speed up the transform, RealDoubleFFT#ft only calculates values which cannot be determined from conjugate symmetry (recall that for real input, \(X_k = (X_{N-k})^*\)). Given an input of length \(N\), RealDoubleFFT#ft outputs only the first floor\((N/2)+1\) values of the FFT.

from herschel.ianumeric.toolbox.xform.util import RealDoubleFFT
# Initialization of the RealDoubleFFT to a certain length \(N\) must be performed
# only once for each new array length
N = 10
signal = Double1d.range(10)
rdfft = RealDoubleFFT(N)
# Create a Complex1d to store the FFT of signal.
spectrum = Complex1d()
# Execute the real double FFT with an explicit copy as the calculation
# invalidates the input signal. Handle the signal array as a Java array.
rdfft.ft(signal.copy().array, spectrum)
# spectrum now holds the FFT of signal
spectrum = ABS(spectrum)
# spectrum now holds the absolute value (ABS) of the FFT of signal.
# Forward transform of real signal of length \(N\)
rdfft = RealDoubleFFT(N)
spectrum = Complex1d()
rdfft.ft(signal.toArray(), spectrum)
# spectrum now holds the absolute value (ABS) of the FFT of signal.
# Inverse transform of complex spectrum of length \(N/2+1\)
recreatedSignal = Double1d(N)
rdfft.bt(spectrum, recreatedSignal.array)
# Normalize signal
signal = recreatedSignal/N

Example 5.11. Transforming a real signal into a spectrum.

FFT_PACK_EVEN (Discrete Cosine Transform for real data with even symmetry) in HCSS User's Reference Manual

FFT_PACK_EVEN implements the Discrete Cosine Transform. It transforms real input into real output, assuming data with even symmetry of the form \((x_0, x_1, ..., x_{N-2}, x_{N-1}, x_{N-2}, ..., x_1)\). FFT_PACK_EVEN is fast for input lengths for which the input array length minus 1 can be decomposed into small prime factors.

N_extended = signal.size
spectrum = FFT_PACK_EVEN(signal[0:N_extended/2+1])
# spectrum now holds the positive real frequencies of the FFT of signal
# (assuming that signal has even symmetry)

Example 5.12. Transforming a real signal with even symmetry into a spectrum.


FFT_PACK_ODD implements the Discrete Sine Transform. It transforms real input into imaginary output (the imaginary part of a complex array) assuming data with odd symmetry of the form \((0, x_0, x_1, ..., x_{N-1}, 0, -x_{N-1}, ..., -x_0)\). FFT_PACK_ODD is fast for input lengths for which the input array length plus 1 can be decomposed into small prime factors.

N_extended = signal.size
Example 5.13. Transforming a real signal with odd symmetry into a spectrum.

5.3.3. Selecting the right Fourier transform

If run-time efficiency is critical, it is necessary to be careful about selecting the Fourier transform suitable for the job at hand. The guidelines below help select the right Fourier transform to minimize execution run-time, based on N, i.e. the length of the input array:

- If N is a power of 2, i.e. \( N = 2^m \) for an integer m, then use FFT.
- If the largest value in the prime number decomposition of N is relatively large, then compare execution run-time between FFT and FFT_PACK.
- If the input is real, use RealDoubleFFT instead of FFT_PACK.
- If input is real and multiple transforms need to be performed on different inputs of the same length, create a single RealDoubleFFT object and perform all transforms using the same object.
- If the input is real and has even symmetry, use FFT_PACK_EVEN. Note that for fast execution, the length of the input to FFT_PACK_EVEN minus one should decompose into small factors.
- If the input is real and has odd symmetry, use FFT_PACK_ODD. Note that for fast execution, the length of the input to FFT_PACK_ODD plus one should decompose into small factors.

![Comparison of FFT, FFT_PACK and RealDoubleFFT execution times](image)

Figure 5.1. The speed of FFT_PACK is dependent on input length: if the input length can be factored into small numbers, FFT_PACK is faster than FFT; if the input length contains a large prime factor, FFT is faster than FFT_PACK. FFT is also faster when input length is a power of two. For strictly real input, RealDoubleFFT is always faster than FFT_PACK.

5.3.4. Inverse Fourier transforms

HIPE offers inverse Fourier transforms which correspond to each forward Fourier transform.
Table 5.2. Options for the inverse Fourier Transforms. Note that the output of RealDoubleFFT#bt depends on the value of N with which the RealDoubleFFT object was created.

<table>
<thead>
<tr>
<th>Name</th>
<th>Input type</th>
<th>Output type</th>
<th>Output length</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFFT</td>
<td>Complex1d</td>
<td>Complex1d</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[ x_n = \frac{1}{N} \sum_{k=1}^{N-1} X_k e^{\frac{2\pi i n k}{N}}, \quad n=0, \ldots, N-1. ]</td>
</tr>
<tr>
<td>IFFT_PACK</td>
<td>Complex1d</td>
<td>Complex1d</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[ x_n = \sum_{k=1}^{N-1} X_k e^{\frac{2\pi i n k}{N}}, \quad n=0, \ldots, N-1. ]</td>
</tr>
<tr>
<td>RealDoubleFFT#bt</td>
<td>Complex1D</td>
<td>Double1d</td>
<td>2L-2</td>
<td>L is the length of the input to RealDoubleFFT#bt.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(N even)</td>
<td>N is the length of input to RealDoubleFFT#ft and is fixed when the RealDoubleFFT object is created.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2L-1</td>
<td>Outputs strictly real data.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(N odd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N even: [ x_n = a_0 + 2 \sum_{k=1}^{(N/2)-1} (a_k \cos k \frac{2\pi n}{N} - b_k \sin k \frac{2\pi n}{N}) + a_{N/2} (-1)^{\frac{N}{2}} n = 0, \ldots, N-1. ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N odd: [ x_n = a_0 + 2 \sum_{k=1}^{(N-1)/2} (a_k \cos k \frac{2\pi n}{N} - b_k \sin k \frac{2\pi n}{N}) , \quad n=0, \ldots, N-1. ]</td>
</tr>
<tr>
<td>IFFT_PACK_EVEN</td>
<td>Double1d</td>
<td>Double1d</td>
<td>N</td>
<td>Inverse discrete cosine transform.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[ x_n = a_0 + 2 \sum_{k=1}^{(N/2)-1} (a_k \cos k \frac{2\pi n}{N} - b_k \sin k \frac{2\pi n}{N}) + a_{N/2} (-1)^{\frac{N}{2}} n = 0, \ldots, N-1. ]</td>
</tr>
<tr>
<td>IFFT_PACK_ODD</td>
<td>Double1d</td>
<td>Double1d</td>
<td>N</td>
<td>Inverse discrete sine transform.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[ x_n = 2 \sum_{k=1}^{N-1} c_k \sin k \frac{n \pi}{N}, \quad n=1, \ldots, N-1. ]</td>
</tr>
</tbody>
</table>

5.3.5. Normalization

The application of the forward transform followed by the application of the inverse transform is an identity operation if the output of the inverse transform is normalized.

Table 5.3. For the following normalizations, assume that the signal has N elements.

<table>
<thead>
<tr>
<th>Forward and inverse transforms</th>
<th>Normalization to identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT, IFFT</td>
<td># Automatically normalized&lt;br&gt;\texttt{signal = IFFT(FFT(signal))}</td>
</tr>
<tr>
<td>FFT_PACK, IFFT_PACK, RealDoubleFFT#ft,</td>
<td>signal = IFFT_PACK(FFT_PACK(signal))/N&lt;br&gt;\texttt{rdfft = RealDoubleFFT#ft(N)}</td>
</tr>
</tbody>
</table>
Forward and inverse transforms

<table>
<thead>
<tr>
<th>Function</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>rdfft.ft</code></td>
<td><code>c = Complex1D()</code>&lt;br&gt;<code>rdfft.ft(signal.toArray(), c)</code>&lt;br&gt;<code># Inverse transform of complex spectrum of length N/2+1</code>&lt;br&gt;<code>recreatedSignal = Double1d(N)</code>&lt;br&gt;<code>rdfft.bt(c, recreatedSignal.array)</code>&lt;br&gt;<code># Normalize signal</code>&lt;br&gt;<code>signal = recreatedSignal/N</code></td>
</tr>
<tr>
<td><code>FFT_PACK_EVEN</code></td>
<td><code>signal = IFFT_PACK_EVEN(FFT_PACK_EVEN(signal))/(2*N-2)</code></td>
</tr>
<tr>
<td><code>IFFT_PACK_EVEN</code></td>
<td></td>
</tr>
<tr>
<td><code>FFT_PACK_ODD</code></td>
<td><code>signal = IFFT_PACK_ODD(FFT_PACK_ODD(signal))/(2*N+2)</code></td>
</tr>
<tr>
<td><code>IFFT_PACK_ODD</code></td>
<td></td>
</tr>
</tbody>
</table>

5.4. Power spectrum

With the `PowerSpectrum` class you can create the power spectrum of each column of a Table Dataset. Table dataset that are suitable for power spectrum conversion typically contain a column bearing units of time, plus other columns of quantities from which to compute power spectra. Since real signals sometimes contain unwanted strong excursions, called glitches or spikes, that will dominate the power spectrum, the Task includes a simple deglitcher, that detects and removes such events from the data stream, replacing them with an average of the surrounding data.

The `Power Spectrum Viewer`, a graphical interface wrapping the functionality of this class, is described in the *Data Analysis Guide*.

You can obtain your power spectra by invoking the `getPowerSpectrum` method on the `PowerSpectrum` class. The method takes the following arguments:

- `table`: the input Table Dataset.
- `flimit`: the inverse cut-off frequency (default 0.1).
- `sigma`: the deglitcher threshold (default 4).
- `deglitch`: boolean, activates the deglitcher if true (default).
- `timeColumn`: a Column containing time information.

The inverse cut-off frequency determines the length of the intervals into which the data timeline is subdivided before performing the FFT. Each of these datasets is Fourier transformed individually, and the resulting power spectra are quadratically co-added to yield a power spectrum with a better S/N ratio, that is, a higher cut-off frequency will yield a better S/N for the resulting power spectrum.

The sigma value controls a simple sigma/kappa deglitcher, that eliminates all datapoints that are more than sigma (default = 4) times the standard deviation away from the mean. After eliminating these data points the procedure is repeated iteratively until no more data can be discarded.

The `getPowerSpectrum` method has the following variants:

- `getPowerSpectrum(table)`
- `getPowerSpectrum(table, timeColumn)`
- `getPowerSpectrum(flimit, table)`
- `getPowerSpectrum(flimit, table, timeColumn)`
• getPowerSpectrum(flimit, sigma, table)
• getPowerSpectrum(flimit, sigma, table, timeColumn)
• getPowerSpectrum(flimit, sigma, deglitch, table)
• getPowerSpectrum(flimit, sigma, deglitch, table, timeColumn)

5.5. Convolution

Convolution is currently supported for Double1d arrays. A direct convolution algorithm is used, although a future release might implement Fourier convolution to improve the speed for large arrays and large kernels. An example of its use is given in Example 5.14.

```python
x = Double1d.range(100)
# Create array [0.0, 1.0, 2.0 ... 99.0]
kernel = Double1d([1,1,1])
#provide kernel for the convolution
f = Convolution(kernel)
#create the convolution
y = f(x)
#apply it to the array x. The result is in array y
```

Example 5.14. Example of the use of the convolution algorithm.

This illustrates a general approach with the numeric library i.e. general function objects may be instantiated using parameters to create a customised function which can then be applied to one or more sets of data.

The constructor of the Convolution class allows optional keyword arguments to be specified, to further customise the function:

• The 'center' parameter allows selection of a causal asymmetric filter for time domain filtering or a symmetric filter for spatial domain filtering.

• The 'edge' parameter controls the handling of edge effects, as well as allowing a choice between periodic (circular) and aperiodic convolution.

The following examples show construction of filters using these options:

| Note |
| Make sure you have input the following import line before trying these out. |

```python
from herschel.ia.numeric.toolbox.filter.Convolution import *
```

Example 5.15. Importing the Convolution module.

Use zeroes for data beyond edges, causal:

```python
f = Convolution(kernel, center=0, edge=ZEROES)
```

Example 5.16. Create a convolution function with zeroes beyond the edges.

Circular convolution, causal:

```python
f = Convolution(kernel, center=0, edge=CIRCULAR)
```

Example 5.17. Create a convolution function with circular wrapping beyond the edges.
Repeat edge values, causal:

\[
f = \text{Convolution}(\text{kernel}, \text{center}=0, \text{edge}=\text{REPEAT})
\]

**Example 5.18.** Create a convolution function with value repetition beyond the edges.

Use zeroes for data beyond edges with centred kernel:

\[
f = \text{Convolution}(\text{kernel}, \text{center}=1, \text{edge}=\text{ZEROES})
\]

**Example 5.19.** Create a centred convolution function with zeroes beyond the edges.

Circular convolution with centred kernel:

\[
f = \text{Convolution}(\text{kernel}, \text{center}=1, \text{edge}=\text{CIRCULAR})
\]

**Example 5.20.** Create a centred convolution function with circular wrapping beyond the edges.

Repeat edge values with centred kernel:

\[
f = \text{Convolution}(\text{kernel}, \text{center}=1, \text{edge}=\text{REPEAT})
\]

**Example 5.21.** Create a centred convolution function with value repetition beyond the edges.

### 5.6. Boxcar and Gaussian filters

Finite Impulse Response (FIR) filters and symmetric spatial domain filters can be defined by instantiating the `Convolution` class with appropriate parameters. In addition, special filter functions are provided for Gaussian filters and box-car filters:

\[
\text{from herschel.ia.numeric.toolbox.filter.Convolution import *}
\]

\[
f = \text{GaussianFilter}(5, \text{center}=1, \text{edge}=\text{ZEROES})
f = \text{BoxCarFilter}(5, \text{center}=0, \text{edge}=\text{ZEROES})
\]

**Example 5.22.** Creating different filtering functions using the Convolution module.

These filters are subclasses of `Convolution` and hence inherit the use of similar keyword arguments.

### 5.7. Interpolation

Interpolation functions are provided for a variety of common interpolation algorithms. **Example 5.23** illustrates the use of the currently available interpolation functions.

```python
# Create the array x [0.0, 1.0, 2.0, ..., 9.0]
x = \text{Double1d}.range(10)
print x # [0.0,1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0]
# Create an array y which contains the sine of each element in x
y = \text{SIN}(x)
# u contains the values at which to interpolate
u = \text{Double1d}.range(80) / 10 + 1
print u # [1.0,1.1,1.2,1.3,...,8.6,8.7,8.8,8.9]
# Linear interpolation
# This sets up the interpolation, linear x-y fit
# Interpolate at specified values
interp = \text{LinearInterpolator}(x,y)
# Prints out the values interpolated at each position noted in array u
```

88
print interp(u) #[0.8414709848,0.848253629....0.5275664375,0.4698424613]
# NearestNeighbour and CubicSpline interpolation may be performed
# in the same way:
# Cubic-spline interpolation
interp = CubicSplineInterpolator(x,y)
# Nearest-neighbour interpolation
interp = NearestNeighborInterpolator(x,y)

**Example 5.23. Interpolation functions in DP**

The result of the interpolations used in the above example is illustrated in Figure 5.2.

![Graph showing various forms of interpolation functions.](image)

**Figure 5.2. Illustration of various forms of interpolation functions.**

### 5.8. Fitting data

Here we provide information on the basic linear and non-linear fitting routines available in HIPE.

#### 5.8.1. General approach

**Input Data:** The fitter package expects your data to be in two datasets that are related to each other. Typically, these are `Double1d` arrays, e.g.,

```python
x = Double1d(range(12))   # Make x vector (the data positions/channels)
y = Double1d([1.0,1.2,0.9,2.2,3.3,4.5,3.6,2.7,1.8,1.2,1.0,1.1])  # Make y vector (the data values)
```

**Example 5.24. Defining some X-Y data points.**

**Model Selection:** Fitting means adjusting the parameters of a known function, called *model*, so that it best matches the input data. This toolbox provides some pre-defined linear models as well as non-linear models. Viewing your data will hopefully give you some hints about what function model would reflect your input data. For example, if it seems to be polynomial of a certain degree, you would choose a `PolynomialModel`.
Note

For the case of non-linear fitters (e.g., used with Gaussians) it is also necessary to provide initial guesses in the form of a parameter set to the model before invoking a fitter. The closer the initial guess for the parameter set to the true values the higher the likelihood that the minimisation will not find a local minimum with wrong/unrealistic parameter estimation.

