Mayavi2 User Guide

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CHAPTER

ONE

Introduction

Mayavi2 seeks to provide easy and interactive visualization of 3D data. It does this by the following:

- an (optional) rich user interface with dialogs to interact with all data and objects in the visualization.
- a simple and clean scripting interface in Python, including ready to use 3D visualization functionality similar to matlab or matplotlib (using *mlab*), or an object-oriented programming interface.
- harnesses the power of VTK without forcing you to learn it.

Additionally, Mayavi2 strives to be a reusable tool that can be embedded in your libraries and applications in different ways or be combined with the Envisage application-building framework to assemble domain-specific tools.

1.1 What is Mayavi2?

Mayavi2 is a general purpose, cross-platform tool for 3-D scientific data visualization. Its features include:

- Visualization of scalar, vector and tensor data in 2 and 3 dimensions.
- Easy scriptability using Python.
- Easy extendability via custom sources, modules, and data filters.
- Reading several file formats: VTK (legacy and XML), PLOT3D, etc.
- Saving of visualizations.
- Saving rendered visualization in a variety of image formats.
- Convenient functionality for rapid scientific plotting via mlab (see *Simple Scripting with mlab*).

Unlike its predecessor Mayavi1, Mayavi2 has been designed with scriptability and extensibility in mind from the ground up. Mayavi2 provides a `mayavi2` application which is usable by itself. However, Mayavi2 may also be used as a plotting engine, in scripts, like with matplotlib or gnuplot, as well as a library for interactive visualizations in any other application. It may also be used as an Envisage plugin which allows it to be embedded in other Envisage based applications natively.

1.2 Technical details

Mayavi2 provides a general purpose visualization engine based on a pipeline architecture similar to that used in VTK. Mayavi2 also provides an Envisage plug-in for 2D/3D scientific data visualization. Mayavi2 uses the Enthought Tool Suite (ETS) in the form of Traits, TVTK and Envisage. Here are some of its features:

- Pythonic API which takes full advantage of Traits.
- Mayavi can work natively and transparently with numpy arrays (this is thanks to its use of TVTK).
- Easier to script than Mayavi-1 due to a much cleaner MVC design.
- Easy to extend with added sources, components, modules and data filters.
- Provides an Envisage plugin. This implies that it is:
  - easy to use other Envisage plugins in Mayavi. For example, Mayavi provides an embedded Python shell. This is an Envisage plugin and requires one line of code to include in Mayavi.
  - easy to use Mayavi inside Envisage based applications. Thus, any envisage based application can readily use the mayavi plugin and script it to visualize data.
- wxPython/Qt4 based GUI (thanks entirely to Traits, PyFace and Envisage). It is important to note that there is no wxPython or Qt4 code used directly in the Mayavi source.
- A non-intrusive reusable design. It is possible to use Mayavi without a wxPython or Qt4 based UI.

CHAPTER

TWO

Installation

Up-to-date install instructions are always available at the Mayavi2 web page. The following instructions are likely not up-to-date but should give you a good idea of the general installation procedure and a start on where to look.

2.1 Requirements

Mayavi requires at the very minimum the following packages:

- VTK >= 4.4 (5.x is ideal)
- numpy >= 1.0.1
- setuptools (for installation and egg builds)
- TVTK (*enthought.tvtk*)
- Traits >= 2.0 (*enthought.traits*)

The following requirements are really optional but strongly recommended, especially if you are new to mayavi:

- Envisage == 2.x (*enthought.envisage*)
- wxPython 2.6.x or 2.8.x

One can install the requirements in several ways.

- Win32: Under Win32 the best way to get all the dependencies is to use Enthought's enstaller. This will also let you install mayavi.
- Linux: Most Linux distributions will have installable binaries available for the some of the above. For example, under Debian or Ubuntu you would need `python-vtk`, `python-wxgtk2.6`, `python-setuptools`, `python-numpy`. More information on specific distributions and how you can get the requirements for each of these should be available from the list of distributions here:

  https://svn.enthought.com/enthought/wiki/Install
- Mac OS X: The best available instructions for this platform are available on the IntelMacPython25 page.

There are several ways to install TVTK, Traits and Mayavi. These are described in the following.

2.2 Python packages: Eggs

Mayavi2 is part of the Enthought Tool Suite (ETS). As such, it is distributed as part of ETS and therefore binary packages and source packages of ETS will contain Mayavi2. Mayavi releases are almost always made along with an ETS release. You may choose to install all of ETS or just Mayavi2 alone from a release.

ETS has been organized into several different Python packages. These packages are distributed as Python Eggs. Python eggs are fairly sophisticated and carry information on dependencies with other eggs. As such they are rapidly becoming the standard for distributing Python packages.

There are primarily two ways to use ETS eggs.

1. The first and easiest is to use pre-built eggs built for your particular platform. More instructions on this are below.
2. The second is to build the eggs from the source tarballs. This is also fairly easy to do if you have a proper build environment.

Given this background please see the following:

- Enthought Install describes how ETS can be installed with eggs. Check this page first. It contains information on how to install the prebuilt binary eggs for various platforms along with any dependencies.
- If there aren't any pre-built eggs for your platform, first make sure the requirements are installed, and then build and install the eggs like so:

  ```
  $ easy_install -f http://code.enthought.com/enstaller/eggs/source \
      > enthought.mayavi
  ```

  This one command will download, build and install all the required ETS related modules that mayavi needs for the latest ETS release. If you run into trouble please check the Enthought Install pages. Note that the above is really one line, it has been split with the \ character into two lines in order to fit on the printed version of this document.

2.3 The bleeding edge: SVN

If you want to get the latest development version of Mayavi, we recommend that you check it out from SVN. Mayavi depends on several packages that are part of ETS. It is highly likely that the in-development mayavi version may depend on some feature of an as yet unreleased component. Therefore, it is very convenient to get all the relevant ETS projects that mayavi recursively depends on in one single checkout. In order to do this easily, Dave Peterson has created a package called ETSProjectTools. This must first be installed and then any of ETS related repositories may be checked out. Here is how you can get the latest development sources.

1. Install ETSProjectTools like so:

   ```
   $ svn co https://svn.enthought.com/svn/enthought/ETSProjectTools/trunk \
          ETSProjectTools
   $ cd ETSProjectTools
   $ python setup.py install
   ```

   This will give you several useful scripts like `etsco`, `etsup`, `etsdevelop` etc.

2. To get just the sources for mayavi and all its dependencies do this:

```
$ etsco enthought.mayavi
```

This will look at the latest available mayavi, parse its ETS dependencies and check out the relevant sources. If you want a particular mayavi release you may do:

```
$ etsco "enthought.mayavi==2.0.2"
```

If you'd like to get the sources for an entire ETS release do this for example:

```
$ etsco "ets==2.7.0"
```

This will checkout all the relevant sources from SVN. Be patient, this will take a while. More options for the `etsco` tool are available in the ETSProjectTools page.

3. Once the sources are checked out you may either do an:

```
$ etsdevelop
```

This will install all the checked out sources via a `setup.py develop` applied to each package.

4. Alternatively, you may want to build binary eggs, of the sources. At this time ETSProjectTools does not provide a build script, however you can use the `egg_builder.py` script from here:

```
$ svn cat https://svn.enthought.com/svn/enthought/sandbox/egg_builder.py \
      > egg_builder.py
```

This script can be used to build eggs like so (here we assume that `etsco` checked out the sources into `ets-2.7.0`):

```
$ cd ets-2.7.0
$ python ../egg_builder.py
```

This will build all the eggs and put them inside a `dist` subdirectory. The mayavi development egg and its dependencies may be installed via:

```
$ easy_install -f dist enthought.mayavi
```

Alternatively, if you'd like just `enthought.mayavi` installed via `setup.py develop` with the rest as binary eggs you may do:

```
$ cd enthought.mayavi_x.y.z
$ python setup.py develop -f ../dist
```

This will pull in any dependencies from the built eggs.

You should now have the latest version of Mayavi installed and usable.

2.4 Testing your installation

The easiest way to test if your installation is OK is to run the mayavi2 application like so:

```
mayavi2
```

To get more help on the command try this:

```
mayavi2 -h
```

`mayavi2` is the mayavi application. On some platforms like win32 you will need to double click on the `mayavi2.exe` program found in your `Python2X\Scripts` folder. Make sure this directory is in your path.

Note: Mayavi can be used in a variety of other ways but the `mayavi2` application is the easiest to start with.

If you have the source tarball of mayavi or have checked out the sources from the SVN repository, you can run the examples in `enthought.mayavi*/examples`. There are plenty of example scripts illustrating various features. Tests are available in the `enthought.mayavi*/tests` sub-directory.

CHAPTER

THREE

An overview of Mayavi

All the following sections assume you have a working Mayavi *Installation*.

3.1 Using Mayavi as an application, or a library?

As a user there are three primary ways to use Mayavi:

1. Use the `mayavi2` application completely graphically. More information on this is in the *Using the Mayavi application* section.
2. Use Mayavi as a plotting engine from simple Python scripts. The `mlab` scripting API provides a simple way of using Mayavi in batch-processing scripts, see *Simple Scripting with mlab* for more information on this.
3. Script the Mayavi application from Python. The Mayavi application itself features a powerful and general purpose scripting API that can be used to adapt it to your needs.

    a. **You can script Mayavi while using the `mayavi2` application** in order to automate tasks and extend Mayavi's behavior.
    b. You can script Mayavi from your own Python based application.
    c. **You can embed Mayavi into your application in a variety of** ways either using Envisage or otherwise.

    More details on this are available in the *Advanced Scripting with Mayavi* chapter.

3.2 Scenes and visualization objects

Mayavi uses a pipeline architecture like VTK. As far as a user is concerned this basically boils down to a simple hierarchy.

- The user visualizes data on a *TVTK Scene* – this is an area where the 3D visualization is performed. New scenes may be created by using the *File->New->VTK Scene* menu.
- On each scene the user loads data (either using a file or created from a script). Any number of data files or data objects may be opened; these objects are called **data sources**.
- This data is optionally processed using *Filters* that operate on the data and visualized using visualization *Modules*. The Filters and Modules are accessible via the *Visualize* menu on the UI or may be instantiated as Python objects.

3.3 Loading data into Mayavi

Mayavi is a scientific data visualizer. There are two primary ways to make your data available to it.

1. Use a supported file format like VTK legacy or VTK XML files etc. See VTK file formats for more information on the VTK formats.
2. Generate a TVTK dataset via numpy arrays or any other sequence.

More information on datasets in general and how to create VTK files or create them from numpy arrays is available in the *Creating data for Mayavi* section.

CHAPTER

FOUR

Learning Mayavi by example

To get acquainted with mayavi you may start up `mayavi2` like so:

```
$ mayavi2
```

On Windows you can double click on the installed `mayavi2.exe` executable (usually in the `Python2X\Scripts` directory).

Once mayavi starts, you may resize the various panes of the user interface to get a comfortable layout. These settings will become the default "perspective" of the mayavi application. More details on the UI are available in the *General layout of UI* section.

Before proceeding on the quick tour, it is important to locate some data to experiment with. The mayavi sources ship with several useful data files for the examples and testing. These may be found in the `examples/data` directory inside the root of the mayavi source tree. If these are not installed, the sources may be downloaded from here: http://code.enthought.com/enstaller/eggs/source/

If for some reason the sample data files are not available or there is no Internet access to download them, one can always create some interesting looking surfaces using the *File->Load data->Create Parametric surface source* menu item. This will let us create very pretty looking surfaces without reference to any external data. This is described in the Parametric surfaces example section below.

4.1 Parametric surfaces example

Parametric surfaces are particularly handy if you are unable to find any data to play with right away. Parametric surfaces are surfaces parametrized typically by 2 variables, u and v. VTK has a bunch of classes that let users explore Parametric surfaces. This functionality is also available in Mayavi. The data basically is a 2D surface embedded in 3D. Scalar data is also available on the surface. More details on parametric surfaces in VTK may be obtained from Andrew Maclean's Parametric Surfaces document.

1. After starting mayavi2, create a simple Parametric surface source by selecting *File->Open->Create Parametric Surface source*. Once you create the data, you will see a new node on the Mayavi tree view on the left that says *ParametricSurface*. Note that you **will not** see anything visualized on the TVTK scene yet.

   You can modify the nature of the parametric surface by clicking on the node for the *ParametricSurface* source object.

2. To see an outline (a box) of the data, navigate to the *Visualize->Modules* menu item and select the *Outline* module. You will immediately see a white box on the TVTK scene. You should also see two new nodes on the tree view, one called *Modules* and one underneath that called *Outline*.

3. You can change properties of the outline displayed by clicking on the *Outline* node on the left. This will create an object editor window on left bottom of the window (the object editor tab) below the tree view. Play with the

settings here and look at the results. If you double-click a node on the left it will pop up an editor dialog rather than show it in the embedded object editor.

4. To navigate the scene look at the section on *Interaction with the scene* section for more details. Experiment with these.

5. To view the actual surface create a *Surface* module by selecting *Visualize->Modules->Surface*. You can show contours of the scalar data on this surface by clicking on the *Surface* node on the left and switching on the *Enable contours* check-box.

6. To view the color legend (used to map scalar values to colors), click on the *Modules* node on the tree view and on the object editor activate the *Show scalar bar* check-box. This will show you a legend on the TVTK scene. The legend can be moved around on the scene by clicking on it and dragging it. It can also be resized by clicking and dragging on its edges. You can change the nature of the color-mapping by choosing among different lookup tables on the object editor.

7. You can add as many modules as you like. Not all modules make sense for all data. Mayavi does not yet grey out (or disable) menu items and options if they are invalid for the particular data chosen. This will be implemented in the future. However making a mistake should not in general be disastrous, so go ahead and experiment.