An example of the use of a linear fitter:

```python
# Choose a model: 4th degree polynomial
myModel = PolynomialModel(4)
# Create a fitter and feed it your positions/channels along the array
# (x, a Double1d array) and your model
myFitter = Fitter(x, myModel)
```

**Example 5.25. Fitting data with a polynomial model (linear).**

Or for a non-linear fitter applied to our array `x`:

```python
myModel = GaussModel()
peak = 4.5
channel = 5.5
sigma = 1.0  # Note that sigma is not the FWHM
initialvalues = Double1d([peak, channel, sigma])
# Apply the initial estimates: peak height, channel position and
# sigma of gaussian
myModel.setParameters(initialvalues)
# Choose non-linear fitter to use
myFitter = AmoebaFitter(x, myModel)  # see later section on available fitters
```

**Example 5.26. Fitting data with a gaussian model (non-linear).**

**Fit Execution (with and without weights):**

```python
# Now actually fit the data values at each x position (the y array) to the model
fitresults = myFitter.fit(y)
# Or with associated weights array
fitresults = myFitter.fit(y, yWeights)
```

**Example 5.27. Executing the fit with or without parameters.**

**Results** Now the fitter has done its job. We can print the results (`fitresults`) to see the parameters fitted.

```python
print fitresults  # from using the polynomial fitter
# [1.0993589743591299,-1.1096331908843398,0.8923489704745665,
# -0.1468839031339513,0.006825466200470528]
# provides coefficients of the polynomial fit
print fitresults  # from using the Gaussian fitter
# [3.751009700481534,5.353351564022887,2.5098951536394383]
# Peak of fit, channel of Gaussian peak, sigma of Gaussian
```

**Example 5.28. Printing the results of the fitting.**

The fit parameters model are computed and we can start using that model to e.g. re-sample your model fit data:

```python
# Re-sample with equally spaced x data points and a finer grid:
x = Double1d.range(1200) / 100     # Re-sampled x positions
ys = myModel(xs)                   # Computed y data points
# a plot of xs versus ys plots out 1200 points with the fit.
```

**Example 5.29. Re-sampling the fit data according to the model.**
Statistical Information  The above procedure demonstrates how to use the fit package to fit your data against a certain model. However, it does not tell you how good the fit actually is. The fitters provide ways to extract such information from the fit.

```plaintext
# After fitting
print myFitter.getChiSquared() # Goodness of the fit
# e.g., 2.576584980727577 for Gaussian fit
print myFitter.autoScale() # How well does the data fit the model.
# e.g., 0.535064350372312 for Gaussian fit
print myFitter.getStandardDeviation() # Standard deviations for the parameters.
# e.g., [0.30907540430060004, 0.24531121048289006, 0.2525757390634412] for Gaussian fit parameters
print myFitter.getHessian() # Retrieve the Hessian matrix
es = myFitter.monteCarloError(xs) # Errors on the resampled datapoints
# es is now an error array with a length the same as "xs" -- 1200 samples
```

Example 5.30. Retrieving the statistical indicators of the goodness of fit.

Warning

If you use `getStandardDeviation` (as in the example above) to obtain the standard deviation array, please note that the results are scaled by a noise estimation value as stated in the method description in the URM in HCSS User's Reference Manual. You can use the method `myFitter.getScale()` to know this value or:

```plaintext
covMat = myFitter.getCovarianceMatrix()
dimension = covMat.getDimension(0) # A square matrix
stdDev = Double1d(dimension)
for i in range(dimension):
    stdDev[i] = SQRT(covMat[i,i])
```

Example 5.31. Retrieving the unscaled standard deviation from the fit.

5.8.2. Available linear models

There are several models that can be used for linear fitting.

In the descriptions below, the models provide parameter fit values $p_0, p_1 \ldots p_k$.

Note

In the following examples the parameter subscripts match the position of the parameter in the output array (`fitsresult` in the previous section). So $p_0$ will be the first element of the `fitsresult` array, $p_1$ the second one, and so on.

**BinomialModel** in HCSS User's Reference Manual, which allows for the fitting of a binomial model with two variables: $f(x,y:p) = \sum p_k x^k y^{d-k}$, where $d$ is the degree. Usage: `BinomialModel(4)` – provides a binomial model of degree 4.

**PolynomialModel** in HCSS User's Reference Manual, which allows for the least squares fitting of a polynomial to the data: $f(x:p) = \sum p_k x^k$. Usage: `PolynomialModel(3)` – provides a third order polynomial fitting of the data.

**SineAmpModel** in HCSS User's Reference Manual, which allows for the fitting of cosine and sine waves of a given frequency to get amplitudes $-f(x:p) = p_0 \cos(2 \pi f x) + p_1 \sin(2 \pi f x)$, where $x$ is the data. Usage: `SineAmpModel(f)` – which provides cosine/sine fits with a frequency, $f$.

**PowerModel** in HCSS User's Reference Manual, which allows for the fitting of a power law of order $k$: $f(x:p) = p_0 x^k$. Usage: `PowerModel(3)` – provides a third-order power-law fit.
SplinesModel in HCSS User’s Reference Manual, which allows for the fitting of a cubic splines with arbitrary knots settings. Usage: SplinesModel(Double1d([12.5, 15.8, 17.7])) – provides a cubic splines fit with three knots.

5.8.3. Available non-linear models

There are a number of models that can be used for non-linear fitting. For fitting of these models we need initial values (guesses) for parameters labelled $p_0$, $p_1$ and $p_2$ (see example given in Section 5.8.1).

ArctanModel in HCSS User’s Reference Manual, which allows for the fitting of a general arctan function – $f(x; p) = p_0 \text{arctan}(p_1 (x - p_2))$. Usage: ArctanModel()

ExpModel in HCSS User’s Reference Manual, which allows for the fitting of a general exponential function – $f(x; p) = p_0 \exp(p_1 x)$. Usage: ExpModel()

LorentzModel in HCSS User’s Reference Manual, which allows for the fitting of a Lorentz function – $f(x; p) = p_0 (p_2^2/(x - p_1)^2 + p_2^2))$. Usage: LorentzModel()

PowerLawModel in HCSS User’s Reference Manual, which allows for the fitting of a general power-law function – $f(x; p) = p_0 (x - p_1)^p$. Usage: PowerLawModel()

SineModel in HCSS User’s Reference Manual, which allows for the fitting of a general cosine/sine wave – $f(x; p) = p_1 \cos(2 \pi p_0 x) + p_2 \sin(2 \pi p_0 x)$. Usage: SineModel()

GaussModel in HCSS User’s Reference Manual, which allows for the fitting of a 1-D gaussian – $f(x; p) = p_0 \exp(-0.5 ((x - p_1)/p_2)^2)$, where $p_0$ is the amplitude, $p_1$ the x-shift (from zero) and $p_2$ the sigma of the fit, with initial values of 1.0, 0.0 and 1.0 respectively. Note that Gauss2DModel produces a fit to 2D data. Usage: GaussModel()

SincGaussModel in HCSS User’s Reference Manual, which allows for the fitting of the convolution of a 1-D sinc function with a 1-D gaussian – $f(x; p) = p_0 \exp(-b^2) (\text{erf}(a - ib) + \text{erf}(a + ib)) / (2 \text{erf}(a))$, with $a = p_2 / (2 \sqrt{0.5} p_3)$ and $b = (x - p_1) / (2 \pi p_3)$, where $p_0$ is the amplitude, $p_1$ is the x-shift (from zero), $p_2$ is the width of the sinc function (distance between first zero-crossings divided by $2\pi$), and $p_3$ is the width of the Gaussian function (sigma), with initial values of 1.0, 0.0, 1.0 and 1.0 respectively. Usage: SincGaussModel()

User supplied non-linear function, which allows for fitting a function (linear or non-linear) constructed by the user. This function must be put in a Jython class and optionally the user could provide an analytical calculation of the partial derivatives with respect to the parameters (otherwise they are calculated numerically). This is shown in the following example for the following function of four parameters: $f(x; p) = p_0(1+(x/p1)^2)^p2 + p_3$ (the so called beta-profile):

```python
from herschel.ia.numeric.toolbox.fit import NonLinearPyModel
class BetaModel(NonLinearPyModel):
    # the full 4-parameter beta-model with partial derivatives
    # f(x; p) = p_0/(1+(x/p1)**2)**p2 + p3
    npar = 4
    def __init__(self):
        # Constructor
        NonLinearPyModel.__init__(self, self.npar)
        self.setParameters(Double1d([1,1,-1,1]))
    # def pyResult(self,x,p):
    # return model
    #
```

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def pyPartial(self, x, p):
    # the partial derivatives
    arg1 = 1.0 + (x/p[1])**2
    dp = Double1d(self.npar)
    #
    dp[0] = 1.0/arg1**p[2] # df/dp0
    dp[1] = 2.0*p[0]*p[2]*x*x/((p[1]**3)*arg1**(p[2]+1.0)) # df/dp1
    dp[3] = 1.0 # df/dp3
    return dp

def myName(self):
    # Return an explicatory name (String). Optional.
    return "beta-profile: f(x:p) = p[0]*{1 + (x/p[1])^2}^p[2] + p[3]"

Example 5.32. Creating a custom non-linear fitting model.

Once we define the function as shown in the example then we can proceed as before and create a model and then perform the fitting using either the Lavenberg-Marquardt or Amoeba fitters:

bm = BetaModel()
bm.setParameters(Double1d([1.0, 1.0, -2.0, 5.0]))
myfit = LevenbergMarquardtFitter(x, bm) # see section on available fitters below
# or myfit = AmoebaFitter(x, bm)
result = myfit.fit(y)
print result

Example 5.33. Using a custom fitting model.

5.8.4. Compound and mixed models

It is possible to add two models, e.g. if one wants to fit a spectral line (a Gaussian) on a background (a Polynomial). The resulting model is non-linear.

myModel = GaussModel()               # Define a Gaussian
myModel += PolynomialModel(1)         # Add a Polynomial to it of order 1. Only with +=
print myModel.toString()              # Information about the model

Example 5.34. Fitting a line using two models at the same time.

More models can be added if wished.

5.8.5. Available fitters

All the following fitters are used as follows (the example uses Fitter):

myFitter = Fitter(xDataPoints, model)

Fitter in HCSS User's Reference Manual. Fitter for linear models. You create a fitter by providing the model assumption and the x points of the data. With that information you compute the parameters within the model by fitting the y data points. Once the computation of those parameters is done, you can extract statistical information from the fitter.

LevenbergMarquardtFitter in HCSS User's Reference Manual. Fitter for non-linear models. The LMFitter is a gradient fitter, which means that it goes downhill from the starting location until it cannot go down anymore. There is no guarantee that the minimum found is an absolute or global minimum. If the chisq-landscape is multimodal it ends in the first minimum it finds. See also Numerical Recipes, Ch 15.5.

AmoebaFitter in HCSS User's Reference Manual. Fitter for non-linear models. The AmoebaFitter implements the Nelder-Mead simplex method. It comes in 2 varieties, one where the simplex simply goes downhill (temperature = 0) and one which implements an annealing scheme. Depending on the temperature, the simplex sometimes takes an uphill step, while a downhill steps always is taken. This way it is able to escape from local minima and it has a better chance of finding the global minimum.
No guarantee, however. *AmoebaFitter* is also able to handle limits on the parameter range. Parameters stay within the limits when they are set. See also Numerical Recipes, Ch. 10.4 and 10.9.

*SingularValueDecompositionFitter* in *HCSS User’s Reference Manual*. Linear fitter based on Singular Value Decomposition (described in the section called “Singular value decomposition”). Much more robust in case of (nearly) degenerated models, at the cost of more CPU use. See Numerical Recipes for more information.

### 5.8.6. Setting the fitter tolerance

The iterative fitters *LevenbergMarquardtFitter* and *AmoebaFitter* have a *tolerance* value, set by default to 0.01, against which the chi square value from each iteration is compared. When the chi square value is lower than the tolerance, the iteration stops.

When the noise level of your data is low compared to the tolerance, iterations stop too early. This is shown in the following example, using mock data with noise of order 0.001.

```python
# The data
array = Double1d([1.001, 1.004, 1.005, 1.002, 1.006, 1.007, 1.007, 1.009, 1.01, 1.011])
time = Double1d(range(10))

# Fitting data with the LevenbergMarquardtFitter
order = 1
poly = PolynomialModel(order)
poly.setParameters(Double1d(order+1))
fitter = LevenbergMarquardtFitter(time, poly)
lineFit = fitter.fit(array)

# Plotting the results
plot = PlotXY()
plot.addLayer(LayerXY(time, array, line=Style.MARKED, symbol=14, symbolSize=5, color=java.awt.Color.BLUE))
plot.addLayer(LayerXY(time, poly(time), line=Style.MARKED, symbol=14, symbolSize=5, color=java.awt.Color.RED))

# Fitting data with the Fitter
fitter = Fitter(time, poly)
linefit = fitter.fit(array)

plot.addLayer(LayerXY(time, poly(time), line=Style.MARKED, symbol=14, symbolSize=5, color=java.awt.Color.GREEN))
plot.xtitle='Time'
plot.ytitle='Array'

plot.
```

Example 5.35. Plotting the results of a polynomial fitting.
Note how the fit given by `LevenbergMarquardtFitter` is offset with respect to the data. You can improve the fit by setting the tolerance to a lower value:

```python
fitter = LevenbergMarquardtFitter(time, poly)
fitter.tolerance = 0.00001
```

**Example 5.36. Setting the tolerance for the LevenbergMarquardt fitter.**

However, if you have a linear model like a `PolynomialModel`, as in the previous example, the preferred fitter is `Fitter` or `SingularValueDecompositionFitter`.

### 5.8.7. 1D fit example

The following example shows how a polynomial can be fitted to a set of 1D data.

```python
# Create some data
x = Double1d([3,4,6,7,8,10,11,13])  # These are the positions of the 1D data
y = Double1d([2,4,5,6,5,6,7,9])  # These are the data values at each position

# The created arrays are:
print x  # [3.0,4.0,6.0,7.0,8.0,10.0,11.0,13.0]
print y  # [2.0,4.0,5.0,6.0,5.0,6.0,7.0,9.0]

# Decide that we will fit it with a polynomial
model = PolynomialModel(3)

# The Fitter class expects the 'x' data point positions and the model.
# In the binomial case, a Double2d array of x,y values is required.
# The Fitter class deals with non-iterative models only.
# [Note: For non-linear models the fitter toolbox provides
#  the AmoebaFitter and the LevenbergMarquardtFitter]

fitter = Fitter(x, model)

# Now we fit the data values(y); the returned array contains the parameters
# that make up a 3rd degree polynomial.
# Note: the model that we fed into the fitter is modified along the
# way, such that it contains the computed parameters of the polynomial.

poly = fitter.fit(y)

# Printing the fit results (truncate to 3 decimal places to fit in line)

print poly # [-6.921,4.463,-0.543,0.022]

# ..and also getting the Chi-squared. The fitter has already been applied
# and we can use the getChiSquared() method to determine the fit

print "Chi-Squared = ", fitter.getChiSquared()

# Chi-Squared =  0.9933079890409999

# The fitted polynomial can then be applied as a function to interpolate
# between fitted points. Interpolate at 'n' uniformly spaced x values

n = 100
u = MIN(x) + Double1d.range(n + 1) * (MAX(x) - MIN(x)) / n

# Apply the model
umodel = model(u)

# Now we can plot the data (x vs y) and the polynomial fit (u vs umodel)
# Set up the plot space
plot = PlotXY()

# Plot x against y in blue.
plot[0] = LayerXY(x, y, name = "Data")

# Overlay a second plot showing the polynomial fit in green.
plot[1] = LayerXY(u, umodel, name = "Fit", color = java.awt.Color.green)

The final plotted display should look like Figure 5.4:
5.8.8. 2D fit example

For 2D data we express the positions at which we have data by a Double2d array. This is a list of x, y positions at which we have known data values that we will fit a 2D Gaussian to. So the x array in our previous example is now replaced by a 2D array of data positions. The y array has the data values at those positions.

In the following example, an array with values that provide a Gaussian with random noise added is fitted by the Gauss2D model.

```python
# We start by making a little routine that creates the data for us.
# The output contains the 'xy' positions as a Double2d array and the data
# values are held in in the Double1d array 'y2'.
def makeData():
    # Define some constants
    N = 9              # We will create an array that is NxN
    a0 = 10.0          # Amplitude of gaussian
    x0 = 0.7           # x position of gaussian
    y0 = -0.3          # y position of gaussian
    s0 = 0.4           # Width

    # Make data with an underlying gaussian model.
    x = Double1d.range(N) / 2.0 - 2  # create x values
    NN = N * N # the number of x and y positions (NxN)
    xy = Double2d(NN, 2) # Create empty array of xy positions
    ym = Double1d(NN)    # Create empty array for amplitude of pure Gaussian
    y2 = Double1d(NN)    # Create empty array for Gaussian with noise (our
data).
    # These have amplitude values only.
    rng = java.util.Random( 12345 ) #provide a random amplitude (noise)
    # To add to our model Gaussian with a seed value.
    si = 1.0 / s0 #just inverse of Gaussian width to be used
    for i in Int1d.range(NN):
        xy[i,0] = x[i / N] # Fills x positions for our data array
        xy[i,1] = x[i % N] # Fills y positions for our data array
        xx = ( xy[i,0] - x0 ) * si
        yy = ( xy[i,1] - y0 ) * si
        ym[i] = a0 * EXP(-0.5 * xx * xx) * EXP(-0.5 * yy * yy)
        y2[i] = ym[i] + 0.2 * rng.nextGaussian()  # ...and adds noise to it
        return xy,y2

# Create the array with a 2D gaussian in it using the above routine.
a = makeData()
```

Figure 5.4. Illustration of polynomial fit.
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# The first item in "a" has the xy positions in it
xy=a[0]
# The second item has the data values
y2=a[1]

# Define the model to be used in the fit
gaus2d = Gauss2DModel()

# Define the fitter: LevenbergMarquardt, a non-linear fitter is needed for
# a gaussian fit. We could use an AmoebaFitter here also -- user preference.
fitter = LevenbergMarquardtFitter(xy, gaus2d)

# A useful way to make data formats prettier for the printout of our results
F = DataFormatter()

# Find the parameters
param = fitter.fit(y2)
print "Parameters %s" % F.p(param)
# Parameters [ 9.645  0.694  -0.300  0.413]
print "Parameters are:  gaussian height, x position, y position, width"
# Find the standard deviations of the all four parameters...
stdev = fitter.getStandardDeviation();
print "Stand Devs %s" % F.p(stdev)
# Stand Devs [   0.218    0.009    0.009    0.007]
# ...and the chi-squared for the fit
print "ChiSq %s" % F.p(fitter.getChiSquared())
# ChiSq 3.552

5.8.9. Additional documentation

The following additional documentation is available, maintained directly by the developer of the fit toolbox:

- The Fit Toolbox in Jython.
- Fitter reference documentation. In particular, see the troubleshooting section if you encounter problems.
- Jython examples for the Fit Toolbox.

5.9. Masks

The Numeric library offers two classes for handling data masks:

- FixedMask represents a traditional mask definition, with different masks (up to 64) defined at different bit offset positions. Note that this class only stores mask definitions, with mask data stored in different arrays. For more information and several examples, see the entry in the User’s Reference Manual: Section 1.150 in HCSS User’s Reference Manual.

- PackedMask instead stores the mask data itself. There is in principle no limit on the number of masks that can be stored in a single PackedMask object. For more information and several examples, see the entry in the User’s Reference Manual: Section 1.292 in HCSS User’s Reference Manual.

5.10. Matrices

Most of the utilities for dealing with matrices are provided by the numeric.toolbox.matrix package. However, we must not forget that simple vectors are just matrices with just one row (or one column), so even vector classes like Double1d provide tools like a dotProduct method for scalar multiplication of vectors:

```python
x = Double1d([1,2,3,4])
```
The Numeric library

y = Double1d([1,3,5,7])
print x.dotProduct(y) # 50.0

Example 5.37. How to get the dot product of two vectors or matrices.

We now take a closer look at the numeric.toolbox.matrix package and its classes and function objects for matrix manipulation.

**Transpose**

To transpose a matrix do the following:

A = Int2d([[1,2],[3,4],[5,6]])
print TRANSPOSE(A) # [[1,3,5],[2,4,6]]

Example 5.38. Transposing a matrix.

**Determinant**

Use this function to find the determinant of a square matrix given by a Double2d array.

A = Double2d([[1,2],[3,4]])
print DETERMINANT(A) # -2.0


Note: This currently does not work for complex matrices.

**Inverse**

You can find the inverse of a square matrix as follows:

A = Float2d([[1,2],[3,4]])
print INVERSE(A) # [[-2.0,1.0],[1.5,-0.5]]

Example 5.40. Inverting a matrix.

Note: This currently does not work for complex matrices.

**Matrix multiplication**

Use MatrixMultiply for matrix multiplication:

x = Double2d([[2,4,6],[1,3,5]])
y = TRANSPOSE(x)
z = MatrixMultiply(y)(x)
print z

Example 5.41. Multiplying matrices this way returns a matrix.

It is important **not** to use the Jython * operator for matrix multiplication. However, the + operator performs element-wise addition as expected.

It is also possible to multiply a matrix by a vector as follows (since, as we already pointed out, a vector is nothing more than a matrix with just one row or column):

a = Double2d([[1,2,3],[7,5,4],[7,4,9]])
b = Double1d([4,1,7])
print MatrixMultiply(b)(a) # [27.0,61.0,95.0]

Example 5.42. Multiplying a matrix by a vector with matrix multiplication.
Warning
The correct syntax to multiply matrix \( a \) by matrix \( b \) is \( \text{MatrixMultiply}(b)(a) \).

LU decomposition

For an \( m \times n \) matrix \( A \), LU decomposition returns matrices \( P \), \( L \) and \( U \) so that \( PA = LU \):

- \( P \) is a permutation matrix, so that the product \( PA \) results in a permutation of \( A \)'s rows. In the class described below, \( P \) is replaced by an equivalent permutation vector \( p \).
- \( L \) is a unit lower triangular matrix.
- \( U \) is an upper triangular matrix.

The \( \text{LUDecomposition} \) class provides this functionality. The following example shows how it is used:

```plaintext
A = Double2d([ [1,1,1],[1,2,3],[1,3,6] ])
p = [ [1.0,0.0,0.0], [1.0,1.0,0.0], [1.0,0.5,1.0] ]
d = LUDecomposition(A)
print d.p # Getting L
print d.u # Getting U
```

Example 5.43. Decomposing a matrix to lower and upper matrices.

You can easily verify that the result is correct:

```plaintext
print MatrixMultiply(d.u)(d.l)
```

Example 5.44. Verifying the results of a LU decomposition.

\( LU \) gives \( A \) with the row order changed as described by the permutation vector: row 0, then row 2, then row 1.

Eigenvalue decomposition

The \( \text{EigenvalueDecomposition} \) class provides eigenvalues and eigenvectors of a real matrix. The following examples shows how it can be used:

```plaintext
A = Double2d([ [[1,1,1],[1,2,3],[1,3,6]] ])
```

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evd = A.apply(EigenvalueDecomposition())  # Performing decomposition
D = evd.d  # Obtaining the block diagonal eigenvalue matrix
V = evd.v  # Obtaining the eigenvector matrix
print evd.imagEigenvalues  # Printing the imaginary parts of the eigenvalues
print evd.realEigenvalues  # Printing the real parts of the eigenvalues
print evd.vcond  # Printing the condition (2-norm) of the matrix, defined as
# the ratio of the highest and smallest singular value

Example 5.45. Getting the eigenvalues of a matrix after decomposing it.

If \( A \) is symmetric, then \( A = V D V^T \), where the eigenvalue matrix \( D \) is diagonal and the eigenvector matrix \( V \) is orthogonal.

If \( A \) is not symmetric, then the eigenvalue matrix \( D \) is block diagonal with the real eigenvalues in 1-by-1 blocks and any complex eigenvalues, \( \lambda + i \mu \), in 2-by-2 blocks, \( [\lambda, \mu; -\mu, \lambda] \). The columns of \( V \) represent the eigenvectors in the sense that \( A V = V D \). The matrix \( V \) may be badly conditioned, or even singular, so the validity of the equation \( A = V D V^{-1} \) depends upon \( vcond \).

**Singular value decomposition**

For an \( m \times n \) matrix \( A \) with \( m \geq n \), the singular value decomposition is an \( m \times n \) orthogonal matrix \( U \), an \( n \times n \) diagonal matrix \( S \), and an \( n \times n \) orthogonal matrix \( V \) so that \( A = U S V' \).

The singular values, \( \sigma_k = S_{kk} \), are ordered so that \( \sigma_0 \geq \sigma_1 \geq ... \geq \sigma_{n-1} \).

The singular value decomposition always exists, so the constructor will never fail. The matrix condition number and the effective numerical rank can be computed from this decomposition.

The `SingularValueDecomposition` class provides this functionality. For more information see the [User’s Reference Manual](https://example.com/usermanual) in HCSS User’s Reference Manual.

**Matrix equations**

Use `MatrixSolve` to solve matrix equations. For example, if you wanted to solve the matrix equation: \( A \cdot X = B \):

```python
x = MatrixSolve(b)(a)
print x  # [-0.9838709677419352, 0.532258064516129032258]
```

**A note on naming conventions**

You might find a bit confusing that some names, like `dotProduct`, start with a lowercase letter and have all the other initials capitalised, while other names, like `MatrixMultiply`, have all initial capitalised, and yet other names like `TRANSPOSE` are all in upper case. You can find more about naming conventions in Section 1.31.

**5.11. Random numbers**

To create pseudorandom numbers you first have to instantiate a `generator`. Three generators are available:

- `RandomUniform`: generates random numbers in the range \( 0 \leq x < 1 \) if invoked without parameters, like this:

```python
myGenerator = RandomUniform()
```

It is also possible to give a maximum value different from 1 to have random numbers created in the range \( 0 \leq x < \text{max} \):
**The Numeric library**

```java
myGenerator = RandomUniform(max)
```

- **RandomGauss**: generates random numbers following a Gaussian distribution.
- **RandomPoisson**: generates random numbers following a Poisson distribution of specified mean value greater than zero. It is instantiated like this:

```java
myGenerator = RandomPoisson(mean)
```

It can only produce integer-type random numbers (int, short and long).

In all cases what is being used under the hood is the Donald Knuth generator (see *The Art of Computer Programming*, Volume 2, Section 3.2.1) as implemented in the java.util.Random class.

Once we have a generator in place, how do we create random numbers? The handy feature is that we can create a single scalar random number or an array of any size and dimension we like (as long as it fits in memory). Just put the type of numeric value you want as input, and the output will be the same thing, but populated with random numbers. A few examples:

```java
myGenerator = RandomUniform()   // Generating random numbers between 0 and 1
print myGenerator(0.0)          // We want a floating point random number...
# 0.8754230073094597            // ...and there it is (don't expect to get the
# same number)
x = Double1d(10)                // Now for an array of ten doubles...
print myGenerator(x)            // We leave it to you to see the result
print myGenerator(Double1d(10)) // Of course you can create the input on the fly
print myGenerator(Int1d(100))   // What's the result of this one? Does it make sense?
```

**Example 5.46. Generating random numbers with this utility class.**

You might have been puzzled to see a hundred zeroes scroll on your screen after executing the last command of the example. It's not so surprising if we think that we asked the computer to produce integer random numbers between zero and one, excluding one. The choice of possible values was pretty limited.

If we want to change the seed of the random number generator we can do so by the `setSeed` method, which takes a long parameter as an input:

```java
myGenerator.setSeed(54653856L)
```

**Example 5.47. Setting a seed for a random number generator.**

## 5.12. Numeric integration

In HIPE you can integrate a function defined analytically or a set of (x, y) values sampling a function.

### 5.12.1. Integrating functions

The function to be integrated has to be declared as a class of a `RealFunction` type, containing a method called `calc` which takes one argument, the independent variable.

The following integrators for a standard integration interval [a,b] are available:

- RectangularIntegrator
- RombergIntegrator
- SimpsonIntegrator
- TrapezoidalIntegrator
• GaussianQuad4Integrator
• GaussianQuad5Integrator
• GaussLegendreIntegrator

All these integrators have two arguments for initialisation: the lower limit of integration (a) and the upper limit (b). Once the integrator is initialised and the user function is defined then to perform the integration a method called integrate() is executed with an argument the user function. This is shown in the following example:

```python
from herschel.ia.numeric.toolbox import RealFunction
class MyFunction(RealFunction):
    def calc(self, x):
        return x*x
f = MyFunction()
a = -3.0
b = 3.0
i = RombergIntegrator(a, b)
print i.integrate(f) # 18.0
print "Analytical answer: ", (b**3 - a**3)/3.0
```

**Example 5.48. Integrating numerically using the Romberg method.**

The following special cases of numeric integration are also implemented:

• GaussHermiteIntegrator: for integration with limits (-Inf,+Inf) of a special class of functions

\[
\int_{-\infty}^{+\infty} e^{-x^2} f(x) \, dx
\]

• GaussLaguerreIntegrator: for integration with limits [0,+Inf) of a special class of functions

\[
\int_{0}^{+\infty} x^\alpha e^{-x} f(x) \, dx
\]

The input for the integrator initialisation is \( \alpha \).

• GaussJacobiIntegrator: for integration with limits [-1,1] for a special class of functions

\[
\int_{-1}^{1} (1-x)^\alpha (1+x)^\beta f(x) \, dx
\]

The input for the integrator initialisation are \( \alpha \) and \( \beta \).

**5.12.2. Integrating discrete values**

If you want to integrate a set of \((x, y)\) values, you have two choices.

**Interpolate first and then apply a suitable integrator.** You use interpolation to create a function based on your data set, and then apply one of the integrators described in the previous section. This is shown in the following example:

```python
from herschel.ia.numeric.toolbox import RealFunction
x = 0.1 + 1.9*Double1d.range(11)/10.0 # 11 points between 0.1 and 2.0
```
y = 1.0/x

f = CubicSplineInterpolator(x, y) # interpolate first.
a = 0.1
b = 2.0
integrator = SimpsonIntegrator(a, b) # use Simpson's rule

res = integrator.integrate(f) #
print "Result: ", res
print "Analytical result: ", LOG(b) - LOG(a)

Example 5.49. Integrating numerically using the Simpson method.

For more information on interpolating discrete values see Section 5.13.

Use the IntTabulated function. This function integrates a tabulated set of (x, y) data using a five-point Newton-Cotes integration formula:

Example 5.50. Integrating tabular data using Newton-Cotes method.

This function is equivalent to the INT_TABULATED function in IDL. For more information on IntTabulated, see the User's Reference Manual: Section 1.226 in HCSS User's Reference Manual.

5.13. Interpolating discrete data

If the objective is to integrate discrete data, this can be done by means of a FitterFunction, which is a function that interpolates the given data, with a specific model. For example:

Example 5.51. Creating a fitter function with different fitters and models.

If more precise fitting is needed, you can do it by yourself, and then pass the already built fitter (or the model) to the FitterFunction:

Example 5.52. Customising the fitter even setting the simplex.

If one of the defined interpolators suits your needs, it can be used directly, instead of a FitterFunction. For example:

Example 5.53. Creating a cubic spline interpolator.
5.14. Statistics

The following statistics functions are available. Follow the links to go to the corresponding entries in the User's Reference Manual.

- **Correlate** in *HCSS User's Reference Manual*: Returns the linear Pearson correlation coefficient between two arrays.
- **Covariance** in *HCSS User's Reference Manual*: Returns the covariance between two arrays.
- **GammaQ** in *HCSS User's Reference Manual*: Computes the complement of the incomplete Gamma function Q(a,x).
- **Sigclip** in *HCSS User's Reference Manual*: Returns array values more than \( n \) sigma from a comparator.

5.15. Wavelet transforms

Fourier transforms offer a convenient way to convert any signal to frequencies. The signal is decomposed on a sinusoidal function. Unfortunately, it is difficult to locate in time the frequencies. To avoid
this problem, the signal can be decomposed inside a window of length L, this window being moved along the time axis. If we replace this window by a function converging (rapidly) to zero and select this function so that it forms a base, we have defined a wavelet. We can dilate the wavelet and build a family of wavelets. Each of them catches a band of frequencies. The frequency and time resolutions are linked by the Heisenberg uncertainty principle, which means that we cannot have an infinite resolution in time and frequency, but only a compromise.

This wavelet toolbox implements signal decomposition and synthesis. You can analyse your signal and filter the coefficients, then rebuild your signal.

5.15.1. Continuous wavelet transform

This decomposition is a redundant decomposition useful to visualise how the signal energy is distributed and evolves in a time-scale scalogram. Elementary steps of decomposition are fixed by the number of voices per octave. Performing a decomposition consists of decomposing the signal on octave number + voices/number of voices per octave. Here are the formulae used for synthesis and decomposition.

Formula of an individual wavelet, derived from a "mother wavelet" by scaling and translation, with $a$ being the scaling factor and $b$ the translation factor:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}} \Psi\left(\frac{t-b}{a}\right)$$

Formula of continuous wavelet transform of a function $f(x)$:

$$Wf(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(x) \overline{\Psi\left(\frac{x-b}{a}\right)} dx$$

Formula of inverse wavelet transform:

$$f(x) = \frac{1}{C_v} \int_{-\infty}^{\infty} Wf(a,b) \frac{1}{\sqrt{a}} \Psi\left(\frac{x-b}{a}\right) db \frac{da}{a^2}$$

Formula of the admissibility condition, that must be satisfied for a successful inverse transform:

$$C_v = \int_{0}^{\infty} \frac{\|\psi\|^2}{w} \, dw < +\infty$$

5.15.2. Example

Worked Jython example:

```python
from herschel.ia.numeric.toolbox.wavelet import ContinuousWavelet
from herschel.ia.numeric.toolbox.wavelet.wutil import WBorder

# Create dummy signal
from herschel.ia.numeric.toolbox.wavelet.wdemo import WSigGenerator
sigGen = WSigGenerator()

# Continuous wavelet transform
algo = ContinuousWavelet("MexicanHat")

# Change data found in octave 2 and voice 10
octave = 2
voice = 10

data = coefs.getNodeForOctaveAndVoice(octave, voice)
data.multiply(0.25)

# Rebuild the signal
res = algo.synthesis(coefs)

# Plot the difference
res.subtract(sig)
print MIN(res), MAX(res), STDDEV(res), MEAN(res)
```
Example 5.54. Transforming a signal with a continuous wavelet.

5.15.3. Modulo Maxima Line

Signal irregularities can be identified with the modulo maxima line or how the irregularities is propagated in the time-scale scalogram. This functionality is available in the wavelet package. First of all, you should activate this functionality, then decompose the signal.

```
plot = PlotXY(res)
```

Figure 5.5. Effects of modulo maxima line.

Note

After `algo.activatesWTMML()`, you cannot run `algo.synthesis()`. Instead, you should run `algo.deactivatesWTMML()` and rerun `algo.decompose()`.

5.15.4. The wavelet library

With the exception of the wavelets used with the CWT algorithm, all wavelets are defined in an XML file stored in `herschel.ia.numeric.toolbox.wavelet.wibrary.wavelets.xml`. You can define another location via the user property file.

The following examples show how to obtain information on the wavelets used in the transformations:

Continuous wavelet

```
from herschel.ia.numeric.toolbox.wavelet.wibrary import WaveletLoader
wloader = WaveletLoader()
wloader.setCwtPreference()
wavelet = wloader.get("MexicanHat")
realPart = wavelet.getData(10.).real
plot = PlotXY(realPart)
plot.setSubtitleText("Mexican Hat wavelet at scale 10")
plot.getXaxis().setTitleText("Support")
plot.getYaxis().setTitleText("")
```

Example 5.55. Selecting one continuous wavelet.

Discrete wavelet

```
from herschel.ia.numeric.toolbox.wavelet.wibrary import WaveletLoader
wloader = WaveletLoader()
wloader.setDwtPreference()
wavelet = wloader.get("db2")
```
Example 5.56. Transforming a signal using a discrete wavelet.

\[
\begin{align*}
\text{db2} & \quad \# \text{Wavelet name} \\
\text{daubechie} & \quad \# \text{Family name} \\
2 & \quad \# \text{Wavelet order} \\
4 & \quad \# \text{Wavelet length} \\
\text{false} & \quad \# \text{Applicability of the wavelet: no continuous transform} \\
\text{true} & \quad \# \text{Applicability of the wavelet: discrete yes} \\
-1 & \quad \# \text{Vanish moment of the scaling function, -1 means undefined} \\
2 & \quad \# \text{Vanish moments of the wavelet} \\
\text{orthogonal} & \quad \# \text{The wavelet is orthogonal} \\
\text{asymmetric} & \quad \# \text{The wavelet is asymmetric} \\
\end{align*}
\]

Last four lines: filter coefficients of the wavelet

\[
\text{Synthesis low pass filter (LoR)} = [0.48296291314469025, 0.836516303737469, 0.22414386804185735, -0.12940952255092145] \\
\text{Synthesis high pass filter (HiR)} = [-0.12940952255092145, -0.22414386804185735, 0.836516303737469, -0.48296291314469025] \\
\text{Decomposition low pass filter (LoD)} = [-0.12940952255092145, 0.22414386804185735, 0.836516303737469, 0.48296291314469025] \\
\text{Decomposition high pass filter (HiD)} = [-0.48296291314469025, 0.836516303737469, -0.22414386804185735, -0.12940952255092145]
\]

5.15.5. Discrete wavelet transform

A continuous wavelet transform produces redundant information and too much data. We can perform an efficiency decomposition if we halve the signal according to the size of the wavelet. Thanks to this dyadic decomposition, the Nyquist condition is respected and the signal can be reconstructed. Two filters will be convolved with our signal:

- A high pass filter, our wavelet catching the detail of the signal.
- A low pass filter, a scaling function getting the approximation of the signal.

Dealing with a one-dimensional image:

```python
from herschel.ia.numeric.toolbox.wavelet import DiscreteWavelet
algo = DiscreteWavelet("db3") # Select db3 as wavelet.
# Create dummy signal
from herschel.ia.numeric.toolbox.wavelet.wdemo import WSigGenerator
sigGen = WSigGenerator()  
signal1d = sigGen.getPredefinedRealFunction1() 
coefs = algo.decompose(signal1d) # Performs wavelet decomposition.
```
Display(coefs.data) # display details at each level
PlotXY(coefs.getApproximation().data) # Get and plot approximation.
data = coefs.getDetailForLevel(2) # Get detail for level 2.
data.add(0.25) # Add value 0.25. Other functions: multiply, divide, subtract and reset
res = algo.synthesis(coefs) # Rebuilt signal taking into account user changes.

**Example 5.57. Discrete wavelet transformation of a one dimensional signal.**

Dealing with two-dimensional data:

```python
from herschel.ia.numeric.toolbox.wavelet import DiscreteWavelet
algo = DiscreteWavelet("db3") # Select discrete wavelet algorithm and db3 wavelet.
# Load the standard test image included with the package
from herschel.ia.numeric.toolbox.wavelet.wdemo import WReadImage
signal2d = WReadImage.loadImage("Lena.png")
coefs = algo.decompose(signal2d) # Perform wavelet decomposition.
res = algo.synthesis(coefs) # Rebuild signal from coefficients.
Display(coefs.compose()) # Show coefficients as Russian dolls.
```

**Example 5.58. Discrete wavelet transformation of a bidimensional signal.**

![Figure 5.7. Signal decomposed: Russian dolls view.](image)

At the top, right hand corner, there are horizontal details.

At the bottom, right hand corner, there are diagonal details.

At the bottom, left hand corner there are vertical details.

The previous figure shows only two scales of decomposition. The signal is halved at each scale.

At the top, left hand corner we found the approximation.

The following example shows how to obtain and change the coefficients:

```python
from herschel.ia.numeric.toolbox.wavelet import DiscreteWavelet
algo = DiscreteWavelet("db5") # Select db5 as wavelet
```
Example 5.59. Discrete Wavelet transformation manually handling the coefficients.

5.15.6. Stationary wavelet transform

DWT does not perform a signal translation-invariant transform. SWT resolves that. When the signal is decimated, we can decimate either the even data, or the odd data. DWT decimates even data, while the SWT algorithm will decimate in each side. We add some redundant data and keep an efficient decomposition. Unlike the continuous wavelet transform, only a dyadic decomposition is performed.

Dealing with a one-dimensional image:

```python
from herschel.ia.numeric.toolbox.wavelet import StationaryWavelet
algo = StationaryWavelet("db3") # Select stationary wavelet algorithm and db3 as wavelet
# Create dummy signal
from herschel.ia.numeric.toolbox.wavelet.wdemo import WSigGenerator
sigGen = WSigGenerator()
signal1d = sigGen.getPredefinedRealFunction1()
# Perform a wavelet decomposition till the level 3 and use ZERO border management
from herschel.ia.numeric.toolbox.wavelet.wutil import WBorder
coefs = algo.decompose(signal1d, WBorder.ZERO, 3)
PlotXY(coefs.getApproximation().data) # Get and plot approximation
data = coefs.getDetailForLevel(2) # Get detail for level 2
data.add(0.25) # Add value 0.25. Other functions: multiply, divide, subtract and reset
res = algo.synthesis(coefs) # Rebuild signal taking into account user changes
```

Example 5.60. Stationary wavelet transformation of a one-dimensional signal.

Dealing with a two-dimensional image:

```python
from herschel.ia.numeric.toolbox.wavelet import StationaryWavelet
algo = StationaryWavelet("db5") # Select stationary wavelet algorithm and db5 as wavelet
# Load the standard test image included with the package
from herschel.ia.numeric.toolbox.wavelet.wdemo import WReadImage
signal2d = WReadImage.loadImage("Lena.png")
coefs = algo.decompose(signal2d) # Decompose two-dimensional signal
level = 2 # Selects level 2
horizontal = coefs.getHorizontalForLevel(level) # Get horizontal detail for level 2
horizontal.multiply(4.0) # Multiply horizontal detail by 0.25
Display(horizontal.data)
vertical = coefs.getVerticalForLevel(level) # Get vertical detail for level 2
vertical.add(-0.25) # Subtract 0.25 from vertical detail
Display(vertical.data)
diagonal = coefs.getDiagonalForLevel(level) # Get diagonal detail for level 2
diagonal.multiply(0.25) # Multiply diagonal detail by 0.25
Display(diagonal.data)
# Level has no sense here unlike the Stationary Wavelet transform
approximation = coefs.getApproximation()
Display(approximation.data)
res = algo.synthesis(coefs) # Rebuild the signal
```

```python
Example 5.60. Stationary wavelet transformation of a two-dimensional signal.
```
approximation = coefs.getApproximationForLevel(level)
Display(approximation.data)
res = algo.synthesis(coefs) # Rebuild the signal

Example 5.61. Stationary wavelet transformation of a bidimensional signal.

5.15.7. Tools

Once your signal is decomposed, you have three tools to threshold your coefficients or to evaluate the noise of your data. These tools are described in the following subsections.

Gaussian noise estimator

This tool evaluates the noise contained in the coefficients. It computes: \( \text{median}(|dc1(i)|)/0.675 \), \( dc1 \) for detail coefficient at first level

Thresholding tool

This tool cuts (sets to zero) the coefficients below the threshold.

Example:

```python
# Load the standard test image included with the package
from herschel.ia.numeric.toolbox.wavelet.wdemo import WReadImage
signal2d = WReadImage.loadImage("Lena.png")
from herschel.ia.numeric.toolbox.wavelet import StationaryWavelet
algo = StationaryWavelet("db5") # Select stationary wavelet algorithm and db5 wavelet
from herschel.ia.numeric.toolbox.wavelet.wutil import WGaussianNoiseVisitor
from herschel.ia.numeric.toolbox.wavelet.wutil import WThresholdingVisitor
coefs = algo.decompose(signal2d) # Decompose two-dimensional signal
estimator = WGaussianNoiseVisitor() # Create the gaussian noise visitor
thresholding = WThresholdingVisitor() # Create the thresholding visitor
coeffs.accept(estimator) # Apply the visitor to the coefficients
print "noise=", estimator.noiseEstimated # Now the visitor contains the estimated noise
# Initialise the 'thresholding' visitor with the gaussian noise level computed previously
thresholding.threshold = estimator.noiseEstimated
# Apply the visitor. All coefficients below the threshold will be considered as noise and removed
coeffs.accept(thresholding)
res = algo.synthesis(coefs) # Rebuild the signal
```

Example 5.62. Use of the wavelet thresholding tool.

Universal threshold

This threshold has been defined by Donoho and Johnstone. In the figure below, \( n \) is the signal length.

Figure 5.8. Formula of universal threshold.

\[
\text{Universal threshold (Donoho & Johnstone)}
\]

\[
\text{threshold} = \sigma \sqrt{2 \log(n)}
\]

```
# Load the standard test image included with the package
from herschel.ia.numeric.toolbox.wavelet.wdemo import WReadImage
signal2d = WReadImage.loadImage("Lena.png")
```
from herschel.ia.numeric.toolbox.wavelet import StationaryWavelet
algo = StationaryWavelet("db5") # Select stationary wavelet algorithm and db5 wavelet
from herschel.ia.numeric.toolbox.wavelet.wutil import WUniversalThresholdVisitor
from herschel.ia.numeric.toolbox.wavelet.wutil import WGaussianNoiseVisitor
coeffs = algo.decompose(signal2d) # Decompose two-dimensional signal
estimator = WGaussianNoiseVisitor() # Create the gaussian noise visitor
thresholding = WUniversalThresholdVisitor() # Create the thresholding visitor
coeffs.accept(estimator) # Apply the visitor to the coefficients
print "noise=" estimator.noiseEstimated # Now the visitor contains the estimated noise
# Initialise the 'thresholding' visitor with the gaussian noise level computed previously
thresholding.sigma = estimator.noiseEstimated
# Apply the visitor. All coefficients below the threshold will be considered as noise and removed
coeffs.accept(thresholding)
res = algo.synthesis(coeffs) # Rebuild the signal

Example 5.63. Applying a threshold for wavelets using the visitor mechanism.

### 5.15.8. Wavelet toolbox overview

The following tables give an overview of the features supported by the wavelet package.

#### Table 5.4. Algorithms

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Continuous Wavelet Transform</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWT</td>
<td>yes</td>
</tr>
<tr>
<td>DWT</td>
<td>yes</td>
</tr>
<tr>
<td>SWT</td>
<td>yes</td>
</tr>
</tbody>
</table>

#### Table 5.5. Tools

<table>
<thead>
<tr>
<th>Algorithm/Tool</th>
<th>Gaussian noise estimator</th>
<th>Thresholding</th>
<th>Universal thresholding</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWT</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>DWT</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>SWT</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

#### Table 5.6. Signal dimensions

<table>
<thead>
<tr>
<th>Algorithm/signal</th>
<th>One-dimensional</th>
<th>Two-dimensional</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWT</td>
<td>yes</td>
<td>-</td>
</tr>
<tr>
<td>DWT</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>SWT</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

#### Table 5.7. Border management

<table>
<thead>
<tr>
<th>Algorithm/padding</th>
<th>Zero</th>
<th>Symmetric</th>
<th>Constant</th>
<th>Periodic</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWT</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>DWT</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>SWT</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

#### Table 5.8. Supported signal types

<table>
<thead>
<tr>
<th>Algorithm/Signal type</th>
<th>Double1d</th>
<th>Double2d</th>
<th>Complex1d</th>
<th>Complex2d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWT</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>-</td>
</tr>
<tr>
<td>Algorithm/Signal type</td>
<td>Double1d</td>
<td>Double2d</td>
<td>Complex1d</td>
<td>Complex2d</td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------</td>
<td>----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>DWT</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SWT</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5.9. Available wavelets

<table>
<thead>
<tr>
<th>Algorithm/Wavelet</th>
<th>Daubechie</th>
<th>Symlet</th>
<th>Coiflet</th>
<th>MexicanHat</th>
<th>Morlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWT</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>DWT</td>
<td>1-10</td>
<td>1-10</td>
<td>1-5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SWT</td>
<td>1-10</td>
<td>1-10</td>
<td>1-5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

For more information on functions for wavelet transforms, follow the links to go to the corresponding entries in the User's Reference Manual.

- CWavelet in HCSS User's Reference Manual: A continuous wavelet (along with an example of the creation of custom continuous wavelets using only Jython).
Chapter 6. Running tasks

Tasks are a standardised format for data reduction routines. A task provides consistent conventions for input and output parameters, processing history and help information. Tasks can be executed from the command line or via a standard graphical interface in HIPE.

With tasks you can create modular and reusable code for data reduction and analysis, easier to use and to distribute.

This chapter shows how to execute tasks from the command line. For information on executing tasks via the HIPE graphical interface, see the HIPE Owner's Guide in HIPE Owner's Guide.

For information on how to develop tasks in Jython or Java, see the HIPE Community website.

6.1. Running a task

This section describes how to run a task from the Console view of HIPE.

Imagine you want to run the clear task, which deletes one or more variables in the HIPE session.

Printing task parameters. You can print a list of parameters, with all their properties such as type and default value, by printing the name of the task:

```
print clear
```

Printing task help. You can print a short help text about a task as follows:

```
print clear.__doc__
```

Example 6.1. Printing the documentation of a task.

Note that there are two underscore characters before and after doc.

Executing the task. Execute the task by passing parameter values within brackets:

```
clear(variable="myVar")
```

Example 6.2. Executing the clear task with one parameter.

The clear task has no output parameter. For tasks with an output parameter, assign its value to a variable when executing the task. In the following example, the task myTask is executed and the value of the output parameter is passed to the myResult variable:

```
myResult = myTask(parameter="value")
```

Example 6.3. Retrieving the output value from a task.

See Section 6.2 for more information on task parameters.

Tip

If you have doubts about the syntax of a task command, try executing the task via its dialogue window. You can open the dialogue window by double clicking on the task name in the Tasks view. When you execute the task, the corresponding command appears in the Console view.

Checking execution result. To make sure that the task executed successfully, you can look at the statusMessage:
Example 6.4. Printing the status message of a task.

6.2. Task parameters

Tasks can have input, output and input/output parameters. Input/output parameters are passed as input and their values are modified by the task.

You can identify parameters by their position or by their name. Look at the following code:

```python
# Positional arguments
result = myTask(param1, param2)

# Named arguments
result = myTask(first=param1, second=param2)
```

Example 6.5. Naming the parameters to omit optional ones or pass them in any order.

Here the task `myTask` has two parameters called `first` and `second`.

You can mix positional and named modes, but only if all positional arguments come first. For example:

```python
result = myTask()(param1, second=param2)
```

Example 6.6. Mixing named and positional parameters.

The following line would cause an error instead:

```python
result = myTask()(first=param1, param2)
```

Example 6.7. Wrong mix of mixed and named parameters.

Note

Identifying parameters by their name, rather than their position, is strongly recommended. This will make your scripts much more maintainable.

Once a task is executed, parameters are reset to their default values.

6.2.1. Output parameters

When a task has multiple output parameters, you can call it in the following ways:

* `myVar = myTask(...)`

In this case (in HIPE 12 and later), `myVar` becomes a list and all outputs are returned as elements of the list.

Jython/Python lists are very powerful and allow advanced functionality like:

* List slicing: Reference and retrieve specific ranges of values using the list indices. Example of assigning the output parameters from the third to the fifth position after running task `myTask()` (remember that indices start at zero):

  ```python
  outPar2, outPar3, outPar4 = myTask(...) [2:4]
  ```

Example 6.8. Assigning output values to variables using list slicing.
• List filtering: Use an anonymous function (a lambda function, see below) to include only values that match a condition. Example of excluding from the list myVar all the values lesser than zero using list comprehension syntax:

\[
myVar = [x \text{ for } x \text{ in myVar if } x \geq 0 ]
\]

Example 6.9. Assigning output values to variables filtering using list comprehension syntax.

• Lambda functions: They are anonymous constructions that take any input (including other functions) and apply a function to them. Lambdas are often used with iterators or the \texttt{map()} function. The previous example is actually a lambda function in shorthand notation. Example of getting the squares of each item of the list myVar using a lambda definition:

\[
myVar = \text{map (lambda } x: x^2, \text{ myVar)}
\]

Example 6.10. Assigning output values to variables filtering with lambda expression.

• List comprehension: These are expressions that make applying lambdas to lists easier. Example of getting the squares of each item of the list myVar using list comprehension syntax:

\[
myVar = [ x^2 \text{ for } x \text{ in myVar }]
\]

Example 6.11. Assigning output values to variables filtering using list comprehension syntax (II).

Another option to deal with named output parameters is using the utility method \texttt{outToIndex()}, that returns the index of the parameters which names are passed as a list. For example (with the help, again, of the list comprehension syntax):

```python
myVar = myTask(...)  
print myVar  
outPar2, outPar1 = [myVar[i] for i in myTask.outToIndex(["parname2","parname1")])  
del(myVar)
```

Example 6.12. Assigning output values to variables using the utility method \texttt{outToIndex}.

The parameter names (\texttt{parname1} and \texttt{parname2} in the example) have to be clearly described in the task documentation.

* \texttt{myVar1, myVar2, ..., myVarN = myTask(...)}

In this case, each output is returned to a different variable. If the number of variables is different from the number of outputs, HIPE gives an error.

An introductory guide of working with lists in Jython can be found beginning in Section 1.10 of this manual. For the more advanced topics outlined above you should refer to the Jython book chapter on Data Types or the Python tutorial chapter on Data Structures.

Tip

To view more information on the parameters of a task, click on the task name in the Tasks view. A table appears in the Outline listing the task parameters and their properties. In particular, you can see at a glance which parameters are input (IN), output (OUT) and input/output (INOUT).
Chapter 7. Storing and accessing data products

This chapter describes how to store, retrieve and search for data products, either on your local system or on remote locations such as the Herschel Science Archive.

Before reading this chapter you should be familiar with the basic concepts explained in the Data Analysis Guide: Section 1.3 in Data Analysis Guide.

7.1. Pools and storages

A product storage is the front-end interface that allows you to communicate with products stored in pools.

By registering a pool to your storage, you can access the products in that pool.

A product storage provides mechanisms to load, save and query products in the registered pools. When doing so you receive a reference to a product (returned by the load() and save() commands) or a set of product references (when querying). This functionality of a product reference is provided by the ProductRef class; it allows to fetch information of the product, such as metadata, without loading the product in memory.

A urn or URN is part of the product reference and stands for Uniform Resource Name. It represents the address of the product. A typical urn looks like this:

```
urn:myPool:herschel.ia.dataset.Product:5
```

A urn consists of four fields separated by colons:

1. A fixed string urn.
2. The name of the pool.
3. The name of the Java class representing the product.
4. A count of the number of products that have been created of that class. Do not think of it as a version — it is not.

7.1.1. Creating a storage and registering pools

Since a storage without registered pools is useless, you usually create a storage and register a pool at the same time. You can pass a string with the name of the pool to be registered, or a variable representing the pool itself:

```
storageName = ProductStorage("poolName")
storageName = ProductStorage(pool)
```

You can also register many pools at once, by passing an array of names or pools:

```
storageName = ProductStorage(["poolName1", "poolName2", ...])
storageName = ProductStorage([pool1, pool2, ...])
```

Example 7.1. Registering many pools at once during storage definition.

If a name does not correspond to an existing pool, a new pool is created.

Use the register method to register pools after you have created the storage:
Example 7.2. Registering pools after storage creation.

To get a list of the currently registered pools:

```
print PoolManager.getPoolMap()
```

Example 7.3. Printing a map of all registered pools.

### 7.1.2. Saving and loading products

Use the `save` and `load` methods to save and load products:

```
HIPE> myReference = myStorage.save(myProduct)
HIPE> print myReference.urn
urn:simple.default:herschel.ia.dataset.Product:0
```

```
HIPE> myReference
= myStorage.load("urn:simple.default:herschel.ia.dataset.Product:0")
```

In both cases you obtain a `ProductRef` object. A reference provides access to parts of the product as well as access to the product itself:

```
HIPE> print myReference.urn
urn:simple.default:herschel.ia.dataset.Product:0
```

```
HIPE> print myReference.type
herschel.ia.dataset.Product
```

```
HIPE> myMeta = myReference.meta  # Getting metadata
```

```
HIPE> myProduct = myReference.product  # Getting the product
```

Note that, if you have multiple pools registered to a storage, only the first registered pool is write-enabled. In other words, all `save` operations write products to the first pool only. If you want to write products to another pool, you have to register it as first pool to another storage.

### 7.1.3. Deleting products

To remove a product from a storage, use the `remove` method:

```
myStorage.remove(urn)
```

Example 7.4. Removing products from a storage.

Note that you need to know the urn of a product to delete it.

Remember that you have write permission only on the first pool registered to a storage. If you try to remove a product from another pool, which is read-only, you get an error. You must first register the pool as first pool to another storage.

In the case of a local pool, you can delete a product by deleting the corresponding FITS file from the local pool directory. Then you need to rebuild the pool index (see Section 7.2.2).

### 7.1.4. Tagging products

Tags are keywords or phrases you can associate to a product, to better describe and remember its contents. For example, you could assign to a product the tag "*to be completed*" to remember that you have not finished processing it. When defining tags, you are free to use the keywords and phrases that work best for you.
To save a product with a given tag:

```java
myStorage.saveAs(myProduct, "myTag")
```

**Example 7.5. Tagging a product and adding it to a storage.**

You can then use the tag to load a reference to the product:

```java
myProductRef = myStorage.load("myTag")
```

**Example 7.6. Loading a tagged product as a product reference.**

To load the product itself, instead of a reference, add a `.product` to the previous command:

```java
myProductRef = myStorage.load("myTag").product
```

**Example 7.7. Loading a tagged product.**

To assign a tag to an existing product already in the storage:

```java
myStorage.setTag("myTag", productUrn)
```

**Example 7.8. Tagging an existing product.**

You can assign multiple tags to the same product by invoking the `setTag` method multiple times. However, a given tag can only be assigned to a single product. In the following example, assigning `myTag` to the product identified by `urn2` removes the same tag from the product identified by `urn1`:

```java
myStorage.setTag("myTag", urn1)
myStorage.setTag("myTag", urn2)
```

**Example 7.9. Tagging a product with several tags.**

To remove a tag:

```java
myStorage.removeTag("myTag")
```

**Example 7.10. Removing tags from a product.**

To check if a given tag exists:

```java
print myStorage.tagExists("myTag")
# Returns 1 if the tag exists, 0 otherwise
```

**Example 7.11. Checking tag existence (in a storage) before tagging.**

### 7.2. Local pools

The **local pool**, also known as **local store** for historical reasons, is the most commonly used type of pool.

#### 7.2.1. The local pool directory

By default, data is stored in a directory with the user-supplied store name in the following directory:

```javascript
home/.hcass/lstore/
```

To change the local pool directory, follow these steps:

1. In HIPE, choose **Edit → Preferences**. The **Preferences** dialogue window opens.
2. Click **Local Store** under **Data Access** in the left-hand list. The **Local Store** panel opens in the right-hand area.
3. Change the directory in the *Local Store directory* field.

4. Click *Apply*.

**Tip**

The local store directory can also be a link to another directory. This is useful if you want to store your products in a different hard disk with more space.

You can rename a local pool by renaming the corresponding directory, but *only if the pool was created with HCSS 4.0 or newer*.

### 7.2.2. Repairing a local pool

A local pool index can become inconsistent, for example if you add or delete files manually in the pool directory. In this case, you must rebuild the pool index as follows:

```java
myPool.rebuildIndex()
```

**Example 7.12. Rebuilding the index of a pool.**

Do not access the pool during the operation, which can take a while depending on pool size.

### 7.2.3. Importing a directory of FITS files into a local pool

To place all FITS files from a directory into a local pool, use the following commands:

```java
myPool.ingest(java.io.File("path_to_directory"), 0)
```

If the second parameter is set to zero, the FITS files are copied into the local pool directory. If the parameter is set to one, only references to the original files are created in the local pool directory.

### 7.2.4. Troubleshooting

You may experience problems with local pools in the following cases:

- When saving data to NFS-mounted disks (you may get an `IllegalMonitorStateException`).
- When saving data to a FAT32 filesystem from a Mac (you may get an `OverlappingFileLockException`).
- In any case involving large observations or the use of the `bg` command (you may get an `org.apache.lucene.store.LockObtainFailedException`).

Both problems are solved by setting the following property:

```java
hcss.ia.pal.pool.lstore.lock = simple
```

See the **HIPE Owner's Guide** in *HIPE Owner's Guide* for information on how to set properties. See the [Known Issues](#) page for information on other issues affecting HIPE.

If this solution does not work, please try removing the lock files (`write.lock`) present in the local store directory. This bash one-liner script can speed up the process on UNIX-based systems (including OS X):

```bash
find <pool> -name 'write.lock' -exec rm {} \;
```

### 7.3. Querying
To find out the contents of a storage, you execute a query on it. This section introduces the syntax for command line queries.

**Note**
The syntax for querying the Herschel Science Archive differs slightly from what is explained in this section. See Section 7.7.1 for more information.

The following example looks for products with *ThatsMe* as creator:

```python
query1 = Query("creator == \"ThatsMe\"")
res = myStorage.select(query1)
print res
```

**Example 7.13. Using keyword queries to retrieve products from a storage.**

You can query any metadata and combine more keywords (note that == and = are equivalent):

```python
query1 = Query("creator == \"ThatsMe\" and instrument = \"SPIRE\"\")
res = myStorage.select(query1)
print res
```

**Example 7.14. Querying a storage with several keywords.**

Now `res` contains a list of references to the products that satisfy the query. Printing `res` will give a list of URN values:

```
HIPE> print res
[urn:default:herschel.ia.dataset.Product:0,
urn:default:herschel.ia.dataset.Product:1,
urn:test:herschel.ia.dataset.Product:0]
```

If you want to execute an unconditional query to find all products in a storage, you can use the following:

```python
query2 = Query(1)
res2 = myStorage.select(query2)
print res2
```

**Example 7.15. Retrieving references to all products in a storage.**

To find all the products of a given class (here `ObservationContext`):

```python
res3 = myStorage.select(Query(ObservationContext))
```

**Example 7.16. Finding all products matching a class.**

Note that the above example puts query and selection on the same line.

You can query metadata and limit the query to a given class at the same time. This is usually a good idea, because it speeds up the query:

```python
res3 = myStorage.select(Query(ObservationContext, "creator == \"ThatsMe\"\"))
```

**Example 7.17. Querying by class and keywords at the same time.**

For information on how to query pools via the Product Browser perspective in HIPE, see the Data Analysis Guide: Section 1.7 in Data Analysis Guide.

### 7.3.1. Inspecting query results

The results of a query come as a list of product references. You can inspect the results as follows, assuming they are held in a variable called `res`:
Example 7.18. Inspecting the results of a query.

7.4. Product versioning

To save a set of versions of a particular product:

```
myStorage.save(myProduct)  # Version 0 of myProduct saved
# After modifying myProduct...
myStorage.save(myProduct)  # Version 1 of myProduct saved
```

Example 7.19. Versioning products within a storage.

To get the latest version of a product, or the list of versions for that product, you need to have available at least one, arbitrary, version. With this, you can recover the latest version of the product, and the list of all versions of the product in the storage:

```
latest = myStorage.getHead(productRefOfAnyVersion)
versions = myStorage.getVersions(productRefOfAnyVersion)
```

Example 7.20. Retrieving the latest version of a product.

You can get information on the current version of each product, as well as tag information, as follows:

```
print myStorage.versioningInfo
```

Example 7.21. Printing version and tag information for each product.

Note that versioning is a property of a pool, not of a storage.

7.4.1. Querying product versions

Querying by default searches for just the latest version of a product:

```
query = Query(Product, "p", "1")
storage.select(query)  # Just the latest version
```

Example 7.22. Using a default query returns the latest version.

If you want to get all versions of products that match a query, add a fourth argument set to 1:

```
query = Query(Product, "p", "1", 1)
storage.select(query)  # All versions of matching products
```

Example 7.23. Returning all versions of a product in a query.

(Note that with this extended query, the special products containing versioning information, VersionTrackProduct and TagsProduct, are also returned if they match the query.)

7.5. Advanced querying

There are three types of queries:

- Attribute query is a (fast) query on meta data that all products contain: `creator`, `creationDate`, `startDate`, `endDate`, `instrument`, `modelName`. This is akin to querying a standard set of FITS header keywords.
• Meta data query is a (semi fast) query on meta data that can be different from product to product. This is akin to doing a query on any FITS keywords (if present).

• Full query is a data mining query that allows querying on all data elements in products.

All query types have the same syntax, but a different purpose as described above. Setting up a query is as follows:

```python
# Simple query
query = Query(expression)

# More advanced queries
query = AttribQuery(product-class, variable, expression)
query = MetaQuery(product-class, variable, expression)
query = FullQuery(product-class, variable, expression)
```

Example 7.24. Creating simple, attribute, metadata and full (or data mining) queries.

The parameters are explained below:

• `product-class`: restricts the query to a family of products. All product classes have `her-schel.ia.dataset.Product` as the base class. You can restrict the query to a sub-family of products. For example, if all HIFI Calibration Product classes stem from `HifiCalProduct`, you can limit your search by specifying that class.

• `variable`: a string denoting the variable name of the product that will be used in the expression.

• `expression`: a string holding the query expression, which is limited to the query type.

• **Query Example**

```python
query = Query("instrument == HIFI and band == 1a")
# A simple query should be enough in most cases.
```

Example 7.25. Creating a simple query.

• **AttribQuery Example**

```python
query = AttribQuery(Product, 'product', 
            'product.creator=="Me" and product.instrument="HIFI"')
```


• **MetaQuery Example**

This type of query allows to inspect any part of the meta data of the product specified in the first argument.

```python
query = MetaQuery(HifiCalProduct, 'h', 'h.meta["key1"].value < 123 and 
        h.meta["key2"].value == "Hello world"')
```

Example 7.27. Creating a metadata query.

• **Note**

To obtain a numerical value (rather than, for instance, the string equivalent) it is necessary to stipulate that the meta key “value” is required, hence the need for the stipulation of query on ‘h.meta["key1"].value’ rather than ‘h.meta["key1"]’

• **FullQuery Example**

A data mining query exploits the full interface of the product in question. Numeric functions defined in the basic toolbox are allowed:

```python
query = FullQuery(Product, 'p', 'p.creator=="Me" and (ANY(p.spectrum.data < 2) 
```

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or ALL(p["myTable"]['myColumn'].data > 5)'

Example 7.28. Creating a full query.

The ANY function used above is one of the standard numerical function provided in HIPE, and checks whether the expression provided in its argument is true for any of the elements in that argument.

7.5.1. Querying for parts of a string

Use the % character when you want to query for parts of a string. For example, the following command looks for all products of type ObservationContext in which the aorLabel metadata value begins by ObsCal:

query = MetaQuery(ObservationContext, 'p', 'p.meta["aorLabel"].value == "ObsCal%"')

Example 7.29. Creating a metadata query with SQL-like wildcards for values.

To look for ObsCal anywhere within the string, rather than just at the beginning, put a % character at either end: %ObsCal%.

7.5.2. Querying for metadata in products

One thing you need to watch out when performing a meta or full query, is when you try to query for a metadata that does not exist in one or more products that you are applying the query to.

For example, consider the following MetaQuery:

query = MetaQuery(Product, 'p', 'p.meta["temperature"] .value==10)
resultset = storage.select(query)

Example 7.30. Querying by metadata requires the keyword to exist in all filtered products.

The query first starts creating a shortlist of all products in the storage matching type Product. It then runs the query string on each product in that shortlist. If any of those products don't contain the information referenced in the query string, an error is raised.

There are two ways to avoid this:

• Be as specific as you can when it comes to specifying the product type in a query. If you know the product type you want to query is of type CalHrsQDCFull, then specify that. Running queries using the most general product type of Product is not recommended, unless the products you have saved are of this type only.

• Run a two-stage query, using the containsKey() operator to check whether a component exists first. For example, first get a sub-set of products that contain the metadata 'temperature':

queryOne = MetaQuery(Product, 'p', 'p.meta.containsKey("temperature")')
resultsetOne = storage.select(queryOne)

Example 7.31. First step filtering the products containing the keyword.

Then run the original query on this subset:

queryTwo = MetaQuery(Product, 'p', 'p.meta["temperature"] .value==10)
resultsetTwo = storage.select(queryTwo, resultSetOne)

Example 7.32. Second step filtering by keyword value.

7.6. Tips and pitfalls
7.6.1. Changes to a product in a pool disappear

While product contexts saved in a pool are cached in memory, leaf products are not cached for performance reasons. This can lead to problems as illustrated by the following example:

```python
ref = ProductRef(Product (creator="me", instrument="SPIRE"))
print ref.product.instrument
  # SPIRE
ref = myStorage.save (ref.product)
ref.product.instrument = "PACS"
print ref.product.instrument
  # SPIRE
```

Example 7.33. Changes to products should be done in memory before saving them to a pool.

The change does not have any effect because the product has been saved to a pool and is no longer cached in memory.

The correct behaviour is obtained by dereferencing the product, that is, by creating a variable that represents the product itself, not a reference to it:

```python
p = ref.product  # Load from pool
p.instrument = "PACS"  # Modify
print p.instrument
  # PACS
ref = myStorage.save (p)  # Save back to pool
print ref.product.instrument
  # PACS
```

Example 7.34. Loading the product back from the pool, changing and saving to persist the change.

After saving the product back to the pool, even the reference correctly shows the modified information.

To check whether the product corresponding to a reference is loaded into memory, use the `isLoaded` method:

```python
print ref.isLoaded()  # 0  # Product not loaded
  # 1  # Product loaded
```

Example 7.35. Checking if a reference is loaded in memory.

7.6.2. Minimising memory usage

You can look at a product's metadata without loading the product into memory:

```python
ref = myStorage.save(myProduct)
ref = myStorage.load(ref.urn)
print ref.meta
```

Example 7.36. Loading specific parts of a product.

The following example saves a context to a pool without having more than one product in memory at any time. This is vital to avoid running out of memory with large contexts:

```python
myContext = ListContext(description = "A very big context")
for i in range(10):  # Saving ten products
  p = Product(description = "Dummy product no. " + str(i))
  myContext.refs.add(myStorage.save(p))
```

Example 7.37. Saving a context to a pool without the leaf products in memory.

7.6.3. Testing if two products are equal
If you have two products in memory, you can use the `equals` method:

```python
print(product1.equals(product2))
```

**Example 7.38. Comparing products in memory.**

This method returns 1 if the two products are equal, 0 otherwise.

If you just have a reference to a product, you can compare hash values as shown in this example:

```python
from herschel.ia.pal.util import HashCoder
hash1 = HashCoder().getHash(myProduct)
hash2 = myProductRef.getHash()
print(hash1 == hash2)
```

**Example 7.39. Comparing product references with hash codes.**

The result is 1 if `myProduct` and the product referenced by `myProductRef` are equal, 0 otherwise.

If you have a product urn, represented by a variable of type `Urn`, you can retrieve the product hash code from the pool where the product is saved, like this:

```python
hash3 = myPool.loadDescriptors(myUrn).get("hash")
```

**Example 7.40. Comparing product URNs using hash codes.**

You can then compare the hash values with the `==` operator as before.

### 7.6.4. Copying a product or context to a different storage

Use the `save` method to copy a product or an entire context from a storage to another:

```python
myStorage.save(myContext)
```

**Example 7.41. Saving a context.**

If a product within the data tree already exists in the destination product storage, it is not copied. A product can exist in the destination storage if it belongs to a pool shared between the origin and destination storage.

Note that a storage may contain multiple versions of a context. A new version of a context is created when a context is saved, modified, then saved again. The older versions of the context are also copied. However, if that context has any descendants that are contexts, the local versions of those descendant contexts are not copied.

### 7.6.5. Tags may point to wrong product after renaming a pool

A tag may end up pointing to the wrong product, or to a non-existing product, in the following scenario:

1. A storage has two pools, a and b, of which a is writable. Remember that only one pool in a storage is writable.
2. You tag a product in pool b. This is written to pool a, since b is read-only.
3. You delete pool b and rename pool a to b. The tag you created now points to a wrong or non-existing product.

Note that this situation can only arise when managing pools and storages from the command line. The graphical tools provided with HIPE work with storages connected to a single pool.
7.6.6. IndexError or IllegalArgumentException when querying

When running a query on a storage, you may get an IndexError or IllegalArgumentException: <query> could not be evaluated correctly message. This can be due to one of the following reasons:

1. Your query string (the third argument of a query, for instance 'p.creator==..')is simply not consistent with the Jython syntax and could not be correctly interpreted. Check your query string by evaluating it on the Jython command line. If your query uses a handle to a product (for example the p in a query p.meta[...] is a handle), then create a dummy product of the type you want to query on the command line to test the query against.

2. It could be possible that the query references some data that does not exist in any of the products that match the product type you have passed in that query. If you see in the details of the error message something along the lines of '〈something〉 does not exist', then this may be the case.

For example, consider the following MetaQuery:

```python
query = MetaQuery(Product, 'p', 'p.meta["temperature"].value==10)
resultset = storage.select(query)
```

**Example 7.42. Filtering directly on metadata values.**

The query first starts creating a shortlist of all products in the storage matching type Product. It then runs the query string on each product in that shortlist. If any of those products don't contain the information referenced in the query string, an error is raised.

There are two ways to avoid this:

a. Be as specific as you can when it comes to specifying the product type in a query. If you know the product type you want to query is of type CalHrsQDCFull, then specify that. Running queries using the most general product type of Product is not recommended, unless the products you have saved are of this type only.

b. Run a two-stage query, using the containsKey() operator to check whether a component exists first, for example:

i. Get a sub-set of products that contain the metadata 'temperature':

```python
queryOne = MetaQuery(Product, 'p', 'p.meta.containsKey("temperature")')
resultsetOne = storage.select(queryOne)
```

**Example 7.43. Filtering products in the archive that contain a specific metadata.**

ii. Run the original query on this subset:

```python
queryTwo = MetaQuery(Product, 'p', 'p.meta["temperature"].value==10)
resultsetTwo = storage.select(queryTwo, resultsetOne)
```

**Example 7.44. Filtering by value a set of products that contain the metadata.**

7.6.7. A query takes a long time to execute

One of the possible reasons is that you are executing a FullQuery, and full queries by their very nature are the most intense of queries and are therefore the slowest.

FullQuery executions should be run as the last stage of a multi-stage query operation. Below is an example of how to search a storage for products of type MyProduct that are created by a developer called 'timo', but contain a specific value in the product data itself.
1. Find all products of type MyProduct with creator 'timo':

```python
attquery = AttQuery(MyProduct, 'p', p.creator=='timo')
resultset = storage.select(attquery)
```

2. Find all products in selection generated from previous queries, # that has a value 10 in the column 'mycolumn' in dataset 'mydataset':

```python
fullquery = FullQuery(Product, 'p', 'p["mydataset"]["mycolumn"].data[5]==10')
storage.select(fullquery, resultset)
```

Example 7.45. Using a full query to filter by data values.

There can be intermediate queries between the two steps involving AttrQuery or MetaQuery, but FullQuery should be left to last.

### 7.7. Pools for remote data

In addition to local pools, you may find these other pool types useful:

- With the **HSA pool** you can connect to the Herschel Science Archive via the command line.
- With the **HTTP client pool** you can access products on a remote server.
- With the **cached pool** you can cache everything retrieved from a pool. It is useful if the pool you are working with is a remote online pool, and you want to work offline.

All the content of the previous sections (except that specific to local pools) also applies to these pools.

#### 7.7.1. The HSA pool

With the HSA pool you can connect to the Herschel Science Archive, query its contents and retrieve products and observations, all from the command line. The HSA pool is used behind the scenes by tasks such as `getObservation` (see the **Data Analysis Guide**: Data Analysis Guide).

You can create an HSA pool as follows:

```python
hsa = HsaReadPool()
```

Example 7.46. Creating a read-only pool connected to the archive.

You can use the HSA pool together with a cached pool, so that retrieved data are cached (see Section 7.7.3):

```python
hsa = CachedPool(HsaReadPool())
```

Example 7.47. Adding cache behaviour to the HSA read pool.

You can now use this pool to query the Herschel Science Archive using the query syntax described in Section 7.3 and Section 7.5. You need to be logged into the HSA to retrieve products. See the Data Analysis Guide for details: Section 1.4.1 in Data Analysis Guide.

Querying the HSA pool differs slightly from what is explained in Section 7.3:

- You can use the `==` operator but not the `=` one: "creator == 'ThatsMe'" is valid, "creator = 'ThatsMe'" is not.
- You can only query a subset of metadata, shown in Section 7.7.4.

**Why would I want to use this pool?** This pool is useful if you want to write scripts that automatically connect to the HSA and perform queries and other operations for which the syntax of getO-
bservation is not enough. You do not need to use this pool directly if you only access the HSA through its graphical interface.

### 7.7.2. The HTTP pool

With the HTTP pool you can query and retrieve data hosted on a remote server pool that can be accessed via a URL.

To access a remote HTTP pool, create an HTTP client pool as follows:

```python
pool = HttpClientPool("http://url.of.remote.pool", "remotePoolName")
```

**Example 7.48. Creating an HTTP client pool.**

You must specify the URL and name of the remote pool. Ask the remote pool administrator for them.

You can use the HTTP pool together with a cached pool, so that retrieved data are cached (see Section 7.7.3):

```python
pool = CachedPool(HttpClientPool("http://url.of.remote.pool", "remotePoolName"))
```

**Example 7.49. Creating a cached pool from a URL.**

The previous examples only describe how to set up a client pool to access remote data. Setting up a server pool to host the data is beyond the scope of this manual, but you can find instructions on the public Herschel TWiki: [http://herschel.esac.esa.int/twiki/bin/view/Public/HttpPool](http://herschel.esac.esa.int/twiki/bin/view/Public/HttpPool).

If you encounter problems while setting up an HTTP server pool, please ask the Herschel Helpdesk (please open this link in a new tab or window) for assistance.

**Why would I want to use this pool?** You should use this pool to access remote data products made available on a server. If you only access products on the Herschel Science Archive and on your local disk, you do not need this pool.

### 7.7.3. The cached pool

The cached pool allows you to cache everything that is retrieved from any remote pool. You can cache any remote pool as follows:

```python
pool = CachedPool(remotePool)
```

**Example 7.50. Creating a cached pool from an already created remote pool.**

Using a cached pool allows you to work offline once you have retrieved the data you need.

The cached pool set-up consists of a remote pool and a pool to store the locally cached products (which we call the delegated pool), held inside a directory with administrative data. We refer to the whole as just "the cached pool".

The delegated pool can be accessed independently as well. However, the cached pool views this as a private storage area, and explicitly assumes that nothing will be added or removed, unless it is through its own interface (by a call to `clearCache()`, for example). Do not modify the delegated pool by accessing it directly if you do not want to risk that the cached pool becomes corrupted and must be cleaned and restarted.

A cache is kept between HIPE sessions, and the cached pool identifies pools by their ID. If you create a new pool in the next HIPE session with the same ID, then it is assumed that this is the same pool as before and the cache will be reused. It is up to you to explicitly clear the cache if this is required (if it is a different pool than the one that the cached data corresponds to). Also, you should be aware of potential name conflicts between pools: if two HTTP client pools are created, connecting to different
hosts, but with the same ID, then if they are both cached in the same HIPE session (or in different
HIPE sessions but simultaneously) a name conflict will arise.

For more information see the CachedPool entry in the User’s Reference Manual: Section 1.51 in

**Why would I want to use this pool?** You should use the pool with the HSA and HTTP pools, if
you use them with any regularity, so that you can minimise network transfers and work offline.

### 7.7.4. Metadata used in the HSA pool

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
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<td>ACMS mode</td>
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<td>String</td>
<td>identification of the active STR</td>
</tr>
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<td>AOR label as entered in HSpot</td>
</tr>
<tr>
<td>aot</td>
<td>String</td>
<td>AOT Identifier</td>
</tr>
<tr>
<td>aperture</td>
<td>String</td>
<td>Instrument aperture in use</td>
</tr>
<tr>
<td>apid</td>
<td>long</td>
<td>Application Programme Identifier</td>
</tr>
<tr>
<td>arrayName</td>
<td>String</td>
<td>Name of Detector Array</td>
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<tr>
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<td>String</td>
<td>Author of the data</td>
</tr>
<tr>
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<td>String</td>
<td>Averaging operator</td>
</tr>
<tr>
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<td>String</td>
<td>Band</td>
</tr>
<tr>
<td>baselineModel</td>
<td>String</td>
<td>Baseline Model</td>
</tr>
<tr>
<td>baselineParams</td>
<td>String</td>
<td>Parameters of Baseline model</td>
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<td>bbCount</td>
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<td>Building Block Count</td>
</tr>
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<td>Bias mode</td>
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<td>double</td>
<td>Bias voltage factor</td>
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<td>long</td>
<td>Bit position of this mask</td>
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<td>String</td>
<td>Calibration file ID</td>
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<tr>
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<td>int</td>
<td>Calibration file version</td>
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<td>Name Camera/ detector array</td>
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<td>Model of the camera (CQM, FM, Sixpack,...)</td>
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<td>CD_1_1 element of CD matrix</td>
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<td>CD_1_2 element of CD matrix</td>
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<td>double</td>
<td>CD_1_3 element of CD matrix</td>
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<td>CD_2_2 element of CD matrix</td>
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<td>CD_2_3 element of CD matrix</td>
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<td>Type</td>
<td>Description</td>
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<td>---------</td>
<td>-----------------------------------------------------------------------------</td>
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<td>CD_3_1 element of CD matrix</td>
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<td>CD_3_2 element of CD matrix</td>
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<td>CD_3_3 element of CD matrix</td>
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<td>cdel1</td>
<td>double</td>
<td>pixel size in axis 1</td>
</tr>
<tr>
<td>cdel2</td>
<td>double</td>
<td>pixel size in axis 2</td>
</tr>
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<td>String</td>
<td>Logging of changes</td>
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<td>Indicates the chop plateau within sequence</td>
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<td>double</td>
<td>Conversion factor from chopper deflection (degrees) to angle on sky</td>
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<td>FineTime</td>
<td>Date of product creation</td>
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<td>crpix2</td>
<td>double</td>
<td>CRPIX2 reference pixel of axis 2</td>
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</tr>
<tr>
<td>crval2</td>
<td>double</td>
<td>Axis 2 coordinate at tangency</td>
</tr>
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</tr>
<tr>
<td>ctype2</td>
<td>String</td>
<td>Type of coordinate axis eg DEC—TAN</td>
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<td>Name of data analyst</td>
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<td>Requested declination of pointing</td>
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<td>Declination of target object</td>
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<td>double</td>
<td>Correction of output angle per pixel unit offset to central pixel</td>
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<tr>
<td>description</td>
<td>String</td>
<td>Full name of product</td>
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<td>FineTime</td>
<td>End date of observation</td>
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<td>double</td>
<td>Equinox of celestial coordinate system</td>
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<td>Type</td>
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<td>-----------</td>
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<td>site that created the product</td>
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<td>Variable</td>
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<td>Position Angle of pointing</td>
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<td>Quality flag</td>
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<td>Actual Right Ascension of pointing</td>
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<td>Coordinate reference frame for the RA and DEC</td>
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<td>Error on Right Ascension of actual pointing</td>
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<td>requested RA of pointing</td>
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<td>RA of target object</td>
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<td>Reference SAA value in the range 0-180 degrees</td>
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<td>Fraction of saturated samples</td>
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<td>Reference to the applicable SIAM</td>
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<td>Spatial resolution</td>
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<td>Detector Source Packet</td>
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<td>Field</td>
<td>Type</td>
<td>Description</td>
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<td>-----------</td>
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<td>FineTime</td>
<td>Start date of observation</td>
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<td>Begin of wavelength interval</td>
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<td>status</td>
<td>String</td>
<td>Pixel status or channel status</td>
</tr>
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<td>boolean</td>
<td>STR interlacing status</td>
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<td>STR quality index</td>
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<td>Sub-instrument identifier</td>
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<td>Zero point offset</td>
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Chapter 8. Overview of data processing packages

Software in the HCSS is organized into a tree or hierarchy of packages. Each package contains one or more classes. Java development automatically leads to documentation of packages, classes, and their methods in the Javadoc, known in the HCSS help system as the Developer's Reference Manual (DRM). This chapter explains when, why and how to use the DRM, and provides an overview of the main DP packages only. A full listing of packages and classes available in your HCSS installation is given in the API documentation, which you can access by selecting HCSS Developer's Reference Manual (API) from the HIPE Help System table of contents.

When to use the DRM. Java developers will already be familiar with the DRM or Javadoc. Users of HIPE will need it only in certain specialised cases:

• When a class is not documented in the User's Reference Manual.
• When you want to view the exhaustive list of methods for a class.
• When you want to browse through all the classes in a given package.
• When you want to browse all the packages in your installation of HIPE.

Definitions. These Java development terms will be encountered in the following sections.

• **Class.** The (Java) class of a product defines the type of object it is. In object-oriented programming a class is a construct that is used as a blueprint to create objects, so all objects of a particular class will have the same organisation and definition.

• **Method.** In object-oriented programming a method is a group of (software) instructions that is given a unique name and can be called up at any point by simply quoting the name. In other languages a method is called a function, subroutine or procedure. Example: `myTask.getSomething();` the getSomething() is a method for myTask and it returns an answer that depends on what is (or is not) in the ()

• **Constructor.** Constructors are methods that create objects of a particular class.

• **Attribute.** An attribute is a field that denotes a particular characteristic of the class, much like a property of a class. For example, an important attribute of an observation context is the observation ID.

• **Interface.** An interface is a named collection of method definitions (without implementations). An interface can also include constant declarations. A class that implements the interface agrees to implement all of the methods defined in the interface, thereby agreeing to certain behaviour.

• **Package.** Multiple classes of larger programs are usually grouped together into a package. Packages correspond to directories in the file system, and may be nested just as directories are nested.

Packages discussed in this chapter. A number of DP packages are discussed elsewhere in some detail. The Numeric package was discussed in Chapter 5, while the Plot and Display packages are discussed in the Data Analysis Guide. Illustrations of how to use parts of several other HCSS packages are also shown in other chapters.

To access functionality within HCSS packages you have to import it into your HIPE session. For many packages this is done automatically by default; if not you can do it manually via commands like the following:

```python
from herschel.ia.numeric import *
```

Example 8.1. Importing a complete package.
8.1. Browsing the list of packages

The Javadoc is normally started up as three frames in a web browser as illustrated in Figure 8.2. The upper left frame contains the packages index which is a clickable list of all packages in the system. The title in that frame represents the HCSS build number for which this documentation is valid. The lower left frame contains the classes index which is a clickable list of all classes. The selection of classes shown in this frame depends on the package that was selected in the packages index frame. The main frame contains overview information on the system and packages or shows the page for a selected class.

Figure 8.1. View of SPIRE packages after opening up and clicking on SPIRE Developer’s Reference Manual (API) in the HIPE help window.

If you are comfortable with Javadoc documentation, you can access it from the HIPE Help System by clicking on any of the developer reference manuals listed in the Developer Reference section at the bottom of the table of contents. To obtain the traditional frame-based Javadoc layout, click on the FRAMES link on any Javadoc page. To get back to the HIPE Help System layout, use the Back button of your browser (clicking on the NO FRAMES link will not work). To have both layouts available, open the Javadoc layout in a new tab or window of your browser, by right-clicking on the FRAMES link.

Then you will see the Javadoc as three frames as illustrated in Figure 8.2. The upper left frame contains the packages index which is a clickable list of all packages in the system. The title in that frame represents the HCSS build number for which this documentation is valid. The lower left frame contains the classes index which is a clickable list of all classes. The selection of classes shown in this frame depends on the package that was selected in the packages index frame. The main frame contains overview information on the system and packages or shows the javadoc for a selected class.
Overview of data processing packages

Click in the Packages index frame to select a package and update the Classes index frame to show those classes for the selected package. Click the Classes index frame to show the javadoc of a particular class in the Main frame.

The Main frame contains a kind of navigation bar at the top where the view in this frame can be selected. The figure above shows the overview of all the packages. Other views are: Package, Class, Tree, Deprecated, Index, and Help. These views will be explained in more detail below. In the overview the Package and Class views are disabled, they become available when a package or class is selected. Figure 8.3 shows the slightly expanded navigation bar for the Class view.

Figure 8.3. Navigation bar on the class view of JavaDocs.

Note that the navigation bar provides the possibility to browse through packages and classes with NEXT and PREVIOUS and provides direct access to the specific parts of the class documentation e.g. constructors (start class/program) or methods (which can be thought of as sub-routine components of programs that can be applied). It is also possible to switch between FRAMES and NO FRAMES. With NO FRAMES only the Main frame of the javadoc will be shown and index frames become unavailable.

8.2. Browsing the contents of a package

Each package has a page that contains a list of its classes and interfaces, with a summary for each. This page can contain four categories: Interfaces summary, Classes summary, Exceptions and Error summary. Not all categories are always present. At the end there is the package description and possible links to specific and/or related documentation.

Figure 8.4 shows the herschel.ia.dataset package which contains a number of interface and classes such as Column and TableDataset. The Classes index frame provides a clear separation of interfaces and classes and the Main frame shows the interface and class summaries and provides a brief package description with links to package specific info at the bottom. You can navigate to the interface and class detailed documentation by clicking the names in the summary tables or in the left sidebar.
8.3. Viewing the details for a class or interface

Each class and interface has its own separate page in the DRM. There are at least two ways to reach a class description page. From within HIPE, right-clicking on a variable and choosing will bring up the page for the corresponding class in the HIPE help system in your web browser. When viewing the contents of a package as described in Section 8.2, clicking on a class name in the sidebar or the main frame brings up the class description page.

Each of these pages has three sections consisting of a class/interface description, summary tables for constructors and methods, and detailed descriptions of constructors, methods and attributes. The information shown in the class view is restricted to the public API (Application Programming Interface).

Each summary entry contains the first sentence from the detailed description for that item. The summary entries are alphabetical, while the detailed descriptions are in the order they appear in the source code. This preserves the logical groupings established by the programmer.

Figure 8.5 is taken from the Main frame of the TableDataset class and shows the class description together with its hierarchy. You can see that the TableDataset implements a number of interfaces and also has many subclasses. The second part of the figure shows a more detailed description of the class usage.
Overview of data processing packages

Class TableDataset

Overview of data processing packages

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Overview of data processing packages

Class TableDataset

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- **Tree view**

  There is a Class Hierarchy page for all packages, plus a hierarchy for each package. Each hierarchy page contains a list of classes and a list of interfaces. The classes are organised by inheritance structure starting with `java.lang.Object`. The interfaces do not inherit from `java.lang.Object`. When viewing the Overview page, clicking on "Tree" displays the hierarchy for all packages. When viewing a particular package, class or interface page, clicking "Tree" displays the hierarchy for only that package.

- **Deprecated view**

  The Deprecated API page lists everything that has been *deprecated*. A deprecated item is not recommended for use, and a replacement is usually suggested.

  Deprecated items may be removed in future versions.

- **Index view**

  The Index contains an alphabetic list of all classes, interfaces, constructors, methods, and fields.

8.5. DP packages

The following short paragraphs outline the packages currently available within the Herschel DP system. For full details please see the Javadoc.

8.5.1. herschel.ia.dataflow

Handles processing threads. Particularly useful for Quick Look Analysis (QLA) and Standard Product Generation (SPG). It can be used in interactive sessions too. Allows the user to connect scripts from process modules as is typically required for a set of data reduction steps. Dataflow also supports event-based processing as well as threads.

Main subpackages:

- **herschel.ia.dataflow.data.process**: Classes for handling the processes used in a dataflow session.

- **herschel.ia.dataflow.example.indicator_control.monothread**: Classes used to illustrate the control of a dataflow.

- **herschel.ia.dataflow.example.indicator_control.multithread**: Same as above, but for multiple threads.

- **herschel.ia.dataflow.template**: Class to allow template dataflow to be created.

- **herschel.ia.dataflow.util**: Class for identifying dataflows.

8.5.2. herschel.ia.dataset

Contains Table Datasets, Array Datasets, Composite Datasets, Products and all auxiliary components such as columns, parameters and metadata. Datasets and products are described in Chapter 2.

Main subpackages:

- **herschel.ia.dataset.demo**: Contains classes that demonstrate the use of datasets.
Overview of data processing packages

- **herschel.ia.dataset.gui**: Contains the Dataset Inspector graphical interface.
- **herschel.ia.dataset.history**: Defines the History Dataset, which records the complete history of the tasks which were executed to produce a Product.
- **herschel.ia.dataset.image**: Provides a framework for defining images, cubes of images and stacks of images. Includes tools for adding World Coordinate System information.
- **herschel.ia.dataset.spectrum**: Contains tools for defining one- and two-dimensional spectra, and spectral cubes.

### 8.5.3. herschel.ia.document

Provides tools to generate documentation of dynamic as well as static DocBook documents in different formats.

### 8.5.4. herschel.ia.gui

Contains several subpackages related to graphical applications.

Main subpackages:
- **herschel.ia.gui.apps**: Contains the classes used to build graphical applications such as HIPE.
- **herschel.ia.gui.cube**: Graphical interfaces to analyse data cubes.
- **herschel.ia.gui.explorer**: Graphical interfaces to analyse datasets, such as TablePlotter and OverPlotter.
- **herschel.ia.gui.image**: Classes for handling images. The display capabilities from this package are discussed in the Data Analysis Guide.
- **herschel.ia.gui.plot**: Plotting utilities. For more details see the Data Analysis Guide.

### 8.5.5. herschel.ia.io

Provides a means of accessing local archives where Products can be saved or loaded from. Products are combinations of data and information and can be likened to the contents of a single FITS file.

Main subpackages:
- **herschel.ia.io.ascii**: Allows input and output of data to and from ASCII files.
- **herschel.ia.io.dbase**: Allows data/products to be put into objects that can be stored in databases (Versant databases are currently available for use with the HCSS).
- **herschel.ia.io.fits**: A FITS implementation that can write Products to a FITS file and read such FITS files back into the system. Allows the production of a FITS archive.

### 8.5.6. herschel.ia.numeric

Contains numeric and mathematical tools described in Chapter 2 and Chapter 5.

Main subpackages:
- **herschel.ia.numeric.toolbox**: Provides a large set of numeric classes. These include mathematical functions (trigonometric functions, polynomials), Fourier transforms, fitter functions, interpolation and matrix functions. Note that these classes are automatically loaded when starting HIPE.

This package contains the following subpackages:
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- **herschel.ia.numeric.toolbox.basic**: Provides classes that allow basic mathematical manipulation of numeric arrays: trigonometric functions, mathematical product, variance and so on.

- **herschel.ia.numeric.toolbox.filter**: Provides the classes BoxCarFilter, Convolution and GaussianFilter.

- **herschel.ia.numeric.toolbox.fit**: Provides classes that allow the fitting of data with numerous models (iterative fitters, sine model fitters, polynomial model fitters and so on).

- **herschel.ia.numeric.toolbox.integr**: Provides integrator functions for several integral models (Gauss-Jacobi, Gauss-Laguerre and so on).

- **herschel.ia.numeric.toolbox.interp**: Provides classes that allow the interpolation of data. These include Interpolator (a general interpolator), LinearInterpolator, CubicSplineInterpolator and NearestNeighborInterpolator.

- **herschel.ia.numeric.toolbox.mask**: Provides tools for creating and managing masks, in particular the two classes FixedMask and PackedMask.

- **herschel.ia.numeric.toolbox.matrix**: Provides classes that allow the manipulation of Double2d arrays holding matrices. It includes the classes MatrixDeterminant, MatrixInverse and MatrixSolve.

- **herschel.ia.numeric.toolbox.random**: Provides tools for generating pseudo-random numbers with uniform (RandomUniform), Gaussian (RandomGauss) and Poisson (RandomPoisson) distributions.

- **herschel.ia.numeric.toolbox.stat**: Provides statistical tools for arrays, to compute covariance (Covariance and CovarianceMatrix), geometric mean (GeoMean) and mode (Mode).

- **herschel.ia.numeric.toolbox.util**: Provides the classes MoreMath, which has methods for mathematical manipulation of single numerical elements (integers, doubles, bytes and so on), and Util, which has utilities for converting arrays.

- **herschel.ia.numeric.toolbox.wavelet**: Provides algorithms to perform continuous, discrete and stationary wavelet transforms.

- **herschel.ia.numeric.toolbox.xform**: Provides the classes FFT, FFT_PACK, RealDoubleFFT, FFT_PACK_EVEN, FFT_PACK_ODD, Hamming and Hanning for Fourier transforms and Hanning/Hamming smoothing of data.

### 8.5.7. herschel.ia.obs

Defines the *Observation Context*, a container for Products applicable to a specific observation, and related classes.

Main subpackages:

- **herschel.ia.obs.auxiliary**: Defines the auxiliary Products related to an observation, and their container, the *Auxiliary Context*.

- **herschel.ia.obs.cal**: Calibration-related classes.

- **herschel.ia.obs.quality**: Defines the *Quality Context* and the flags used for quality control.

### 8.5.8. herschel.ia.pal

Defines the *Product Access Layer*, which allows storage and retrieval of Products both locally and remotely. The Product Access Layer is treated in detail in [Chapter 7](#).

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Main subpackages:

- **herschel.ia.pal.browser**: Defines the Product Browser graphical application.
- **herschel.ia.pal.io**: Defines classes for importing and exporting Products to FITS format.
- **herschel.ia.pal.pool**: Defines, in various subpackages, the available types of Product Pools.
- **herschel.ia.pal.query**: Defines the types of query that can be applied to a Product Storage.

### 8.5.9. herschel.ia.pg

Describes the Product Generation Framework, on which running of instrument pipelines is based.

Main subpackages:

- **herschel.ia.pg.od**: Defines the Operational Day Plugin, used to process an entire OD before processing its observations.
- **herschel.ia.pg.plugins**: Defines basic versions of other plugins that are applied during pipeline processing, such as BasicLevel0Plugin and BasicQualityPlugin.

### 8.5.10. herschel.ia.qcp

Defines components and utilities to handle Quality Control messages.

Main subpackages:

- **herschel.ia.qcp.example**: Provides an example Task for using the facilities of this package.
- **herschel.ia.qcp.flags**: Provides a hierarchical structure of Quality Control flags.
- **herschel.ia.qcp.gui**: Provides graphical components for displaying Quality Control messages.
- **herschel.ia.qcp.plugin**: Provides plugins for logging Quality Control messages during Operational Day and pipeline processing.
- **herschel.ia.qcp.tools**: Provides a standalone application for displaying Quality Control information.

### 8.5.11. herschel.ia.spg

Manages the execution of the data reduction process for all the instrument in the Herschel satellite. It is built upon the framework defined in the herschel.ia.pg package (see Section 8.5.9).

Main subpackages:

- **herschel.ia.spg.gui**: Contains the Pipeline Manager graphical interface.
- **herschel.ia.spg.kayako**: Contains a helper class for creating a ticket in the kayako system.
- **herschel.ia.spg.od**: Tools for scheduling and executing Operational Day processing.
- **herschel.ia.spg.ops**: Miscellaneous tools for configuring pipeline processing.
- **herschel.ia.spg.tools**: Classes for memory monitoring and the remote management of processing queues.

### 8.5.12. herschel.ia.task
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Provides the tools needed to create a data processing task which you can then incorporate into your scripts. For more information on tasks please see Chapter 6.

Main subpackages:

- **herschel.ia.task.example**: Provides example Tasks that demonstrate some features of the package.
- **herschel.ia.task.gui**: Provides components used to build graphical interfaces for Tasks.
- **herschel.ia.task.history**: Provides a class for managing the history of a Task.
- **herschel.ia.task.mode**: Provides different execution modes for a Task (interactive, on demand, systematic and test).
- **herschel.ia.task.util**: Miscellaneous utility functions for Task development.

### 8.5.13. herschel.ia.toolbox

Provides tools for a wide range of data analysis needs. Tools are organized in thematic subpackages.

Main subpackages:

- **herschel.ia.toolbox.astro**: Astronomical utilities.
- **herschel.ia.toolbox.cube**: Tasks for importing and analysing data cubes.
- **herschel.ia.toolbox.fit**: Tasks for function fitting.
- **herschel.ia.toolbox.hsa**: Provides an interface for accessing the Herschel Science Archive.
- **herschel.ia.toolbox.image**: Tasks for image processing (cropping, smoothing and so on).
- **herschel.ia.toolbox.mapper**: Tasks for mapmaking.
- **herschel.ia.toolbox.pointing**: Provides a task for plotting pointing information.
- **herschel.ia.toolbox.spectrum**: Tasks for analysing spectra. This package contains several subpackages, among which are the following:
  - **herschel.ia.toolbox.spectrum.fit**: Tools for fitting spectra.
  - **herschel.ia.toolbox.spectrum.operations**: Tools for performing mathematical operations on spectra (divide, average, resample and so on).
  - **herschel.ia.toolbox.spectrum.projection**: Tools for projecting spectral data on the sky.
  - **herschel.ia.toolbox.spectrum.selections**: Tools for selecting and managing ranges and discrete values within spectra.
  - **herschel.ia.toolbox.spectrum.standingwaves**: Tools for fitting and removing fringes.
  - **herschel.ia.toolbox.spectrum.utils**: Other utilities, for example to integrate and interpolate spectra.
- **herschel.ia.toolbox.srcext**: Tools for point source extraction.
- **herschel.ia.toolbox.util**: Miscellaneous tools, among which are tasks for importing from and exporting to ASCII tables and FITS files.

### 8.5.14. herschel.ia.vo

Contains tools that implement the interface to the Virtual Observatory.
8.5.15. herschel.share.fltdyn

Contains classes and interfaces related to flight dynamics, such as time measurement and ephemerides.

Main subpackages:

- **herschel.share.fltdyn.constraint**: Classes to define time intervals and time constraints.

- **herschel.share.fltdyn.ephem**: Classes to define planetary ephemerides and spacecraft orbital ephemerides.

- **herschel.share.fltdyn.math**: Mathematical classes for handling spacecraft attitudes, rotations and coordinates.

- **herschel.share.fltdyn.time**: Time classes with microsecond resolution and handling of leap-seconds. For more information see Chapter 9.
Chapter 9. Time and astronomical measurements

The first part of this chapter describes how time is defined within HCSS and how to deal with it. Unfortunately, there are several ways in which time can be represented. The standard for the HCSS/DP is a FineTime - which is the number of microseconds since the beginning of 1 January 1958. This provides the kind of accuracy needed to represent time on a space mission.

However, there are several other time representations and it is often the case that conversions between times/dates is necessary. In particular, it is noted that the standard Java commands lead to date measurements with respect to 1 January 1970. This chapter indicates how to deal with times within DP and converting between the various times, particularly between dates and FineTime's.

The last section of this chapter explains how to carry out great circle and position angle calculations.

9.1. Time Definitions

9.1.1. System time in HIPE

There are many ways to access the system time in HIPE. See also the description of the Java class "Date" for a discussion of slight discrepancies that may arise between "computer time" and coordinated universal time (UTC).

The Java Date class is deprecated and is being replaced by a more flexible SimpleDateFormat capability within Java that allows the user to express dates more conveniently. A Date object is still obtained and can be turned into a FineTime (see below) once created.

Two possibilities for creating a "Date" object are:

```java
# To get the current time in milliseconds:
# The difference, measured in milliseconds, between the current
# time and midnight, January 1, 1970 UTC.
print java.lang.System.currentTimeMillis()
# To get the number of milliseconds since January 1, 1970, 00:00:00 GMT represented by a Date object.
d = java.util.Date()
#printing this gives the current time and date at the location of the
#system on which the java is being run.
print d
#We can also get the number of milliseconds since Jan 1, 1970 using
#this Java Date
print d.getTime()
```

Example 9.1. How to obtain the current time by various methods.

Note that while the unit of time of the return value is a millisecond, the granularity of the value depends on the underlying operating system and may be larger.

If we want to get the number of milliseconds since 1 January 1970 for any other date then we can use a non-default form of the Java Date capability where the year, month, day, hour, minute and second are provided.

- Year format -- year (A.D.) - 1900. So the year 2006 = 2006 - 1900 = 106
- Month format -- number of the month, beginning from January = 0. E.g. March = 2.
- Day -- just day number in the month.
• Hours, minutes, seconds -- on the 24-hour clock.

NOTE: This is the time on our computer system.

```java
// Format of date is year (in units of true year - 1900), month (number 0...11),
// day, hour, minute, second. So the following gives us the number of milliseconds
// between the beginning of 1 January 1970 and 3:15:00 pm on 23 October 2004.
d = java.util.Date(104, 9, 23, 15, 15, 0)
print d  # should indeed show we have 3:15pm on 23 October 2004
print d.getTime()  # provides the number of milliseconds between this
# date and 1 Jan 1970.
```

Example 9.2. Different ways of formatting time variables.

The following sample code shows how to use `SimpleDateFormat` to create a "Date" object.