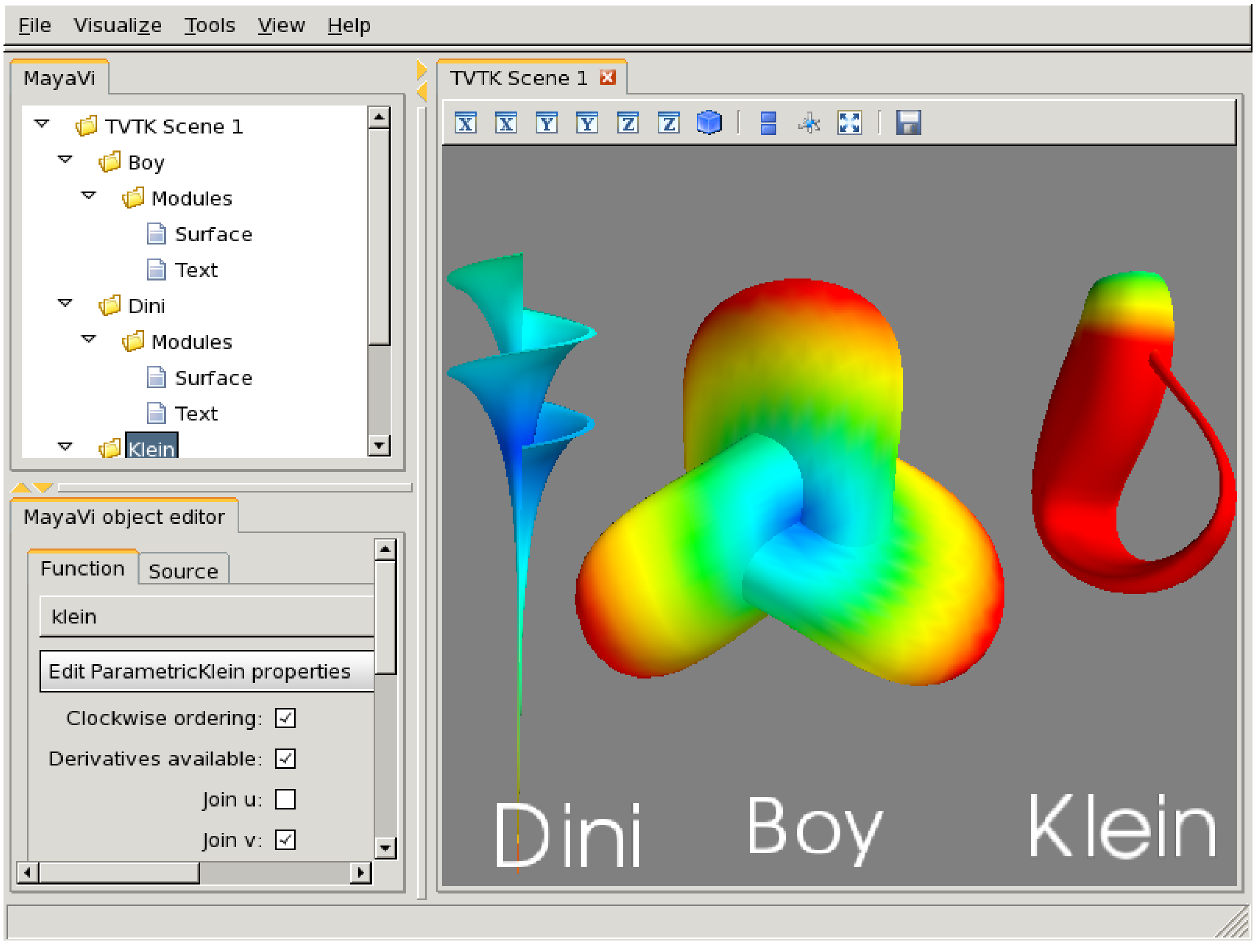
8. You may add as many data sources as you like. It is possible to view two different parametric surfaces on the same scene. Whether this makes sense or not is up to the user. You may also create as many scenes you want to and view anything in those. You can cut/paste/copy sources and modules between any nodes on the tree view using the right click options.

9. To delete the *Outline* module say, right click on the *Outline* node and select the Delete option. You may also want to experiment with the other options.

10. You can save the rendered visualization to a variety of file formats using the *File->Save Scene As* menu.

11. The visualization may itself be saved out to a file via the *File->Save Visualization* menu and reloaded using the *Load visualization* menu.

Shown below is an example visualization made using the parametric source. Note that the positioning of the different surfaces was effected by moving the actors on screen using the actor mode of the scene via the 'a' key. For more details on this see the section on *Interaction with the scene*.



The examples detailed above should provide a good general idea of how to visualize data with Mayavi2 and also an idea of its features and capabilities.

4.2 `heart.vtk` example

This section describes a simple example with the `heart.vtk` file. This is a simple volume of 3D data (32 x 32 x 12 points) with scalars at each point (the points are equally spaced). The data is a structured dataset (an *ImageData* in fact), we'll read more about these later but you can think of it as a cube of points regularly spaced with some scalar data associated with each point. The data apparently represents a CT scan of a heart. I have no idea whose heart! The file is a readable text file, look at it in a text editor if you'd like to.

1. With `mayavi2` started, we start by opening the data file. Go to the *File->Open->VTK File* menu item and then in the file dialog, navigate to the directory that contains the sample data. There select the `heart.vtk` file.

   Once you choose the data, you will see a new node on the Mayavi tree view on the left that says *VTK file (heart.vtk)*. Note that you **will not** see anything visualized on the TVTK scene yet.

2. To see an outline (a box) of the data, navigate to the *Visualize->Modules* menu item and select the *Outline* module. You will immediately see a white box on the TVTK scene. You should also see two new nodes on the tree view, one called *Modules* and one underneath that called *Outline*.

3. You can change properties of the outline displayed by clicking on the *Outline* node on the left. This will create an object editor window on left bottom of the window (the object editor tab) below the tree view. Play with the

settings here and look at the results. If you double-click a node on the tree view it will pop up an editor dialog rather than show it in the embedded object editor.

Note that in general, the editor window for a *Module* will have a section for the *Actor*, one for the *Mapper* and one for *Property*. These refer to TVTK/VTK terminology. You may think of Properties as those related to the color, representation (surface, wireframe, etc.), line size etc. Things grouped under *Actor* are related to the object that is rendered on screen and typically the editor will let you toggle its visibility. In VTK parlance, the word *Mapper* refers to an object that converts the data to graphics primitives. Properties related to it will be grouped under the *Mapper* head.

4. To interact with the TVTK scene window, look at the section on *Interaction with the scene* for more details. Experiment with these options till you are comfortable.

5. Now create an iso-surface by selecting the *Visualize->Modules->IsoSurface* menu item. You will see a new *IsoSurface* node on the left and an iso-contour of the scalar data on the scene. The iso-surface is colored as per the particular iso-value chosen. Experiment with the settings of this module.

6. To produce meaningful visualizations you need to know what each color represents. To display this legend on the scene, click on the *Modules* node on the tree view and on the object editor activate the *Show scalar bar* check-box. This will show you a legend on the TVTK scene. The legend can be moved around on the scene by clicking on it and dragging on it. It can also be resized by clicking and dragging on its edges. You can change the nature of the color-mapping by choosing various options on the object editor.

7. Create a simple "grid plane" to obtain an idea of the actual points on the grid. This can be done using the *GridPlane* module, and created via the *Visualize->Modules->GridPlane* menu item.

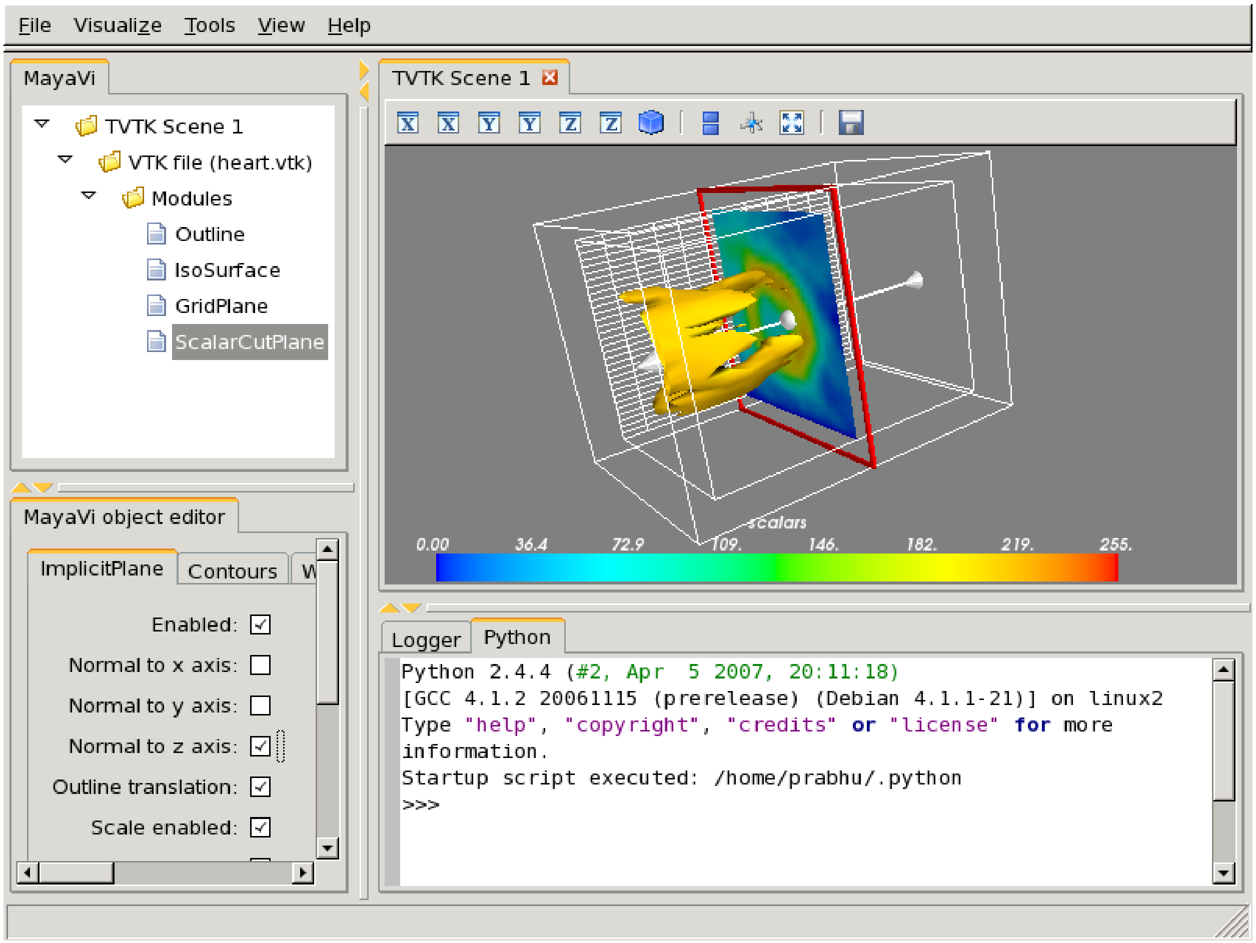
8. You can delete a particular module by right clicking on it and choosing delete. Try this on the *GridPlane* module. Try the other right click menu options as well.

9. Experiment with the *ContourGridPlane* module and also the *ScalarCutPlane* module a little.

   The *ScalarCutPlane* module features a very powerful feature called *3D widgets*. On the TVTK scene window you will see a cut plane that slices through your data showing you colors representing your data. This cut plane will have a red outline and an arrow sticking out of it. You can click directly on the cut plane and move it by dragging it. Click on the arrow head to rotate the plane. You can also reset its position by using the editor window for the scalar cut plane.

10. You can save the visualization to an image produced by clicking on the little save icon on the TVTK scene or via any of the options on the *File->Save Scene As* menu.

You should have a visualization that looks something like the one shown below.



The nice thing about mayavi is that although in this case all of the above was done using the user interface, all of it can be done using pure Python scripts as well. More details on this are available in the *Advanced Scripting with Mayavi* section.

Opening data files and starting up modules can also be done from the command line. For example we could simply have done:

```
$ mayavi2 -d /path/to/heart.vtk -m Outline -m IsoSurface \
> -m GridPlane -m ScalarCutPlane
```

More details are available in the *Command line arguments* section.

4.3 `fire_ug.vtu` example

Like `heart.vtk`, the `fire_ug.vtu` example dataset is available in the `examples/data` directory. This dataset is an unstructured grid stored in a VTK XML file. It represents a room with a fire in one corner. A simulation of the fluid flow generated by this fire was performed and the resulting data at a particular instant of time is stored in the file. The dataset was provided by Dr. Philip Rubini, who at the time was at Cranfield University. A VRML file (`room_vis.wrl`) is also provided to show the context of the room in which the fire is taking place.

1. With mayavi2 started, select *File->Open->VTK XML file* to load the data. Again, you will see a node on the tree view on the left but nothing on the TVTK scene. This dataset contains different scalars and vectors in the same data file. If you select the *VTK XML file ...* node on the left the reader may be configured in the object

editor pane of the UI. On this, you will see a drop list of all the scalars, vectors etc. in this data file. Select any that you wish to view.

2. Create an outline of the data as described earlier using an *Outline* module. View an iso-surface of the data by creating an *IsoSurface* module. Also experiment with the *ScalarCutPlane* module.

3. Show the scalar bar that represents the color mapping (via a Look up table that maps scalar values to colors) by clicking on the *Modules* and enabling the *Show scalar bar*. Experiment with the different color maps provided by default.

4. Now click on the *VTK XML file ...* and select different scalar values to see how the data has changed. Your legend should automatically update when the scalar value is changed.

5. This data also features vectors. The scalar data has *u*, *v* and *w* but not the magnitude of the velocity. Lets say we'd like to be able to view iso-contours of the magnitude of the velocity. To do this lets use the *ExtractVectorNorm* filter. This is created by choosing the *Visualize->Filters->Extract Vector Norm* menu.

6. If you now create a *ScalarCutPlane*, you will see a new *Modules* node under the *ExtractVectorNorm* node. This scalar cut plane is displaying colors for the velocity magnitude that the filter has created. You can drag the iso-surface module from the other *Modules* node and drop it on this *Modules* node so that the IsoSurface generated is for the velocity magnitude and not for the scalars chosen in the data.

   Note that the view on the left represents a pipeline of the flow of the data from *source -> filter -> modules*. Essentially the data flows from the parent node down to the children nodes below it.

   Now if you want to visualize something on a different "branch" of the pipeline, lets say you want to view iso-surfaces of the temperature data you must first click on the modules or the source object (the *VTK XML File ...* node) itself and then select the menu item. When you select an item on the tree, it makes that item the *current object* and menu selections made after that will in general create new modules/filters below the current object.

7. You can filter "filtered data". So select the *ExtractVectorNorm* node to make it the active object. Now create a Threshold filter by selecting *Visualize->Filters->Threshold*. Now set the upper and lower thresholds on the object editor for the Threshold to something like 0.5 and 3.0. If you create a *VectorCutPlane* module at this point and move the cut plane you should see arrows but only arrows that are between the threshold values you have selected. Thus, you can create pretty complicated visualization pipelines using this approach.

8. There are several vector modules. *VectorCutPlane*, *Vectors*, *WarpVectorCutPlane* and *Streamlines*. If you view streamlines then mayavi will generate streamlines of vector data in your dataset. To view streamlines of the original dataset you can click on the original *Outline* module (or the source) and then choose the *Streamline* menu item. The streamline lets you move different type of seeds on screen using 3D widgets. Seed points originating from these positions are used to trace out the streamlines. Sphere, line and plane sources may be used here to initialize the streamline seeds.

9. You can view the room in which the fire is taking place by opening the VRML file by the *File->Open->VRML2 file* menu item and selecting the `room_vis.wrl` file included with the data.

10. Once you setup a complex visualization pipeline and want to save it for later experimentation you may save the entire visualization via the *File->Save Visualization* menu. A saved file can be loaded later using the *File->Load Visualization* menu item. This option is not 100% robust and is still experimental. Future versions will improve this feature. However, it does work and can be used for the time being.