```java
simpleDate = java.text.SimpleDateFormat("yyyy.MM.dd HH:mm:ss z")
# set up how you want to set up your input Date format. In this
# case we could input "2006.01.14 01:00:00 CST" for 1a.m. on 14
# January 2006. z -- indicates the time zone (default is the zone for the
# computer system being used).

simpleDate.applyPattern("dd/MM/yy HH:mm")
# change the pattern to a different format

startTime = simpleDate.parse("13/01/06 14:06")
# create the data object "startTime"

print startTime
#...and see what this looks like
```

Example 9.3. Creating a date object.

Allowed choices for the data format are available from Java documentation of the `SimpleDateFormat` capability.

9.1.2. International Atomic Time (TAI) and FineTime

TAI is an international standard measurement of time based on the comparison of many atomic clocks. TAI is the basis for Coordinated Universal Time (UTC). Finetime is based on TAI as measured from 00:00:00 1 January 1958.

9.1.3. Coordinated Universal Time (UTC)

UTC, World Time, is the standard time common to every place in the world. UTC is derived from International Atomic Time (TAI) by the addition of a whole number of "leap seconds" to synchronise it with Universal Time 1 (UT1), thus allowing for the eccentricity of the Earth's orbit and the rotational axis tilt (23.5 degrees), but still showing the Earth's irregular rotation, on which UT1 is based.

9.1.4. DecMec Time [PACS only]

The commands DPUSSelectTime and DPUWriteTime are selecting and setting a start time which is written to the TMP1 and TMP2 fields of the Dec/Mec headers. This is used in coordinating the activities of the mechanical devices on board PACS. It is possible to construct an absolute time by adding counters (CRDC) to the start time considering an offset between setting and writing the start time.

This offset is expected to be a number with an uncertainty depending on the system load. It might require a calibration file. Currently this offset is not considered.

In case the commands and are not given the TMP1 and TMP2 fields are zero. To avoid software confusions the time will be related to a fixed date (1 Jan 1970, 0:00).
During construction of the SpuBuffer the time is computed from the TMP1, TMP2 entries in the Dec/Mec header and the CRDC counter. This time is used during construction of the DataFrameSequence and the associated Tables holding the SPU science data.

Between the Dec/Mec time and the packet time (see the PusTmBinStruct class in the herschel.binstruct package) we have an offset. Therefore the association between HK and science data will be within an accuracy of 2 seconds.

9.2. Time in Instrument House-Keeping (HK) Data

The most convenient method of obtaining time stamped HK information is the use of the herschel.binstruct package.

When dealing with HK time information directly, it is important to know that telemetry packets contain the time as defined within the "PUS Data Field Header". The field represents the on-board reference time of the packet, referenced to TAI, expressed in spacecraft time units - CCSDS Unsegmented Time Code (CUC) units. CUC units are multiples of 1/65536 sec from 1 January 1958 in TAI time. CUC units cannot be expressed in whole microseconds but can be converted to the FineTime standard (see below).

CUC time is written for HK by the data processing unit (DPU).

Current PusTmBinStruct methods related to time:

`long getTime()`

Returns the packet time of the Pus telemetry packet.

`boolean isTimeSynchronized()`

Returns true if the telemetry packet is synchronized, false otherwise.

`java.util.Date getTimeAsDate()`

Returns the packet time as a Date object.

`FineTime getTimeAsFineTime()`

Returns the packet time of the Pus telemetry packet as FineTime.

9.3. Time conversion

9.3.1. Time conversion in HIPE

It can often be the case that we need to convert between FineTime (TAI) and Date (UTC). Coordinated Universal Time is expressed using a 24-hour clock and uses the Gregorian calendar. FineTime represents a TAI time (epoch 1958), whereas the Java Date class is used to represent UTC, by resetting the system clock whenever a leap second occurs and don't need to handle leap seconds. Converting between Java dates and the FineTime standard requires the use of the DateConverter() class. Long integers can also be directly converted to FineTimes and are interpreted as representing the number of microseconds since 00:00:00 1 January 1958. In Example 9.4 we illustrate how to create a FineTime from a long integer and convert back and forth between FineTime and Java Dates.

```
# FineTime to Date
# Enter a time in seconds (a long integer - put letter "l" at the end of the number)
c = FineTime(1436094449715400l) # convert to a FineTime
```
9.3.2. CucConverter

Converts between Spacecraft Elapsed Time, in CCSDS Unsegmented Time Code (CUC) format and FineTime (TAI). This implementation is for the Herschel CUC format, which is corrected on-board the spacecraft to TAI (epoch 1 Jan 1958). This representation uses 32-bits for seconds and 16 bits for fractional seconds. CUC times are multiples of 1/65536 sec and cannot be expressed as an exact multiple of 1 microsecond (the resolution of FineTime). However, the following relations hold for 'coarse' and 'fine' values in the allowed range:

- **long coarse(FineTime t)**
  Return the number of whole seconds since the epoch 1 Jan 1958.

- **long cucValue(FineTime t)**
  Return the number of 1/65536 fractional seconds since the epoch 1 Jan 1958.

- **int fine(FineTime t)**
  Return the fractional part of the number of 1/65536 seconds since the epoch 1 Jan 1958.

- **FineTime toFineTime(long cuc)**
  Return a new FineTime constructed from a 48-bit CUC time.

- **FineTime toFineTime(long coarse, int fine)**
  Return a new FineTime constructed from CUC coarse & fine fields.

```python
don=CucConverter.toFineTime(50000000000000L)
#Converts the long integer - representative of a CUC time -
#into a FineTime. The FineTime is stored in d.
e=CucConverter.coarse(d)
#provides the number of whole seconds since 1 Jan 1958
#print e
```

9.4. Great circle and position angle calculations

This functionality is available within the herschel.share.fltdyn.math package. This package is a low level library written for the mission planning system. It uses radians throughout, except where indicated in the method names (for instance, Direction.fromDegrees(ra,dec) and Direction.getRaDegrees()). Please see the following example:

```python
HIPE> from herschel.share.fltdyn.math import *
HIPE> x = Direction(125./180*Math.PI, 80./180*Math.PI)
HIPE> y = Direction(125./180*Math.PI, 70./180*Math.PI)
```
HIPE> print x.distanceTo(y)
0.17453292519943298
HIPE> print x.distanceTo(y)/Math.PI*180
10.000000000000002
HIPE> z = Direction(100./180*Math.PI,80./180*Math.PI)
HIPE> print x.distanceTo(z)/Math.PI*180
4.307863243850451

Note the manual conversions between radians and degrees throughout the example. However, the Direction class has factory methods that accept degrees. Conversion of the result to degrees is most elegantly achieved using the Math.toDegrees() method. So, the previous example simplifies to the following:

HIPE> x = Direction.fromDegrees(125,80)
HIPE> y = Direction.fromDegrees(125,70)
HIPE> print Math.toDegrees(x.distanceTo(y))
10.000000000000002

The position angle is given by the following command:

pos = x.positionAngleTo(y)

Example 9.6. Calculating the angle between vectors.

The Direction class is recommended for calculations of any complexity. It does all the internal calculations using the Vector3 and Quaternion classes, which are fast and avoid problems with singularities at the poles.
Appendix A. Jython operators

The following tables shows all the various operators you can use in Jython. HCSS and HIPE use Jython version 2.5.2.

This list and the associated operator descriptions have been largely taken from the Python Reference Manual, which you can find online at http://docs.python.org/reference/.

Table A.1. Jython unary arithmetic operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operator description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Unary plus: yields its numeric argument unchanged.</td>
<td>print +5 #5</td>
</tr>
<tr>
<td>-</td>
<td>Unary minus: yields the negation of its numeric argument.</td>
<td>print -5 #-5</td>
</tr>
<tr>
<td>~</td>
<td>Invert: yields the bitwise invert of its plain or long integer argument.</td>
<td>print ~5 #-6</td>
</tr>
</tbody>
</table>

Table A.2. Jython binary arithmetic operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operator description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Sum: yields the sum of its arguments.</td>
<td>print 2 + 2 # 4</td>
</tr>
<tr>
<td>-</td>
<td>Subtraction: yields the difference of its arguments.</td>
<td>print 2 - 3 # -1</td>
</tr>
<tr>
<td>*</td>
<td>Multiplication: yields the product of its arguments.</td>
<td>print 3 * 2 # 6</td>
</tr>
<tr>
<td>/</td>
<td>Division: yields the quotient of its arguments.</td>
<td>print 5 / 2 # 2 print 5.0 / 2 # 2.5</td>
</tr>
<tr>
<td>//</td>
<td>Floor division (Jython 2.2 alpha only): yields the result of the floor() function applied to the quotient of its arguments.</td>
<td>print 5 // 2 # 2 print 5.0 // 2 # 2.0</td>
</tr>
<tr>
<td>%</td>
<td>Modulo: yields the remainder from the division of its arguments.</td>
<td>print 5 % 2 # 1</td>
</tr>
<tr>
<td>**</td>
<td>Power: yields its left argument raised to the power of its right argument.</td>
<td>print 5**2 # 25</td>
</tr>
</tbody>
</table>

Table A.3. Jython shifting operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operator description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;&lt;</td>
<td>Left shift: a &lt;&lt; b shifts plain or long integer a by b bits.</td>
<td>print 5 &lt;&lt; 1 # 10</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Right shift: a &gt;&gt; b shifts plain or long integer a by b bits.</td>
<td>print 5 &gt;&gt; 1 # 2</td>
</tr>
</tbody>
</table>
### Table A.4. Jython binary bitwise operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operator description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>Bitwise AND: yields the bitwise AND of its plain or long integer arguments.</td>
<td><code>print 5 &amp; 6</code> # 4</td>
</tr>
<tr>
<td>^</td>
<td>Bitwise XOR: yields the bitwise exclusive OR of its plain or long integer arguments.</td>
<td><code>print 5 ^ 6</code> # 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bitwise OR: yields the bitwise inclusive OR of its plain or long integer arguments.</td>
</tr>
</tbody>
</table>

### Table A.5. Jython comparison operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operator description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
<td>Less than: ( a &lt; b ) yields true if ( a ) is less than ( b ).</td>
<td><code>print 5 &lt; 6</code> # 1</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than: ( a &gt; b ) yields true if ( a ) is greater than ( b ).</td>
<td><code>print 5 &gt; 6</code> # 0</td>
</tr>
<tr>
<td>==</td>
<td>Equal to: ( a == b ) yields true if ( a ) and ( b ) are equal.</td>
<td><code>print 5 == 6</code> # 0</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Greater or equal to: ( a &gt;= b ) yields true if ( a ) is greater than or equal to ( b ).</td>
<td><code>print 5 &gt;= 6</code> # 0</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Less or equal to: ( a &lt;= b ) yields true if ( a ) is less than or equal to ( b ).</td>
<td><code>print 5 &lt;= 6</code> # 1</td>
</tr>
<tr>
<td>!= (preferred) or &lt;&gt;</td>
<td>Not equal to: ( a != b ) yields True if ( a ) is not equal to ( b ).</td>
<td><code>print 5 != 6</code> # 1, <code>print 5 &lt;&gt; 5</code> # 0</td>
</tr>
</tbody>
</table>

### Table A.6. Jython boolean operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operator description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>and</td>
<td>Boolean AND: yields True if both arguments are true, False otherwise.</td>
<td><code>print 1 and 0</code> # 0</td>
</tr>
<tr>
<td></td>
<td>Example A.1. Boolean and operation between integers is also valid.</td>
<td></td>
</tr>
<tr>
<td>or</td>
<td>Boolean OR: yields True if at least one argument is true, False otherwise.</td>
<td><code>print 1 or 0</code> # 1</td>
</tr>
<tr>
<td></td>
<td>Example A.2. Boolean or operation between integers is also valid.</td>
<td></td>
</tr>
<tr>
<td>not</td>
<td>Boolean NOT: yields True if the argument is false, False otherwise.</td>
<td><code>print not 1</code> # 0</td>
</tr>
<tr>
<td></td>
<td>Example A.3. Boolean not operation between integers is also valid.</td>
<td></td>
</tr>
</tbody>
</table>
# Appendix B. Naming conventions

## B.1. Naming Conventions

for Java and Jython users and developers. Version 0.3, 6th December 2006

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Naming convention</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class</strong></td>
<td>Defines the state and behaviour of something. Classes are defined as declaring variables (fields) and functions (methods) associated with the objects of that class.</td>
<td>Names should be nouns and written in mixed case starting with an upper case letter. Do not use underscores to separate words. DataFrameGenerator, FitsArchive</td>
</tr>
<tr>
<td><strong>Interface</strong></td>
<td>Defines a collection of method definitions and constant values. It can later be implemented by classes that define this interface with the implements keyword.</td>
<td>Names have the same convention as class names but are preferably adjectives. Try to end the names with -able or -ible: Sortable, Accessible, Savable</td>
</tr>
<tr>
<td><strong>Variable</strong></td>
<td>An item of data named by an identifier. Each variable has a type, such as <code>int</code> of <code>Frame</code>, and a scope.</td>
<td>Names should be mixed case starting with a lower case letter. Do not use underscores to separate words. FrameBufferCounter, nSamples, line, detectorNo</td>
</tr>
<tr>
<td><strong>Instance Variable</strong></td>
<td>A variable that is part of an object.</td>
<td>Names should start with an underscore, otherwise follow the general conventions for variables (see above). _packetType, _isVisible</td>
</tr>
<tr>
<td><strong>Local Variable</strong></td>
<td>A variable that is part of a function or method.</td>
<td>Names follow the naming convention of normal variables. counter, length, pixelName</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>A variable whose value cannot be changed during execution.</td>
<td>Names should be all uppercase using an underscore to separate words: MAX_ITERATIONS</td>
</tr>
<tr>
<td><strong>Boolean variable and method</strong></td>
<td>A logical type/function that can only have or return the values 'true' or 'false'. Methods have parentheses () while variables haven’t.</td>
<td>Names should start with is-, has-, can-, or should-. isVisible, hasChanged(), canHandle(), shouldAbort</td>
</tr>
<tr>
<td><strong>Parameter</strong></td>
<td>An argument to a function or a method.</td>
<td>Names follow the naming convention of normal variables.</td>
</tr>
</tbody>
</table>
### Naming conventions

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Naming convention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
<td>A platform independent implementation of environment variables and settings.</td>
<td>Names should be all lower case and start with 'hcss'. The hierarchical parts should be separated with a dot.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>hcss.binstruct.services</code></td>
</tr>
<tr>
<td>Method</td>
<td>A function defined in a class.</td>
<td>Names should be verbs and written in mixed case starting with a lower case letter. Do not use underscores to separate words.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>getName()</code>, <code>load()</code></td>
</tr>
<tr>
<td>Function</td>
<td></td>
<td>Section 1.27</td>
</tr>
<tr>
<td></td>
<td>A jython function is a collection of code lines to perform a specific task under one name. Functions take arguments and provide one output. They are like methods, except they are not inside a class. A function can also be an instance of the Task class.</td>
<td>Names follow the same convention as method names in classes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>resample()</code>, <code>readTm()</code></td>
</tr>
<tr>
<td>Numeric function</td>
<td>Parameterless Java functions provided by the herschel.ia.numeric toolbox, for these functions only one instance is needed. Other numeric functions follow the same convention as classes.</td>
<td>Names are in all uppercase with an underscore to separate words.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>UNIQ</code>, <code>MEDIAN</code>, <code>IS_FI-NITE</code></td>
</tr>
<tr>
<td>Task</td>
<td></td>
<td>Section 5.1</td>
</tr>
<tr>
<td></td>
<td>A Task is a class which can be called as a function. Tasks do input and output parameter type checking and provide history to Products.</td>
<td>Names follow the same conventions as for classes. Task names should end with the word 'Task'.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>DisplayDataFrameTask</code>, <code>ResampleTask</code></td>
</tr>
<tr>
<td>Package</td>
<td>Defines a collection of related classes and interfaces in Java. Packages provide the namespace in Java and Jython.</td>
<td>Names should be in lower-case letters and digits, don’t use underscores.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>herschel.ia.numeric</code></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Package names should be short so that the fully qualified package name doesn’t become excessively long.</td>
</tr>
</tbody>
</table>

Abbreviations and acronyms should **not** be all uppercase when used as a name:

<table>
<thead>
<tr>
<th>GOOD</th>
<th>BAD</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>exportAsHtml()</code></td>
<td><code>exportAsHTML()</code></td>
</tr>
<tr>
<td><code>saveAsJpeg()</code></td>
<td><code>saveAsJPEG()</code></td>
</tr>
<tr>
<td><code>OolPacket</code></td>
<td><code>OOLPacket</code></td>
</tr>
</tbody>
</table>

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Using all uppercase for the abbreviations in base names will give conflicts with the naming conventions given above. A variable of this type would have to be named HTML, JPEG etc. which obviously is not very readable. Another problem is illustrated in the examples above: when the name is connected to another, the readability is seriously reduced, since the word following the acronym does not stand out as it should.

The term compute can be used in methods where something is computed and might take considerable time to execute.

computeAverage(), matrix.computeInverse()

Give the reader the immediate clue that this is a potential time consuming operation, and if used repeatedly, he might consider caching the result. Consistent use of the term enhances readability.

The 'n' prefix should be used for variables representing a number of objects, note that the names are plural.

nPoints, nLines, nSamples

The notation is taken from mathematics where it is an established convention for indicating a number of objects. Note that Sun uses the num prefix in the core Java packages for such variables. This is probably meant as an abbreviation of number of, but as it looks more like number it makes the variable name strange and misleading. If "number of" is the preferred phrase, numberOf prefix can be used instead of just n. The num prefix must not be used.

The 'No' suffix should be used for variables representing an entity number.

tableNo, employeeNo

The notation is taken from mathematics where it is an established convention for indicating an entity number.

Reserved words: the following words are reserved by Java as language keywords and can not be used for variables, methods or class names in Java.

abstract, continue, for, new, synchronized, assert, default, goto, package, this, boolean, double, if, private, throws, break, do, implements, protected, throw, byte, else, import, public, transient, case, enum, instanceof, return, try, catch, extends, interface, short, void, char, finally, int, static, volatile, class, final, long, super, while, const, float, native, switch.

B.1.1. Jython code example

```python
# herschel.ia.dataset.gui = PACKAGE; DatasetInspector = CLASS
from herschel.ia.dataset.gui import DatasetInspector
# PI = CONSTANT
from java.lang.Math import PI
# testName = VARIABLE
testName = "chop_freq_test_2909_1832_1902_"
# load = METHOD
t2 = fits.load(myDir+testname+"PHOTF.fits").default
# MAX = NUMERIC FUNCTION
maxStep = MAX(step[step.where(step < 0xffff)])
# startEndTimes = FUNCTION; step, maxStep, time... = FUNCTION PARAMETERS
def startEndTimes(step, maxStep, time, startTime, endTime):
    for i in range(0, maxStep): # i = LOCAL VARIABLE
        temp=step[step.where(step == i+1)]
        endTime[i] = time[MAX(temp.toInt1d())]
return endTime
# len = FUNCTION
```


B.1.2. Java code example

```java
package herschel.ia.numeric; // herschel.ia.numeric: PACKAGE
public final class Complex1d // Complex1d: CLASS
    implements Serializable // Serializable: INTERFACE
{
    private transient double[][] _internal; // _internal: INSTANCE VARIABLE
    // writeObject: METHOD
    private void writeObject(ObjectOutputStream os) { // os = METHOD PARAMETER
        os.defaultWriteObject();
        os.writeInt(length());
        if (length()==0) return;
        for (int i=0,n=length();i<n;i++) { // i = LOCAL VARIABLE
            os.writeDouble(_re[i]); os.writeDouble(_im[i]);
        }
    }
}
```
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