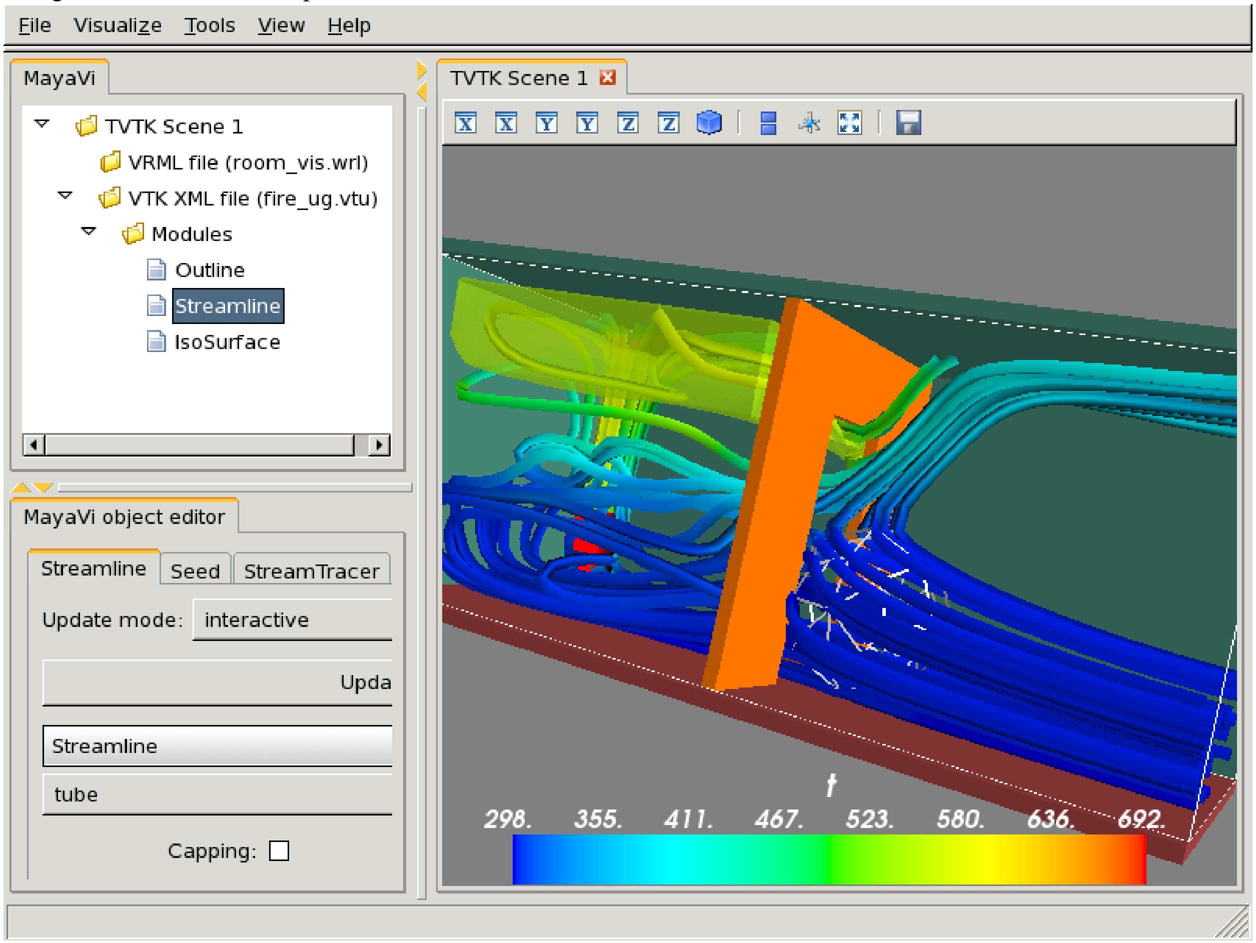
Once again, the visualization in this case was created by using the user interface. It is possible to script this entirely using Python scripts. A simple script demonstrating several of the above modules is available in `examples/streamline.py`. This file may be studied. It can be run either like so:

```
$ cd examples
$ python streamline.py
```

or so:

```
$ mayavi2 -x streamline.py
```

As can be seen from the example, it is quite easy to script mayavi to visualize data. An image of a resulting visualization generated from this script is shown below.



Using the Mayavi application

This chapter primarily concerns using the `mayavi2` application. Some of the things mentioned here also apply when mayavi is scripted. We recommend that new users read this chapter before going to the more advanced ones.

5.1 General layout of UI

When the *mayavi2* application is started it will provide a user interface that looks something like the figure shown below.

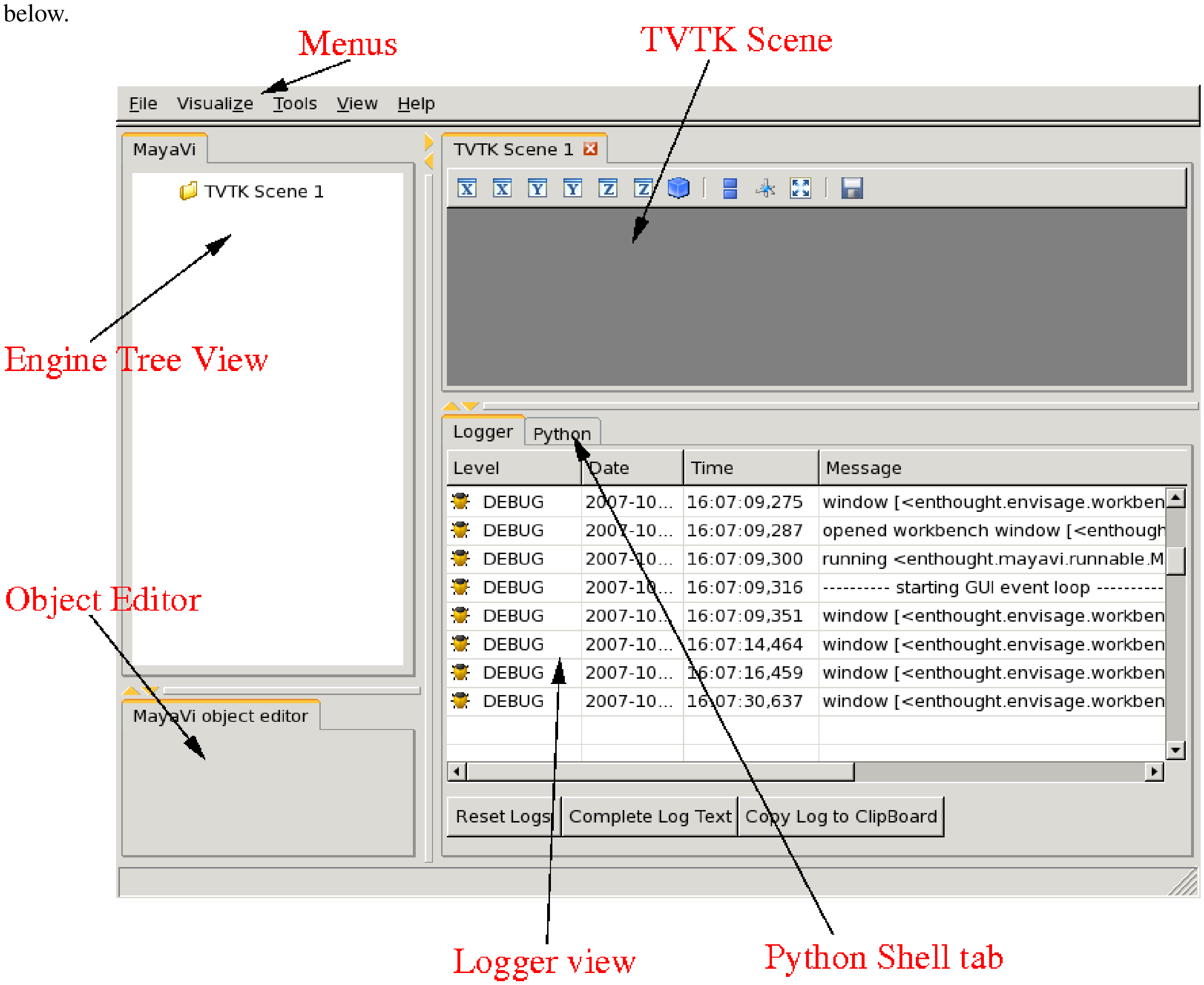


Figure of Mayavi's initial UI window.

The UI features several sections described below.

Menus The menus let you open files, load modules, set preferences etc.

The Mayavi engine tree view **This is a tree view of the mayavi pipeline.**
- Right click a tree node to rename, delete, copy the objects.
- Left click on a node to edit its properties on the object editor below the tree.
- It is possible to drag the nodes around on the tree. For example it is possible to drag and move a module from one set of Modules to another, or to move a visualization from one scene to another.

The object editor This is where the properties of mayavi pipeline objects can be changed when an object on the engine's pipeline is clicked.

TVTK scenes This is where the visualization of the data happens. One can interact with this scene via the mouse and the keyboard. More details are in the following sections.

Python interpreter The built-in Python interpreter that can be used to script mayavi and do other things. You can drag nodes from the mayavi tree and drop them on the interpreter and then script the object represented by the node!

Logger Application log messages may be seen here.

Mayavi's UI layout is highly configurable:

- the line in-between the sections can be dragged to resize particular views.
- most of the "tabs" on the widgets can be dragged around to move them anywhere in the application.
- Each view area (the mayavi engine view, object editor, python shell and logger) can all be disabled and enabled at will using the *View* menu by toggling the views on and off.

Each time you change the appearance of mayavi it is saved and the next time you start up the application it will have the same configuration. In addition, you can save different layouts into different "perspectives" using the *View->Perspectives* menu item.

Shown below is a specifically configured mayavi user interface view. In this view the size of the various parts are changed. The Python shell is activated by default.

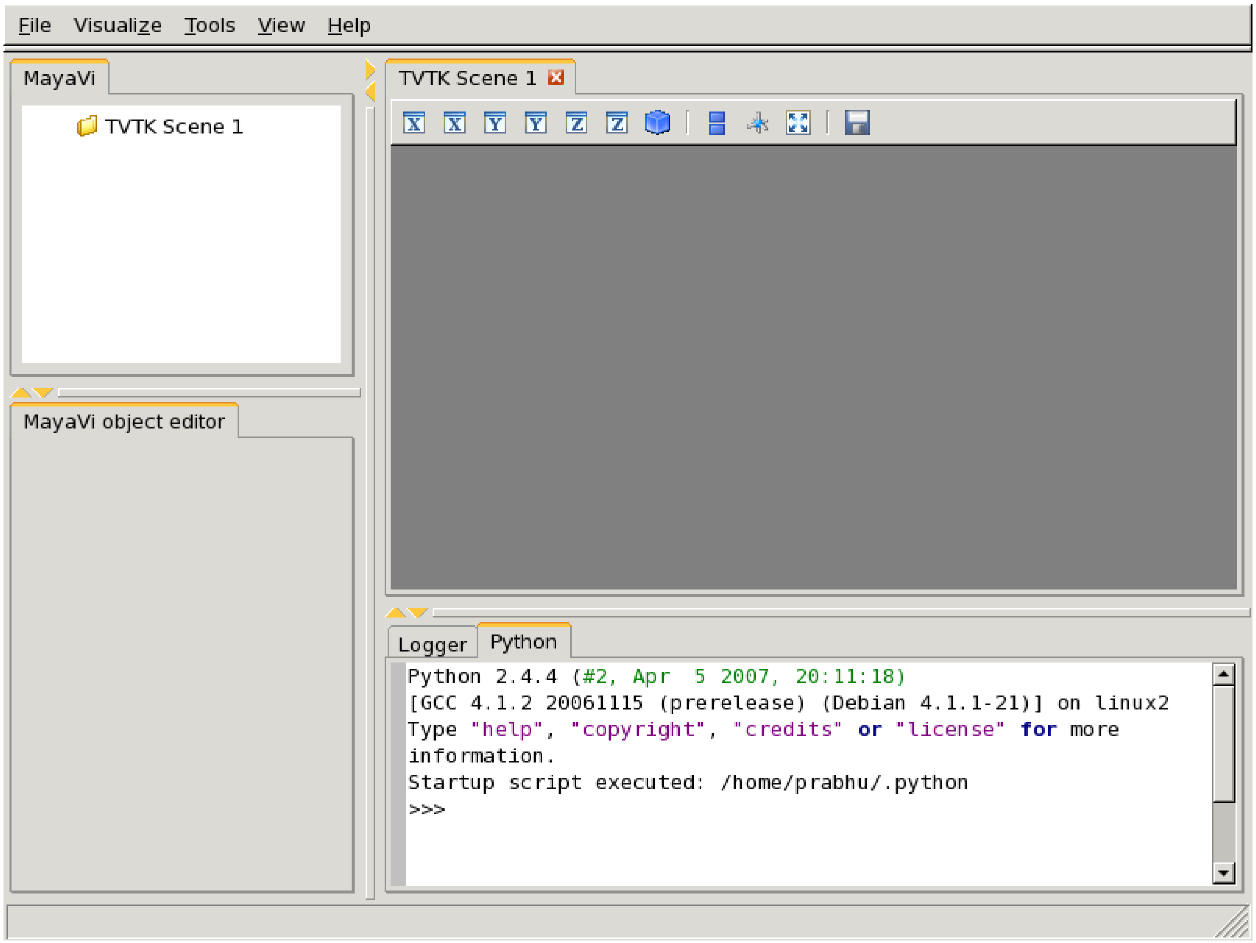


Figure of Mayavi's UI after being configured by a user.

5.2 Visualizing data

Mayavi modules can be used to visualize the data as described in the *An overview of Mayavi* section and the *Learning Mayavi by example* section. One needs to have some data or the other loaded before a *Module* or *Filter* may be used. Mayavi supports several data file formats most notably VTK data file formats. More information on this is available here in the *Creating data for Mayavi* section.

Once data is loaded one can optionally use a variety of Filters to filter or modify the data in some way or the other and then visualize the data using several Modules.

5.2.1 Modules

Modules are the objects that perform the visualization itself: they use data to create the visual elements on the scene.

Here is a list of the Mayavi modules along with a brief description.

Axes Draws simple axes.

ContourGridPlane A contour grid plane module. This module lets one take a slice of input grid data and view contours of the data.

CustomGridPlane A custom grid plane with a lot more flexibility than GridPlane module.

Glyph Displays different types of glyphs oriented and colored as per scalar or vector data at the input points.

GridPlane A simple grid plane module.

HyperStreamline A module that integrates through a tensor field to generate a hyperstreamline. The integration is along the maximum eigenvector and the cross section of the hyperstreamline is defined by the two other eigenvectors. Thus the shape of the hyperstreamline is "tube-like", with the cross section being elliptical. Hyperstreamlines are used to visualize tensor fields.

ImageActor A simple module to view image data efficiently.

ImagePlaneWidget A simple module to view image data.

IsoSurface A module that allows the user to make contours of input point data.

Labels Allows a user to label the current dataset or the current actor of the active module.

OrientationAxes Creates a small axes on the side that indicates the position of the co-ordinate axes and thereby marks the orientation of the scene. Requires VTK-4.5 and above.

Outline A module that draws an outline for the given data.

ScalarCutPlane Takes a cut plane of any input data set using an implicit plane and plots the data with optional contouring and scalar warping.

SliceUnstructuredGrid This module takes a slice of the unstructured grid data and shows the cells that intersect or touch the slice.

Streamline Allows the user to draw streamlines for given vector data. This supports various types of seed objects (line, sphere, plane and point seeds). It also allows the user to draw ribbons or tubes and further supports different types of interactive modes of calculating the streamlines.

StructuredGridOutline Draws a grid-conforming outline for structured grids.

Surface Draws a surface for any input dataset with optional contouring.

TensorGlyph Displays tensor glyphs oriented and colored as per scalar or vector data at the input points.

Text This module allows the user to place text on the screen.

VectorCutPlane Takes an arbitrary slice of the input data using an implicit cut plane and places glyphs according to the vector field data. The glyphs may be colored using either the vector magnitude or the scalar attributes.

Vectors Displays different types of glyphs oriented and colored as per vector data at the input points. This is merely a convenience module that is entirely based on the Glyph module.

Volume The Volume module visualizes scalar fields using volumetric visualization techniques.

WarpVectorCutPlane Takes an arbitrary slice of the input data using an implicit cut plane and warps it according to the vector field data. The scalars are displayed on the warped surface as colors.

5.2.2 Filters

Filters transform the data, but do not display it. They are used as an intermediate between the data sources and the modules.

Here is a list of the Mayavi Filters.

CellDerivatives Computes derivatives from input point scalar and vector data and produces cell data on the gradients. Can be used to approximately calcuate the vorticity for example.

CellToPointData Transforms cell attribute data to point data by averaging the cell data from the cells at the point.

Contour A contour filter that wraps around the Contour component to generate iso-surfaces on any input dataset.

CutPlane This class represents a cut plane that can be used to slice through any dataset. It also provides a 3D widget interface to position and move the slice interactively.

DecimatePro Reduces the number of triangles in a triangular mesh by approximating the original mesh.

Delaunay2D Performs a 2D Delaunay triangulation.

Delaunay3D Performs a 3D Delaunay triangulation.

ElevationFilter Creates scalar data corresponding to the elevation of the points along a line.

ExtractEdges This filter extracts cell edges from any input data.

ExtractGrid Allows a user to select a part of a structured grid.

ExtractTensorComponents Wraps the TVTK `ExtractTensorComponents` filter to extract components from a tensor field.

ExtractUnstructuredGrid Allows a user to select a part of an unstructured grid.

ExtractVectorNorm Computes the norm (Euclidean) of the input vector data (with optional scaling between [0, 1]). This is useful when the input data has vector input but no scalar data for the magnitude of the vectors.

ExtractVectorComponents Wraps the TVTK ExtractVectorComponents filter to extract components of a vector. This is useful for analysing individual components of a vector data.

GaussianSplatter This filter splat points into a volume with an elliptical, Gaussian distribution.

GreedyTerrainDecimation Approximates a height field (image data) with a triangle mesh, keeping the number of triangles minimum.

ImageDataProbe A filter that can be used to probe any dataset using a Structured Points dataset. The filter also allows one to convert the scalar data to an unsigned short array so that the scalars can be used for volume visualization.

MaskPoints Selectively passes the input points downstream. This can be used to subsample the input points. Note that this does not pass geometry data, this means all grid information is lost.

PointToCellData Does the inverse of the CellToPointData filter.

PolyDataNormals Computes normals from input data. This gives meshes a smoother appearance. This should work for any input dataset. Note: this filter is called "Compute Normals" in Mayavi2 GUI (Visualize/Filters/Compute Normals).

QuadricDecimation Reduce triangles in a mesh, forming a good approximation of the original mesh.

SelectOutput A filter that allows a user to select one among several of the outputs of a given input. This is typically very useful for a multi-block data source.

SetActiveAttribute This filter lets a user set the active data attribute (scalars, vectors and tensors) on a VTK dataset. This is particularly useful if you need to do something like compute contours of one scalar on the contour of another scalar.

Threshold A simple filter that thresholds on input data.

TransformData Performs a linear transformation to input data.

Tube Turns lines into tubes.

UserDefined This filter lets the user define their own filter dynamically/interactively. It is like *FilterBase* but allows a user to specify the class without writing any code.

Vorticity This filter computes the vorticity of an input vector field. For convenience, the filter allows one to optionally pass-through the given input vector field. The filter also allows the user to show the component of the vorticity along a particular cartesian co-ordinate axes. It produces point data on output which is ready to visualize.

WarpScalar Warps the input data along a particular direction (either the normals or a specified direction) with a scale specified by the local scalar value. Useful for making carpet plots.

WarpVector Warps the input data along a the point vector attribute scaled as per a scale factor. Useful for showing flow profiles or displacements.

5.3 Interaction with the scene

The TVTK scenes on the UI can be closed by clicking on the little 'x' icon on the tab. Each scene features a toolbar that supports various features:

- Buttons to set the view to view along the positive or negative X, Y and Z axes or obtain an isometric view.
- A button to turn on parallel projection instead of the default perspective projection. This is particularly useful when one is looking at 2D plots.
- A button to turn on an axes to indicate the x, y and z axes.
- A button to turn on full-screen viewing. Note that once full-screen mode is entered one must press 'q' or 'e' to get back a normal window.
- A button to save the scene to a variety of image formats. The image format to use is determined by the extension provided for the file.
- A button that provides a UI to configure the scene properties.

The primary means to interact with the scene is to use the mouse and keyboard.

5.3.1 Mouse interaction

There are two modes of mouse interaction:

- Camera mode: the default, where the camera is operated on with mouse moves. This mode is activated by pressing the 'c' key.
- Actor mode: in this mode the mouse actions operate on the actor the mouse is currently above. This mode is activated by pressing the 'a' key.

The view on the scene can be changed by using various mouse actions. Usually these are accomplished by holding down a mouse button and dragging.

- holding the left mouse button down and dragging will rotate the camera/actor in the direction moved.
  - Holding down "SHIFT" when doing this will pan the scene – just like the middle button.
  - Holding down "CONTROL" will rotate about the camera's focal point.
  - Holding down "SHIFT" and "CONTROL" and dragging up will zoom in and dragging down will zoom out. This is like the right button.
- holding the right mouse button down and dragging upwards will zoom in (or increase the actors scale) and dragging downwards will zoom out (or reduce scale).
- holding the middle mouse button down and dragging will pan the scene or translate the object.
- Rotating the mouse wheel upwards will zoom in and downwards will zoom out.

5.3.2 Keyboard interaction

The scene supports several features activated via keystrokes. These are:

- '3': Turn on/off stereo rendering. This may not work if the 'stereo' preference item is not set to True.
- 'a': Use actor mode for mouse interaction instead of camera mode.
- 'c': Use camera mode for mouse interaction instead of actor mode.
- 'e'/'q'/'Esc': Exit full-screen mode.
- 'f': Move camera's focal point to current mouse location. This will move the camera focus to center the view at the current mouse position.
- 'j': Use joystick mode for the mouse interaction. In joystick mode the mouse somewhat mimics a joystick. For example, holding the mouse left button down when away from the center will rotate the scene.
- 'l': Configure the lights that are illumining the scene. This will pop-up a window to change the light configuration.
- 'p': Pick the data at the current mouse point. This will pop-up a window with information on the current pick. The UI will also allow one to change the behavior of the picker to pick cells, points or arbitrary points.
- 'r': Reset the camera focal point and position. This is very handy.
- 's': Save the scene to an image, this will first popup a file selection dialog box so you can choose the filename, the extension of the filename determines the image type.
- 't': Use trackball mode for the mouse interaction. This is the default mode for the mouse interaction.
- '='/'+': Zoom in.
- '-': Zoom out.
- 'left'/'right'/'up'/'down' arrows: Pressing the left, right, up and down arrow let you rotate the camera in those directions. When "SHIFT" modifier is also held down the camera is panned.

5.4 The embedded Python interpreter

The embedded Python interpreter offers extremely powerful possibilities. The interpreter features command completion, automatic documentation, tooltips and some multi-line editing. In addition it supports the following features:

- The name `mayavi` is automatically bound to the `enthought.mayavi.script.Script` instance. This may be used to easily script mayavi.
- The name `application` is bound to the envisage application.
- If a Python file is opened via the `File->Open File...` menu item one can edit it with a color syntax capable editor. To execute this script in the embedded Python interpreter, the user may type `Control-r` on the editor window. To save the file press `Control-s`. This is a very handy feature when developing simple mayavi scripts.
- As mentioned earlier, one may drag and drop nodes from the Mayavi engine tree view onto the Python shell. The object may then be scripted as one normally would. A commonly used pattern when this is done is the following:

```
>>> tvtk_scene_1
<enthought.mayavi.core.scene.Scene object at 0x9f4cbe3c>
>>> s = _
```

In this case the name `s` is bound to the dropped tvtk_scene object. The _ variable stores the last evaluated expression which is the dropped object. Using `tvtk_scene_1` will also work but is a mouthful.

5.5 Command line arguments

The `mayavi2` application features several useful command line arguments that are described in the following section. These options are described in the `mayavi2` man page as well.

Mayavi can be run like so:

```
mayavi2 [options] [args]
```

Where `arg1`, `arg2` etc. are optional file names that correspond to saved Mayavi2 visualizations (`filename.mv2`), Mayavi2 scripts (`filename.py`) or any datafile supported by Mayavi. If no options or arguments are provided mayavi will start up with a default blank scene.

The options are:

-h
This prints all the available command line options and exits. Also available through –help.

-V
This prints the Mayavi version on the command line and exits. Also available through –version.

-z file_name
This loads a previously saved Mayavi2 visualization. Also available through –viz file_name or –visualization file_name.

-d data_file
Opens any of the supported data file formats. This includes VTK file formats (.vtk, *.xml, *.vt[i,p,r,s,u], *.pvt[i,p,r,s,u]), VRML2 (.wrl), 3D Studio (.3ds), PLOT3D (.xyz) and various others that are supported. Also available through –data.

-m module-name
A module is an object that actually visualizes the data. The given `module-name` is loaded in the current `ModuleManager`. The module name must be a valid one if not you will get an error message.

If a module is specified as `package.sub.module.SomeModule` then the module (`SomeModule`) is imported from `package.sub.module`. Standard modules provided with `mayavi2` do not need the full path specification. For example:

```
mayavi2 -d data.vtk -m Outline -m user_modules.AModule
```

In this example `Outline` is a standard module and `user_modules.AModule` is some user defined module. Also available through –module.

-f filter-name
A filter is an object that filters out the data in some way or the other. The given `filter-name` is loaded with respect to the current source/filter object. The filter name must be a valid one if not you will get an error message.

If the filter is specified as `package.sub.filter.SomeFilter` then the filter (`SomeFilter`) is imported from `package.sub.filter`. Standard modules provided with `mayavi2` do not need the full path specification. For example:

```
mayavi2 -d data.vtk -f ExtractVectorNorm -f user_filters.AFilter
```

In this example `ExtractVectorNorm` is a standard filter and `user_filters.AFilter` is some user defined filter. Also available through –filter.

-M Starts up a new module manager on the Mayavi pipeline. Also available through –module-mgr.

-n **Creates a new window/scene. Any options passed after this will** apply to this newly created scene. Also available through –new-window.

-o –offscreen

Run Mayavi in offscreen mode without any graphical user interface. This is most useful for scripts that need to render images offscreen (for an animation say) in the background without an intrusive user interface popping up. Mayavi scripts (run via the -x argument) should typically work fine in this mode.

-x script-file This executes the given script in a namespace where we guarantee that the name 'mayavi' is Mayavi's script instance – just like in the embedded Python interpreter. Also available through –exec.

Warning: Note that `-x` or `-exec` uses *execfile*, so this can be dangerous if the script does something nasty!

It is important to note that mayavi's **command line arguments are processed sequentially** in the same order they are given. This allows users to do interesting things.

Here are a few examples of the command line arguments:

```
$ mayavi2 -d heart.vtk -m Axes -m Outline -m GridPlane \
> -m ContourGridPlane -m IsoSurface

$ mayavi2 -d fire_ug.vtu -m Axes -m Outline -m VectorCutPlane \
> -f MaskPoints -m Glyph
```

In the above examples, `heart.vtk` and `fire_ug.vtu` VTK files can be found in the `examples/data` directory in the source. They may also be installed on your computer depending on your particular platform.

CHAPTER

SIX

Simple Scripting with mlab

The enthought.mayavi.mlab module, that we call mlab, provides an easy way to visulize data in a script or from an interactive prompt with one-liners as done in the matplotlib pylab interface but with an emphasis on 3D visualization using Mayavi2. This allows users to perform quick 3D visualization while being able to use Mayavi's powerful features.

Mayavi's mlab is designed to be used in a manner well suited to scripting and does not present a fully object-oriented API. It is can be used interactively with IPython.

Important: IPython must be invoked with the -wthread command line option like so:

```
$ ipython -wthread
```

If you are using the Enthought Python Distribution, or the latest Python(x,y) distribution, the Pylab menu entry will start ipython with the right switch. In older release of Python(x,y) you need to start "Interactive Console (wxPython)".

For more details on using mlab and running scripts, read the section running Mlab scripts

6.1 A demo

Once started, here is a pretty example showing a spherical harmonic:

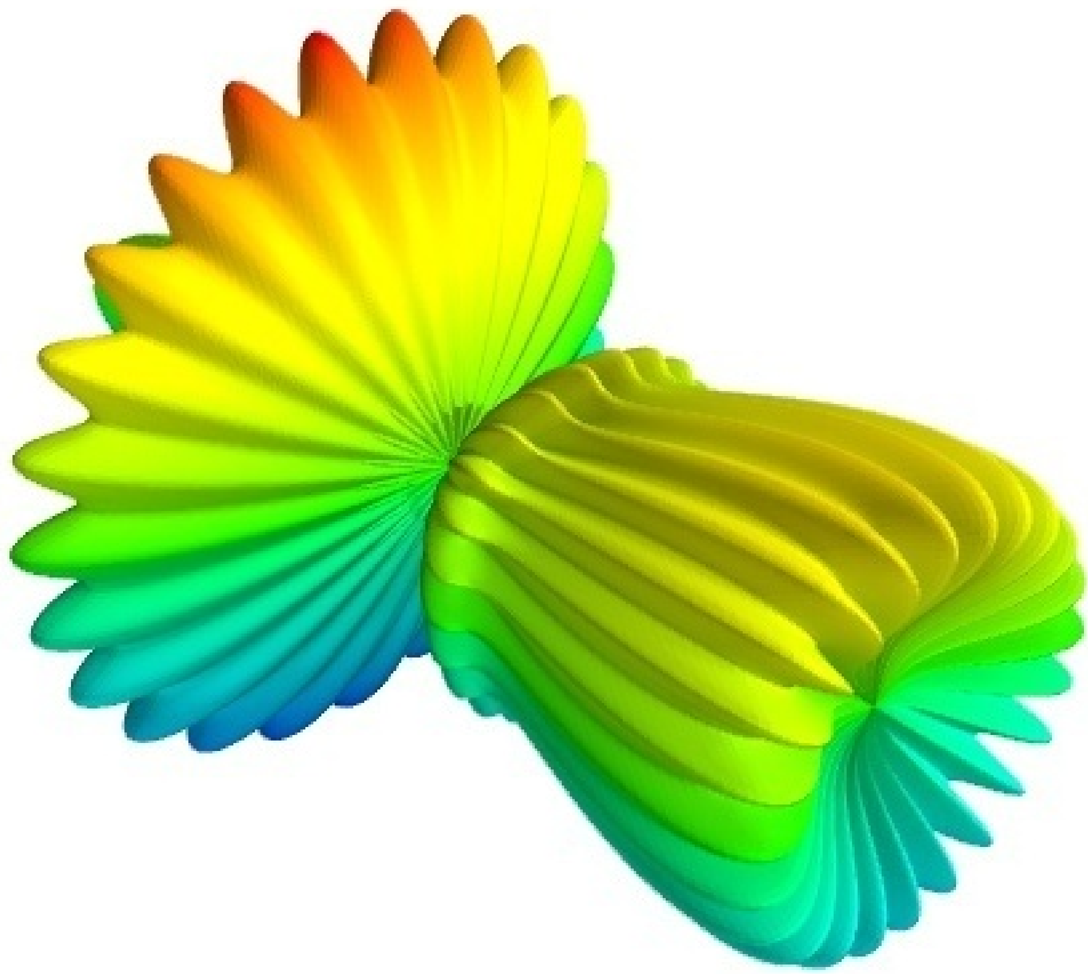
```
from numpy import *
from enthought.mayavi import mlab

# Create the data.
dphi, dtheta = pi/250.0, pi/250.0
[phi,theta] = mgrid[0:pi+dphi*1.5:dphi,0:2*pi+dtheta*1.5:dtheta]
m0 = 4; m1 = 3; m2 = 2; m3 = 3; m4 = 6; m5 = 2; m6 = 6; m7 = 4;
r = sin(m0*phi)**m1 + cos(m2*phi)**m3 + sin(m4*theta)**m5 + cos(m6*theta)**m7
x = r*sin(phi)*cos(theta)
y = r*cos(phi)
z = r*sin(phi)*sin(theta)

# View it.
s = mlab.mesh(x, y, z)

mlab.show()
```

Bulk of the code in the above example is to create the data. One line suffices to visualize it. This produces the following visualization:



The visualization is created by the single command `mesh` in the above.

6.2 Plotting functions

Visualization can be created in mlab by a set of functions operating on numpy arrays. In this section, we only list the different functions. They are described in details in the `mlab` reference, at the end of the user guide.

The mlab plotting functions take numpy arrays as input, describing the `x`, `y`, and `z` coordinates of the data. They build full-blown visualizations: they create the data source, filters if necessary, and add the visualization modules. Their behavior, and thus the visualization created, can be fine-tuned through keyword arguments, similarly to pylab. In addition, they all return the visualization module created, thus visualization can also be modified by changing the attributes of this module.

6.2.1 0D and 1D data

The `plot3d()` and `points3d()` functions are respectively used to draw lines, and sets of points, specifying the `x`, `y` and `z` coordinates as numpy arrays.

6.2.2 2D data

A 2D array can be shown as a image using `imshow()`, or as a surface with the elevation given by its values using `surf()`. The contours (lines) of same values can be plotted using `contour_surf()`.

The `mesh()` function also creates surfaces, however, unlike `surf()`, the surface is defined by its `x`, `y` and `z` coordinates, and more complex surfaces can be created, as in the above example.

6.2.3 3D data

To plot isosurfaces of a 3D scalar field use `contour3d()`. A vector field can be represented using `quiver3d()`, and the trajectories of particles along this field can plotted using `flow()`.

6.3 Handling figures

All mlab functions operate on the current scene, that we also call `figure()`, for compatibility with matlab and pylab. The different figures are indexed by key that can be an integer or a string. A call to the `figure()` function giving a key will either return the corresponding figure, if it exists, or create a new one. The current figure can be retrieved with the `gcf()` function. It can be refreshed using the `draw()` function, saved to a picture file using `savefig()` and cleared using `clf()`.

6.4 Figure decorations

Axes can be added around a visualization object with the `axes()` function, and the labels can be set using the `xlabel()`, `ylabel()` and `zlabel()` functions. Similarly, `outline()` creates an outline around an object. `title()` adds a title to the figure.

Color bars can be used to reflect the color maps used to display values (LUT, or lookup tables, in VTK parlance). `colorbar()` creates a color bar for the last object created, trying to guess whether to use the vector data or the scalar data color maps. The `scalarbar()` and `vectorbar()` function scan be used to create color bars specifically for scalar or vector data.

A small *xyz* triad can be added to the figure using `orientationaxes()`.

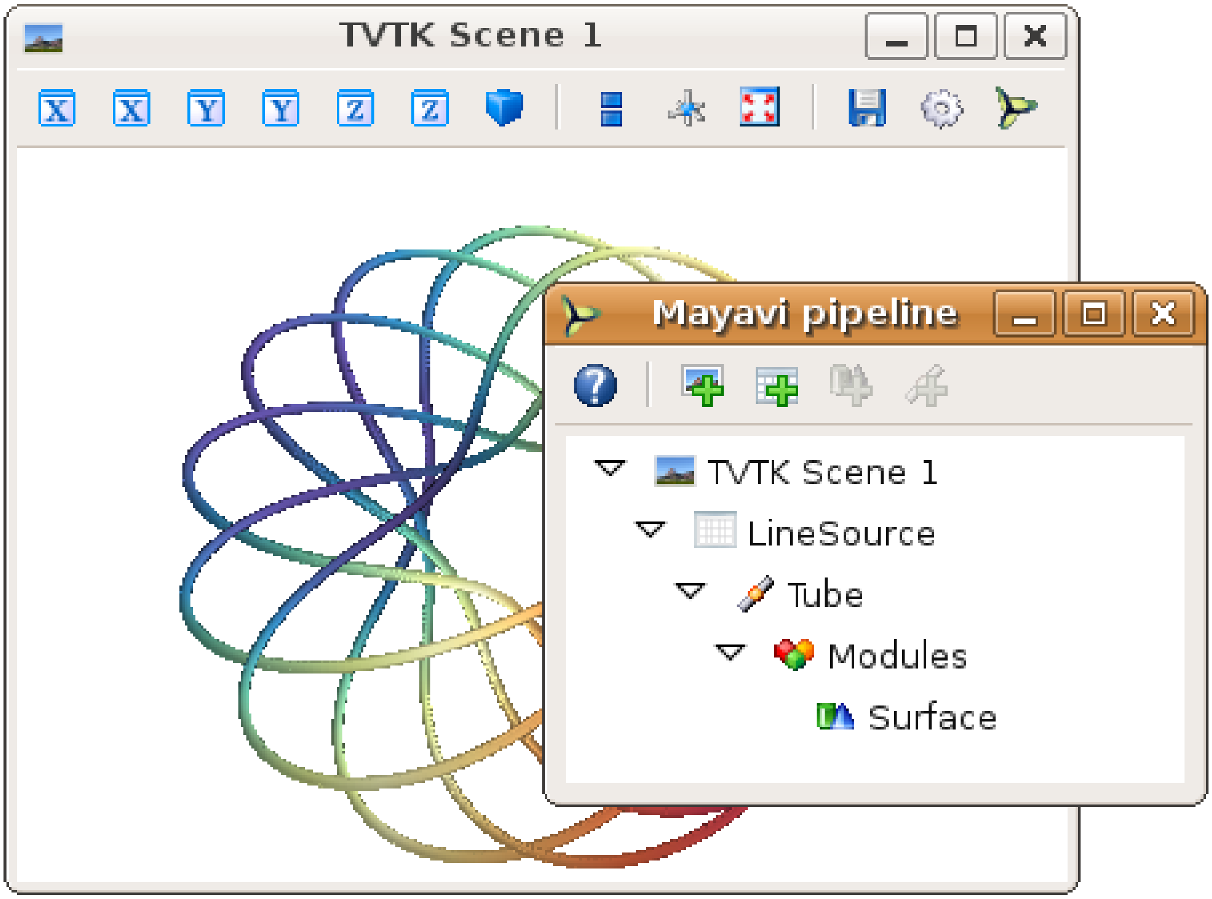
6.5 Moving the camera

The position and direction of the camera can be set using the `view()` function. They are described in terms of Euler angles and distance to a focal point. The `view()` function tries to guess the right roll angle of the camera for a pleasing view, but it sometimes fails. The `roll()` explicitly sets the roll angle of the camera.

6.6 Interacting graphically with the visualization

Mayavi, and thus mlab, allow you to interactively modify your visualization.

The Mayavi pipeline tree can be displayed by clicking on the mayavi icon in the figure's toolbar, or by using `show_pipeline()` mlab command. One can now change the visualization using this dialog by double-clicking on each object to edit its properties, as described in other parts of this manual, or add new modules or filters by using this icons on the pipeline, or through the right-click menus on the objects in the pipeline.



In addition, for every object returned by a mlab function, `this_object.edit_traits()` brings up a dialog that can be used to interactively edit the object's properties. If the dialog doesn't show up when you enter this command, please see the next paragraph.

6.7 Running mlab scripts

Mlab, like the rest of Mayavi, is an interactive application. To interact with the figures or the rest of the drawing elements, you need to use the `show()` function. For instance, if you are writing a script, you need to call `show()` each time you want to display one or more figures and allow the user to interact with them.

6.7.1 Using mlab interactively

Alternatively, using IPython mlab instructions can be run interactively, or in scripts using IPython's `%run` command, as soon as they are executed, alleviating the need to use the `show()` function.

Mlab can also be used interactively in the Python shell of the mayavi2 application, or in any interactive Python shell of wxPython-based application (such as other Envisage-based applications, or Stani's Python editor).

6.7.2 In scripts

Mlab commands can be written to a file, to form a script. This script can be loaded in the Mayavi application using the *File->Open file* menu entry, and executed using the *File->Refresh code* menu entry or by pressing `Control-r`.

It can also be executed during the start of the Mayavi application using the `-x` command line switch.

As already mentioned, you can call the `show()` function to pause your script and have the user interact with the figure. You can also use `show()` to decorate a function, and have it run in the event-loop, which give you more flexibility:

```
from enthought.mayavi import mlab
from numpy import random

@mlab.show
def image():
   mlab.imshow(random.random((10, 10)))
```

CHAPTER

SEVEN

Advanced Scripting with Mayavi

As elaborated in the *An overview of Mayavi* section, mayavi can be scripted from Python in order to visualize data. Mayavi2 was designed from the ground up to be highly scriptable. Everything that can be done from the user interface can be achieved using Python scripts.

If you are not looking to script mayavi itself but looking for quick ways to get your visualization done with simple code you may want to check out mayavi's mlab module. This is described in more detail in the *Simple Scripting with mlab* section.

To best understand how to script mayavi, a reasonable understanding of the mayavi internals is necessary. The following sections provides an overview of the basic design and objects in the mayavi pipeline. Subsequent sections consider specific example scripts that are included with the mayavi sources that illustrate the ideas.

Mayavi2 uses Traits and TVTK internally. Traits in many ways changes the way we program. So it is important to have a good idea of Traits in order to understand mayavi's internals. If you are unsure of traits it is a good idea to get a general idea about traits now. Trust me, your efforts learning Traits will not be wasted!

7.1 Design Overview

This section provides a brief introduction to mayavi's internal architecture.

The "big picture" of a visualization in mayavi is that an `Engine` (`enthought.mayavi.engine.Engine`) object manages the entire visualization. The `Engine` manages a collection of `Scene` (`enthought.mayavi.core.scene.Scene`) objects. In each `Scene`, a user may have created any number of `Source` (`enthought.mayavi.core.source.Source`) objects. A `Source` object can further contain any number of `Filters` (`enthought.mayavi.core.filter.Filter`) or `ModuleManager` (`enthought.mayavi.core.module_manager.ModuleManager`) objects. A `Filter` may contain either other filters or `ModuleManagers`. A `ModuleManager` manages any number of `Modules`. The figure below shows this hierarchy in a graphical form.

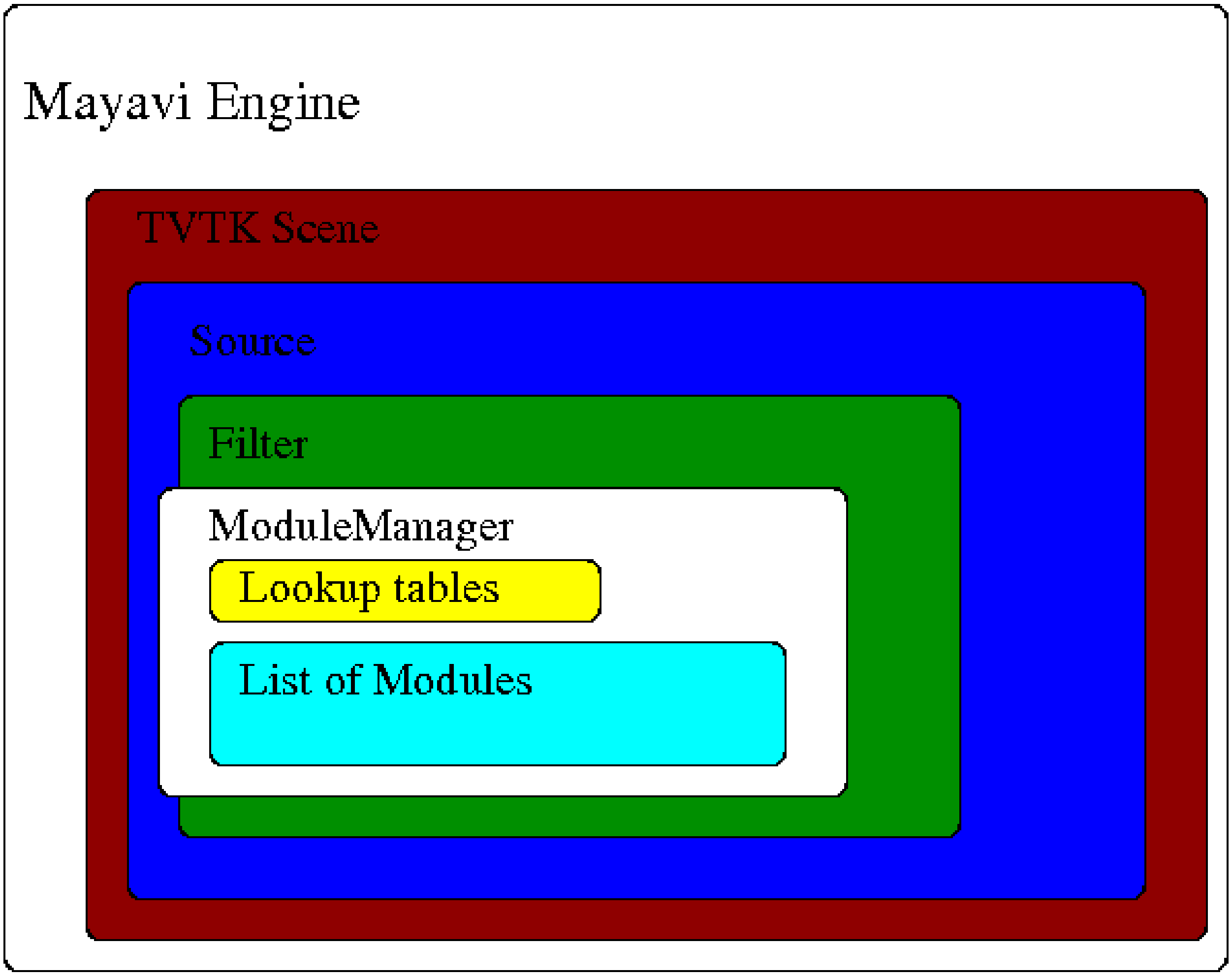


Illustration of the various objects in the mayavi pipeline.

This hierarchy is precisely what is seen in the Mayavi tree view on the UI. The UI is therefore merely a graphical representation of this internal world-view. A little more detail on these objects is given below. For even more details please refer to the sources.

All objects in the mayavi pipeline feature `start` and `stop` methods. The reasoning for this is that any object in mayavi is not usable (i.e. it may not provide any outputs) unless it has been started. Similarly the `stop` method "deactivates" the object. This is done because mayavi is essentially driving VTK objects underneath. These objects require inputs in order to do anything useful. Thus, an object that is not connected to the pipeline cannot be used. For example, consider an `IsoSurface` module. It requires some data in order to contour anything. Thus, the module in isolation is completely useless. It is usable only when it is added to the mayavi pipeline. When an object is added to the pipeline, its inputs are setup and its `start` method is called automatically. When the object is removed from the pipeline its `stop` method is called automatically.

Apart from the `Engine` object, all other objects in the mayavi pipeline feature a `scene` trait which refers to the current `enthought.pyface.tvtk.tvtk_scene.TVTKScene` instance that the object is associated with. The objects also feature an `add_child` method that lets one build up the pipeline by adding "children" objects. The `add_child` method is "intelligent" and will try to appropriately add the child in the right place.

Here is a brief description of the key objects in the mayavi pipeline.

`Engine` The Mayavi engine is defined in the `enthought.mayavi.engine` module.

- It possesses a `scenes` trait which is a Trait `List` of `Scene` objects.

- Features several methods that let one add a Filter/Source/Module instance to it. It allows one to create new scenes and delete them. Also has methods to load and save the entire visualization.
- The EnvisageEngine defined in the enthought.mayavi.envisage_engine module is a subclass of Engine and is the one used in the mayavi2 application. The Engine object is not abstract and itself perfectly usable. It is useful when users do not want to use Envisage but still desire to use mayavi for visualization.

Scene Defined in the enthought.mayavi.core.scene module.

- scene attribute: manages a TVTKScene (enthought.pyface.tvtk.tvtk_scene) object which is where all the rendering occurs.
- The children attribute is a List trait that manages a list of Source objects.

PipelineBase Defined in the enthought.mayavi.core.pipeline_base module. Derives from Base which merely abstracts out common functionality. The PipelineBase is the base class for all objects in the mayavi pipeline except the Scene and Engine (which really isn't *in* the pipeline but contains the pipeline).

- This class is characterized by two events, pipeline_changed and data_changed. These are Event traits. They determine when the pipeline has been changed and when the data has changed. Therefore, if one does:

```
object.pipeline_changed = True
```

  then the pipeline_changed event is fired. Objects downstream of object in the pipeline are automatically setup to listen to events from an upstream object and will call their update_pipeline method. Similarly, if the data_changed event is fired then downstream objects will automatically call their update_data methods.
- The outputs attribute is a trait List of outputs produced by the object.

Source Defined in the enthought.mayavi.core.source module. All the file readers, Parametric surface etc. are subclasses of the Source class.

- Contains the rest of the pipeline via its children trait. This is a List of either Modules or other Filters.
- The outputs attribute is a trait List of outputs produced by the source.

Filter Defined in the enthought.mayavi.core.filter module. All the Filters described in the *Filters* section are subclasses of this.

- Contains the rest of the pipeline via its children trait. This is a List of either Modules or other Filters.
- The inputs attribute is a trait List of input data objects that feed into the filter.
- The outputs attribute is a trait List of outputs produced by the filter.
- Also features the three methods:
  - **setup_pipeline: used to create the underlying** TVTK pipeline objects if needed.
  - update_pipeline: a method that is called when the upstream pipeline has been changed, i.e. an upstream object fires a pipeline_changed event.
  - update_data: a method that is called when the upstream pipeline has **not** been changed but the data in the pipeline has been changed. This happens when the upstream object fires a data_changed event.

ModuleManager Defined in the enthought.mayavi.core.module_manager module. This object is the one called *Modules* in the tree view on the UI. The main purpose of this object is to manage Modules and share common data between them. All modules typically will use the same lookup table (LUT) in order to produce a meaningful visualization. This lookup table is managed by the module manager.

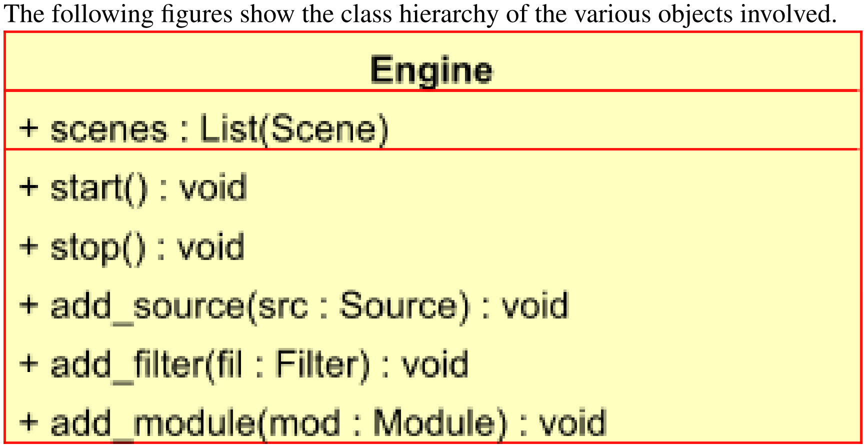
- The source attribute is the Source or Filter object that is the input of this object.

- Contains a list of `Modules` in its `children` trait.
- The `scalar_lut_manager` attribute is an instance of a `LUTManager` which basically manages the color mapping from scalar values to colors on the visualizations. This is basically a mapping from scalars to colors.
- The `vector_lut_manager` attribute is an instance of a `LUTManager` which basically manages the color mapping from vector values to colors on the visualizations.
- The class also features a `lut_data_mode` attribute that specifies the data type to use for the LUTs. This can be changed between 'auto', 'point data' and 'cell data'. Changing this setting will change the data range and name of the lookup table/legend bar. If set to 'auto' (the default), it automatically looks for cell and point data with point data being preferred over cell data and chooses the one available. If set to 'point data' it uses the input point data for the LUT and if set to 'cell data' it uses the input cell data.

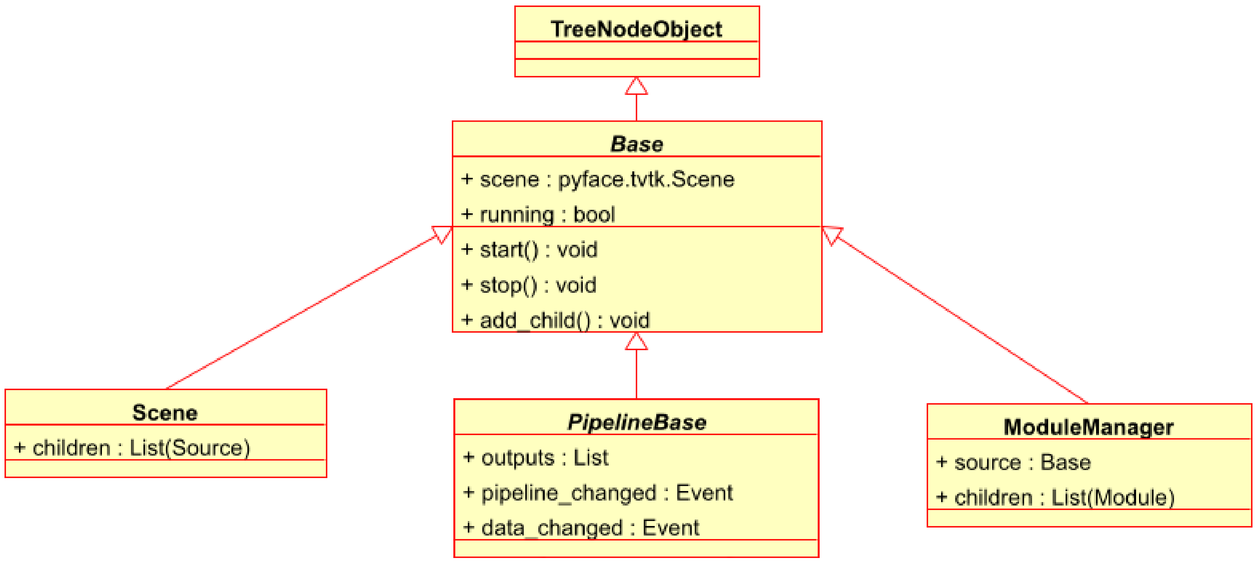
`Module` Defined in the `enthought.mayavi.core.module` module. These objects are the ones that typically produce a visualization on the TVTK scene. All the modules defined in the *Modules* section are subclasses of this.

- The `components` attribute is a trait `List` of various reusable components that are used by the module. These usually are never used directly by the user. However, they are extremely useful when creating new modules. A `Component` is basically a reusable piece of code that is used by various other objects. For example, almost every `Module` uses a TVTK actor, mapper and property. These are all "componentized" into a reusable *Actor* component that the modules use. Thus, components are a means to promote reuse between mayavi pipeline objects.
- The `module_manager` attribute specifies the `ModuleManager` instance that it is attached to.
- Like the `Filter` modules also feature the three methods:
  - **`setup_pipeline`: used to create the underlying** TVTK pipeline objects if needed.
  - `update_pipeline`: a method that is called when the upstream pipeline has been changed, i.e. an upstream object fires a `pipeline_changed` event.
  - `update_data`: a method that is called when the upstream pipeline has **not** been changed but the data in the pipeline has been changed. This happens when the upstream object fires a `data_changed` event.

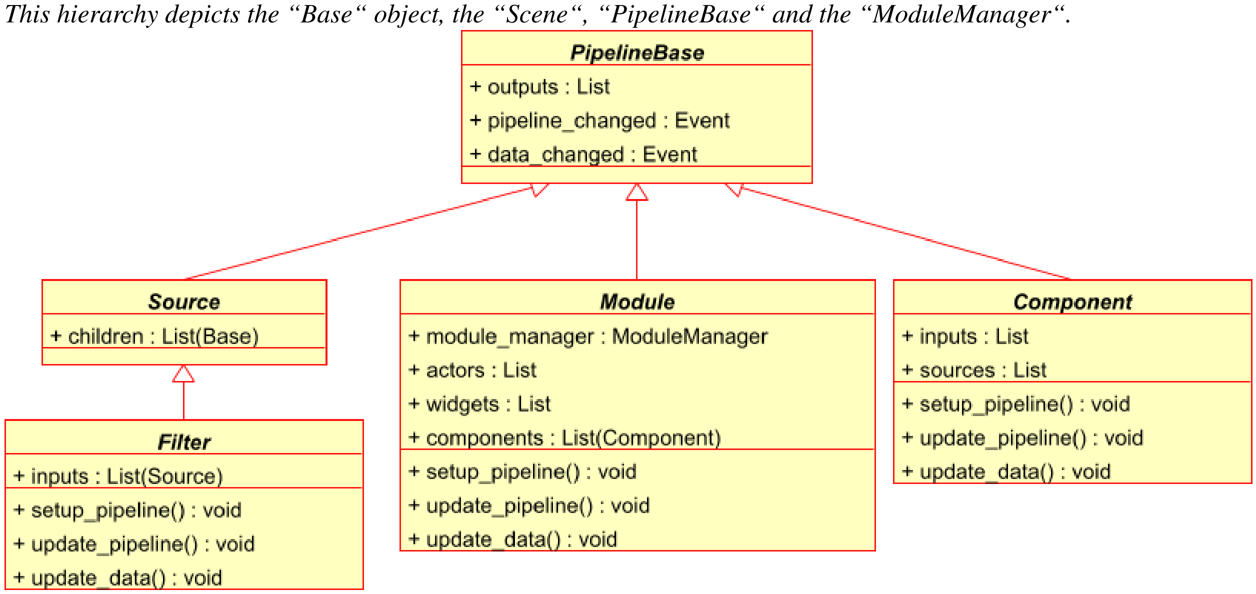
The following figures show the class hierarchy of the various objects involved.



The "Engine" object and its important attributes and methods.



This hierarchy depicts the "Base" object, the "Scene", "PipelineBase" and the "ModuleManager".



This hierarchy depicts the "PipelineBase" object, the "Source", "Filter", "Module" and the "Component".

7.2 Scripting the `mayavi2` application

The `mayavi2` application is implemented in the `enthought.mayavi.scripts.mayavi2` module (look at the `mayavi2.py` file and not the `mayavi2` script). This code handles the command line argument parsing and runs the application.

`mayavi2` is an Envisage application. It starts the Envisage application in its `main` method. The code for this is in the `enthought.mayavi.app` module. Mayavi uses several envisage plugins to build up its functionality. These plugins are defined in the `enthought.mayavi.plugin_definitions` module. In this module there are two lists of plugins defined, `PLUGIN_DEFINITIONS` and the `NONGUI_PLUGIN_DEFINITIONS`. The default application uses the former which produces a GUI that the user can use. If one uses the latter (`NONGUI_PLUGIN_DEFINITIONS`) then the mayavi tree view, object editor and menu items will not be available when the application is run. This allows a developer to create an application that uses mayavi but does not show its user interface. An example of how this may be done is provided in `examples/nongui.py`.

7.2.1 Scripting from the UI

When using the `mayavi2` application, it is possible to script from the embedded Python interpreter on the UI. On the interpreter the name `mayavi` is automatically bound to an `enthought.mayavi.script.Script` instance that may be used to easily script mayavi. This instance is a simple wrapper object that merely provides some nice conveniences while scripting from the UI. It has an `engine` trait that is a reference to the running mayavi engine.

As described in *The embedded Python interpreter* section, one can always drag a mayavi object from the tree and drop it on the interpreter to script it directly.

One may select the *File->Open File...* menu to open an existing Python file in the text editor, or choose the *File->New File* menu to create a new file. The text editor is Python-aware and one may write a script assuming that the `mayavi` name is bound to the `Script` instance as it is on the shell. To execute this script one can press `Control-r` as described earlier. `Control-s` will save the script.

The nice thing about this kind of scripting is that if one scripts something on the interpreter or on the editor, one may save the contents to a file, say `script.py` and then the next time mayavi run it like so:

```
$ mayavi2 -x script.py
```

This will execute the script for automatically. The name `mayavi` is available to the script and is bound to the `Script` instance. This is very convenient. It is possible to have mayavi execute multiple scripts. For example:

```
$ mayavi2 -d foo.vtk -m IsoSurface -x setup_iso.py -x script2.py
```

will load the `foo.vtk` file, create an `IsoSurface` module, then run `setup_iso.py` and then run `script2.py`.

There are several scripts in the mayavi `examples` directory that should show how this can be done. The `examples/README.txt` contains some information on the recommended ways to script.

7.2.2 Scripting from IPython

It is possible to script Mayavi using IPython. IPython will have to be invoked with the `-wthread` command line option in order to allow one to interactively script the mayavi application:

```
$ ipython -wthread
```

To start a visualization do the following:

```
from enthought.mayavi.app import main
# Note, this does not process any command line arguments.
mayavi = main()
# 'mayavi' is the mayavi Script instance.
```

It is also possible to use mlab (see *Simple Scripting with mlab*) for this purpose:

```
from enthought.mayavi.tools import mlab
f = mlab.figure() # Returns the current scene.
mayavi = mlab.get_mayavi() # Returns the Script instance.
```

With this it should be possible to script mayavi just the way it is done on the embedded interpreter or on the text editor.

7.2.3 An example

Here is an example script that illustrates various features of scripting mayavi:

```
# Create a new mayavi scene.
mayavi.new_scene()

# Get the current active scene.
s = mayavi.engine.current_scene

# Read a data file.
from enthought.mayavi.sources.api import VTKXMLFileReader
d = VTKXMLFileReader()
# You must specify the full path to the data here.
d.initialize('fire_ug.vtu')
mayavi.add_source(d)

# Import a few modules.
from enthought.mayavi.modules.api import Outline, IsoSurface, Streamline

# Show an outline.
o = Outline()
mayavi.add_module(o)
o.actor.property.color = 1, 0, 0 # red color.

# Make a few contours.
iso = IsoSurface()
mayavi.add_module(iso)
iso.contour.contours = [450, 570]
# Make them translucent.
iso.actor.property.opacity = 0.4
# Show the colormapping.
iso.module_manager.scalar_lut_manager.show_scalar_bar = True

# A streamline.
st = Streamline()
mayavi.add_module(st)
# Position the seed center.
st.seed.widget.center = 3.5, 0.625, 1.25
st.streamline_type = 'tube'

# Save the resulting image.
s.scene.save('test.png')

# Make an animation:
for i in range(36):
    # Rotate the camera by 10 degrees.
    s.scene.camera.azimuth(10)

    # Resets the camera clipping plane so everything fits and then
    # renders.
    s.scene.reset_zoom()

    # Save the scene.
    s.scene.save_png('anim%d.png'%i)
```

Sometimes, given a mayavi `Script` instance or `Engine`, it is handy to be able to navigate to a particular module/object. In the above this could be achieved as follows:

```
x = mayavi.engine.scenes[0].children[0].children[0].children[-1]
print x
```

In this case `x` will be set to the `Streamline` instance that we just created.

There are plenty of examples illustrating various things in the `examples` directory. These are all fairly well documented.

In particular, the `standalone.py` example illustrates how one can script mayavi without using the envisage application at all. The `offscreen.py` example illustrates how this may be done using off screen rendering (if supported by your particular build of VTK).

`examples/README.txt` contains some information on the recommended ways to script and some additional information.

7.3 Using the mayavi envisage plugins

The mayavi related plugin definitions to use are:

- `mayavi_plugin_definition.py`
- `mayavi_ui_plugin_definition.py`

These are in the `enthought.mayavi` package. To see an example of how to use this see the `enthought.mayavi.plugin_definitions` module and the `enthought.mayavi.app` module.

If you are writing Envisage plugins for an application and desire to use the mayavi plugins from your plugins/applications then it is important to note that mayavi creates three application objects for your convenience. These are:

- `enthought.mayavi.services.IMAYAVI`: This is an `enthought.mayavi.script.Script` instance that may be used to easily script mayavi. It is a simple wrapper object that merely provides some nice conveniences while scripting from the UI. It has an `engine` trait that is a reference to the running mayavi engine.
- `enthought.mayavi.services.IMAYAVI_ENGINE`: This is the running mayavi engine instance.
- `enthought.mayavi.services.IMAYAVI_ENGINE_VIEW`: This is the view of the engine and is only exposed if the `mayavi_ui_plugin_definition.py` is used.

A simple example that demonstrates the use of the mayavi plugin in an envisage application is included in the `examples/explorer` directory. This may be studied to understand how you may do the same in your envisage applications.

CHAPTER

EIGHT

Creating data for Mayavi

Describing data in three dimension in the general case is a complex problem. Mayavi helps you focus on your visualization work and not worry too much about the underlying data structures, for instance using mlab (see *Simple Scripting with mlab*). However, if you want to create data for a more efficient visualization, it helps to understand the VTK data structures that Mayavi uses.

8.1 VTK data structures

The 5 VTK structures used are the following (ordered by the cost of visualizing them).:

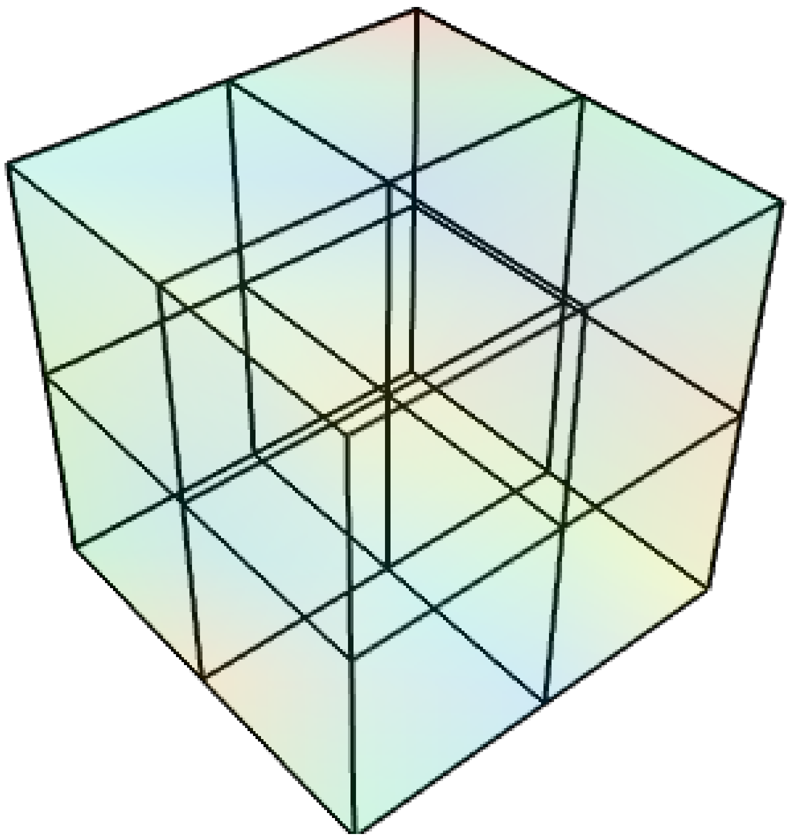
VTK name	Connectivity	Suitable for	Required information
ImageData	Implicit	Volumes and surfaces	3D data array and spacing along each axis
RectilinearGrid	Implicit	Volumes and surfaces	3D data array and 1D array of spacing for each axis
StructuredGrid	Implicit	Volumes and surfaces	3D data array and 3D position arrays for each axis
PolyData	Explicit	Points, lines and surfaces	x, y, z, positions of vertices and arrays of surface Cells
UnstructuredGrid	Explicit	Volumes and surfaces	x, y, z positions of vertices and arrays of volume Cells

Implicit connectivity: connectivity or positioning is implicit. In this case the data is considered as arranged on a lattice-like structure, with equal number of layers in each direction, x increasing first along the array, then y and finally z.

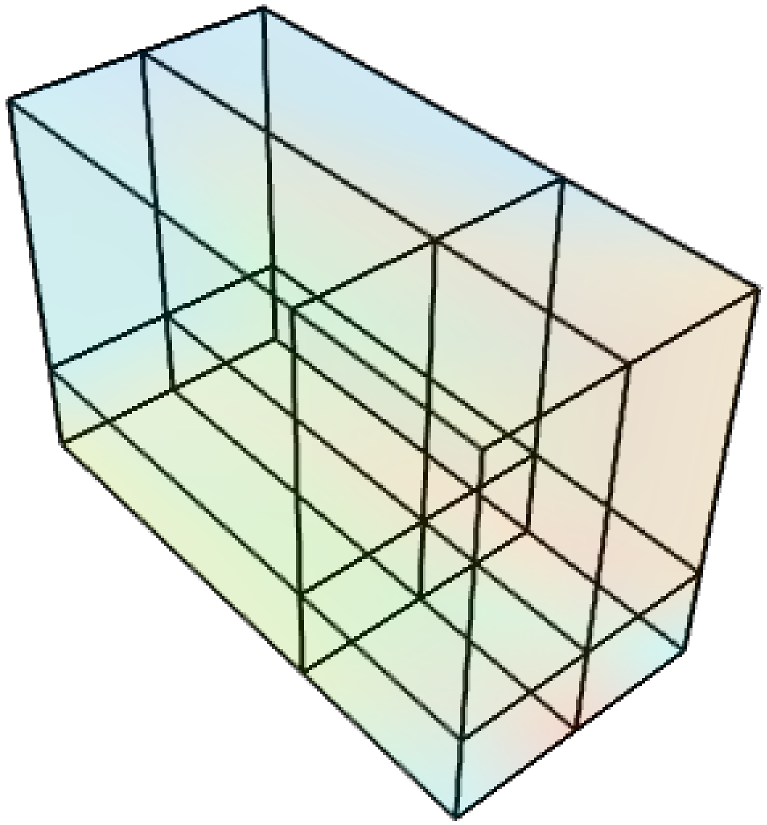
Cell data and point data: Each VTK dataset is defined by vertices and cells, explicitly or implicitly. The data, scalar or vector, can be positioned either on the vertices, in which case it is called point data, or associated with a cell, in which case it is called cell data.

Description of the datasets:

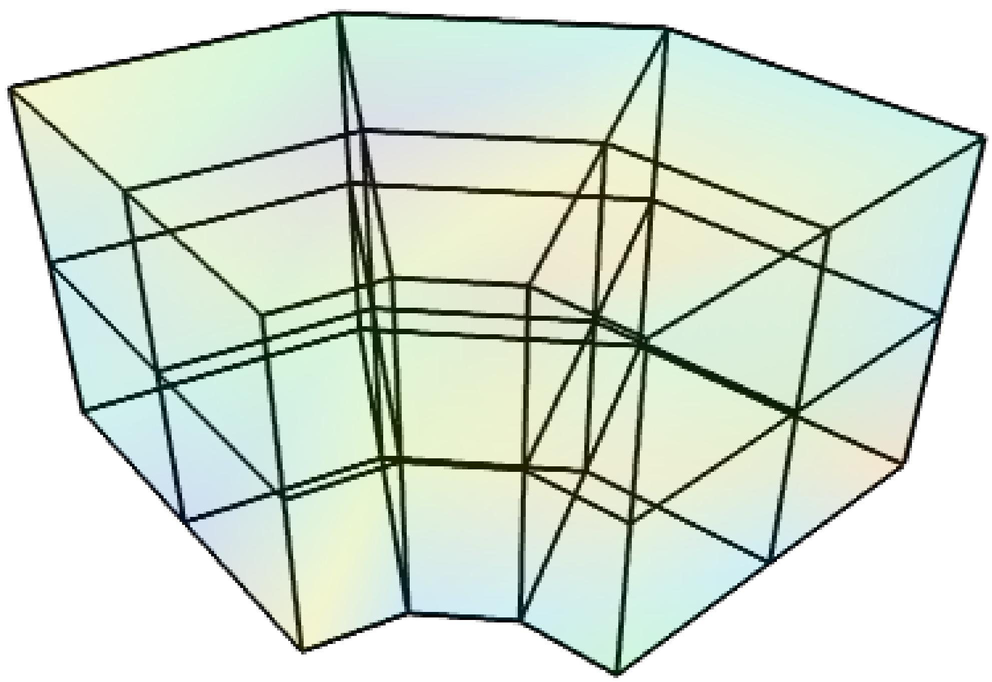
ImageData This dataset is made of data points positioned on an orthogonal grid, with constant spacing along each axis. The position of the data points are inferred from their position on the data array (implicit positioning), an origin and a spacing between 2 slices along each axis. In 2D, this can be understood as a raster image.



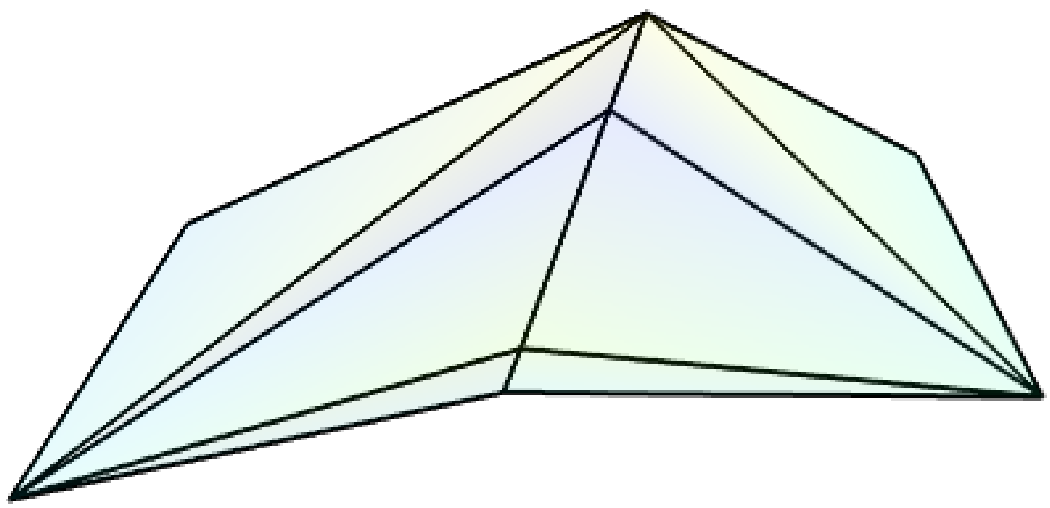
RectilinearGrid This dataset is made of data points positioned on an orthogonal grid, with arbitrary spacing along the various axis. The position of the data points are inferred from their position on the data array, an origin and the list of spacings of each axis.



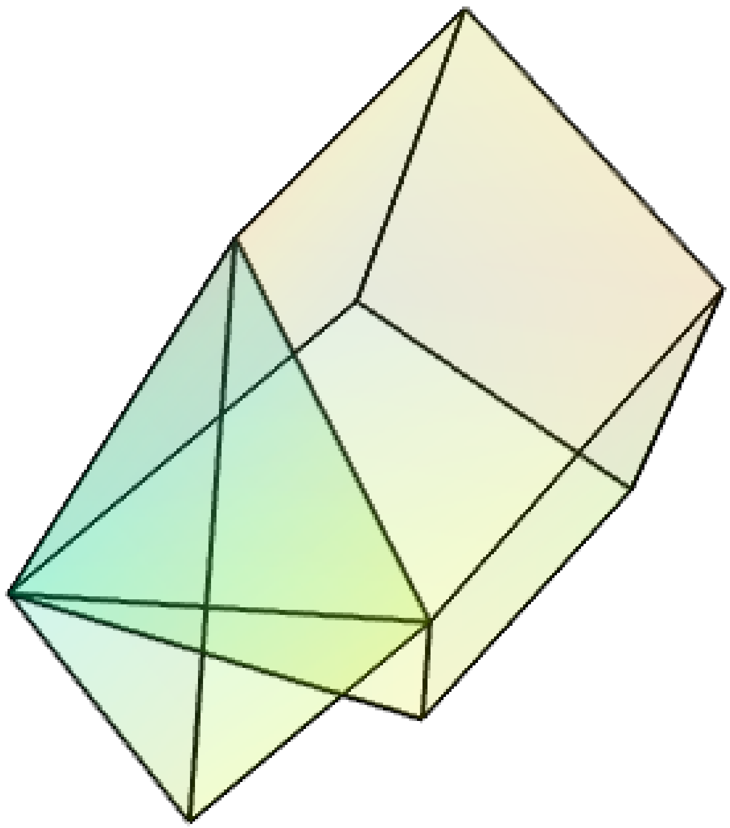
StructuredGrid This dataset is made of data points positioned on arbitrary grid: each point is connected to its nearest neighbors on the data array. The position of the data points are fully described by 1 coordinate arrays, specifying x, y and z for each point.



PolyData This dataset is made of arbitrarily positioned data points that can be connected to form lines, or grouped in polygons to from surfaces (the polygons are broken up in triangles). Unlike the other datasets, this one cannot be used to describe volumetric data.



UnstructuredGrid This dataset is the most general dataset of all. It is made of data points positioned arbitrarily. The connectivity between data points can be arbitrary (any number of neighbors). It is described by specifying connectivity, defining volumetric cells made of adjacent data points.



8.2 External references

This section of the user guide will be improved later. For now, the following two presentations best describe how one can create data objects or data files for Mayavi and TVTK.

- Presentation on TVTK and Mayavi2 for course at IIT Bombay

  https://svn.enthought.com/enthought/attachment/wiki/MayaVi/tvtk_mayavi2.pdf

  This presentation provides information on graphics in general, 3D data representation, creating VTK data files, creating datasets from numpy in Python, and also about mayavi.

- Presentation on making TVTK datasets using numpy arrays made for SciPy07.

  https://svn.enthought.com/enthought/attachment/wiki/MayaVi/tvtk_datasets.pdf

  This presentation focuses on creating TVTK datasets using numpy arrays.

8.3 Datasets creation examples

There are several examples in the mayavi sources that highlight the creation of the most important datasets from numpy arrays. These may be found in the `examples` directory. Specifically they are:

- `datasets.py` : Generate a simple example for each type of VTK dataset.
- `polydata.py`: Demonstrates how to create Polydata datasets from numpy arrays and visualize them in mayavi.

- `structured_points2d.py`: Demonstrates how to create a 2D structured points (an ImageData) dataset from numpy arrays and visualize them in mayavi. This is basically a square of equispaced points.
- `structured_points3d.py`: Demonstrates how to create a 3D structured points (an ImageData) dataset from numpy arrays and visualize them in mayavi. This is a cube of points that are regularly spaced.
- `structured_grid.py`: Demonstrates the creation and visualization of a 3D structured grid.
- `unstructured_grid.py`: Demonstrates the creation and visualization of an unstructured grid.

These scripts may be run like so:

```
$ mayavi2 -x structured_grid.py
```

or better yet, all in one go like so:

```
$ mayavi2 -x polydata.py -x structured_points2d.py \
> -x structured_points3d.py -x structured_grid.py -x unstructured_grid.py
```

CHAPTER

NINE

Tips and Tricks

Below are a few useful tips and tricks that you may find useful when you use Mayavi2.

9.1 Customizing Mayavi2

There are two ways a user can customize mayavi:

1. At a global, system wide level via a `site_mayavi.py`. This file is to be placed anywhere on `sys.path`.
2. At a local, user level. This is achieved by placing a `user_mayavi.py` in the users `~/.mayavi2/` directory. If a `~/.mayavi2/user_mayavi.py` is found, the directory is placed in `sys.path`.

The files are similar in their content. Two things may be done in this file:

1. Registering new sources, modules or filters in the mayavi registry (`enthought.mayavi.core.registry.registry`). This is done by registering metadata for the new class in the registry. See `examples/mayavi/user_mayavi.py` to see an example.
2. Adding additional envisage plugins to the mayavi2 application. This is done by defining a function called `get_plugins()` that returns a list of plugins that you wish to add to the mayavi2 application.

The `examples/mayavi/user_mayavi.py` example documents and shows how this can be done. To see it, copy the file to the `~/.mayavi2` directory. If you are unsure where ~ is on your platform, just run the example and it should print out the directory.

Warning: In the `user_mayavi.py` or `site_mayavi.py`, avoid mayavi imports like `from enthought.mayavi.modules.outline import Outline` etc. This is because `user_mayavi` is imported at a time when many of the imports are not complete and this will cause hard-to-debug circular import problems. The `registry` is given only metadata mostly in the form of strings and this will cause no problem. Therefore to define new modules, we strongly recommend that the modules be defined in another module or be defined in a factory function as done in the example `user_mayavi.py` provided.

9.2 Off screen rendering

Often you write Mayavi scripts to render a whole batch of images to make an animation or so and find that each time you save an image, Mayavi "raises" the window to make it the active window thus disrupting your work. This is needed since VTK internally grabs the window to make a picture. To get around this behavior you may click on the scene and set the "Off screen rendering" option on. Or from a script:

```
mayavi.engine.current_scene.scene.off_screen_rendering = True
```

This will stop raising the window. However, this may not be enough. If you are using win32 then off screen rendering should work well out of the box. On Linux and the Mac you will need VTK-5.1 (currently from CVS) to get this working properly.

If upgrading VTK is a problem there is another approach for any OS that supports X11. This option should work irrespective of the version of VTK you are using. The idea is to use the virtual framebuffer X server for X11 like so:

- Make sure you have the *xvfb* package installed.
- Create the virtual framebuffer X server like so:

  ```
  xvfb :1 -screen 0 1280x1024x24
  ```

  This creates the display ":1" and creates a screen of size 1280x1024 with 24 bpp. For more options check your `xvfb` man page.
- Export display to :1 like so (on bash):

  ```
  $ export DISPLAY=:1
  ```

- Now run your mayavi script. It should run uninterrupted on this X server and produce your saved images.

This probably will have to be fine tuned to suit your taste.

Note that if you want to use mayavi without the envisage UI or even a traits UI (i.e. with a pure TVTK window) and do off screen rendering with Python scripts you may be interested in the `examples/offscreen.py` example. This simple example shows how you can use MayaVi without using Envisage or the MayaVi envisage application and still do off screen rendering.

9.3 Using `mlab` with the full envisage UI

Sometimes it is convenient to write an mlab script but still use the full envisage application so you can click on the menus and use other modules etc. To do this you may do the following before you create an mlab figure:

```
from enthought.mayavi import mlab
mlab.options.backend = 'envisage'
f = mlab.figure()
# ...
```

This will give you the full-fledged UI instead of the default simple window.

9.4 Scripting mayavi without using Envisage

The example `examples/standalone.py` demonstrates how one can use Mayavi without using Envisage. This is useful when you want to minimize dependencies. `examples/offscreen.py` demonstrates how to use mayavi without the envisage UI or even a traits UI (i.e. with a pure TVTK window) and do off screen rendering.

9.5 Embedding mayavi in your own traits UI

You've written your traits based application complete with a nice UI and now you want to do some 3D plotting and embed that UI inside your own UI. This can be easily done. `examples/mayavi_traits_ui.py` is a fairly comprehensive example that demonstrates how you can embed almost the entire mayavi UI into your traits based UI. `examples/mlab_traits_ui.py` demonstrates how you can do some simple mlab based visualization.

9.6 Computing in a thread

`examples/compute_in_thread.py` demonstrates how to visualize a 2D numpy array and visualize it as image data using a few modules. It also shows how one can do a computation in another thread and update the mayavi pipeline once the computation is done. This allows a user to interact with the user interface when the computation is performed in another thread.

9.7 Polling a file and auto-updating mayavi

Sometimes you have a separate computational process that generates data suitable for visualization. You'd like mayavi to visualize the data but automatically update the data when the data file is updated by the computation. This is easily achieved by polling the data file and checking if it has been modified. The `examples/poll_file.py` demonstrates this. To see it in action will require that you edit the scalar data in the `examples/data/heart.vtk` data file.

CHAPTER

TEN

Miscellaneous

10.1 Tests for Mayavi2

Mayavi features a few simple tests. These are in the `tests` directory. The testing is performed using the same technique that VTK employs. Basically, a visualization is scripted and the resulting visualization window is captured and compared with an existing test image. If there are differences in the images then there is an error, if not the test passes. The test cases are themselves relatively simple and the magic of the actual generation of test images etc. is all in the `tests/common.py` module.

To run a test you may do something like the following:

```
$ cd tests
$ python test_array_source.py
```

10.2 Getting help

Most of the user and developer discussion for mayavi2 occurs on the Enthought OSS developers mailing list (enthought-dev@mail.enthought.com). This list is also available via gmane from here: http://dir.gmane.org/gmane.comp.python.enthought.devel

Discussion and bug reports are also sometimes sent to the mayavi-users mailing list (Mayavi-users@lists.sourceforge.net). We recommend sending messages to the enthought-dev list though.

The Mayavi web page: https://svn.enthought.com/enthought/wiki/MayaVi

is a trac page where one can also enter bug reports and feature requests.

If this manual, the mayavi web page and google are of no help feel free to post on the enthought-dev mailing list for help.

10.3 Helping out

We are always on the lookout for people to help this project grow. Feel free to send us patches – these are best sent to the mailing list. Thanks!

CHAPTER

ELEVEN

MLab reference

Reference list of all the main functions of `enthought.mayavi.mlab` with documentation and examples.

11.1 Plotting functions

11.1.1 imshow

imshow(**args, **kwargs*)

Allows one to view a 2D Numeric array as an image. This works best for very large arrays (like 1024x1024 arrays).

Function signatures:

```
imshow(2darray, ...)
```

Keyword arguments:

opacity The overall opacity of the vtk object.

colormap type of colormap to use.

color the color of the vtk object. Overides the colormap, if any, when specified.

vmin vmin is used to scale the colormap If None, the min of the data will be used

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

representation the representation type used for the surface. Must be 'surface' or 'wireframe' or 'points'. Default: surface

transparent make the opacity of the actor depend on the scalar.

figure Figure to populate.

name the name of the vtk object created.

Example:

```
def test_imshow():
    return imshow(numpy.random.random((10,10)), colormap='gist_earth')
```

11.1.2 quiver3d

quiver3d(**args, **kwargs*)

Plots glyphs (like arrows) indicating the direction of the vectors for a 3D volume of data supplied as arguments.

Function signatures:

```
quiver3d(u, v, w, ...)
quiver3d(x, y, z, u, v, w, ...)
quiver3d(x, y, z, f, ...)
```

If only 3 arrays u, v, w are passed the x, y and z arrays are assumed to be made from the indices of vectors.

If 4 positional arguments are passed the last one must be a callable, f, that returns vectors.

Keyword arguments:

opacity The overall opacity of the vtk object.

scale_factor the scaling applied to the glyphs. The size of the glyph is by default in drawing units. Must be a float. Default: 1.0

colormap type of colormap to use.

color the color of the vtk object. Overides the colormap, if any, when specified.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

transparent make the opacity of the actor depend on the scalar.

name the name of the vtk object created.

vmin vmin is used to scale the colormap If None, the min of the data will be used

scale_mode the scaling mode for the glyphs ('vector', 'scalar', or 'none').

mode the mode of the glyphs. Must be '2darrow' or '2dcircle' or '2dcross' or '2ddash' or '2ddiamond' or '2dhooked_arrow' or '2dsquare' or '2dthick_arrow' or '2dthick_cross' or '2dtriangle' or '2dvertex' or 'arrow' or 'cone' or 'cube' or 'cylinder' or 'point' or 'sphere'. Default: 2darrow

figure Figure to populate.

resolution The resolution of the glyph created. Forspheres, for instance, this is the number ofdivisions along theta and phi.

Example:

```
def test_quiver3d():
    dims = [8, 8, 8]
    xmin, xmax, ymin, ymax, zmin, zmax = [-5,5,-5,5,-5,5]
    x, y, z = numpy.mgrid[xmin:xmax:dims[0]*1j,
                          ymin:ymax:dims[1]*1j,
                          zmin:zmax:dims[2]*1j]
    x = x.astype('f')
    y = y.astype('f')
    z = z.astype('f')

    sin = numpy.sin
    cos = numpy.cos
    u = cos(x)
    v = sin(y)
    w = sin(x*z)

    obj = quiver3d(x, y, z, u, v, w, mode='cone', extent=(0,1, 0,1, 0,1),
                   scale_factor=0.9)

    return u, v, w, obj
```

11.1.3 plot3d

plot3d(**args, **kwargs*)

Draws lines between points.

Function signatures:

```
plot3d(x, y, z, ...)
plot3d(x, y, z, s, ...)
```

Keyword arguments:

opacity The overall opacity of the vtk object.

tube_radius radius of the tubes used to represent the lines Must be a float. Default: 0.025

colormap type of colormap to use.

color the color of the vtk object. Overides the colormap, if any, when specified.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

transparent make the opacity of the actor depend on the scalar.

figure Figure to populate.

name the name of the vtk object created.

vmin vmin is used to scale the colormap If None, the min of the data will be used

representation the representation type used for the surface. Must be 'surface' or 'wireframe' or 'points'. Default: surface

tube_sides number of sides of the tubes used to represent the lines. Must be an integer. Default: 6

Example:

```
def test_plot3d():
    """Generates a pretty set of lines."""
    n_mer, n_long = 6, 11
    pi = numpy.pi
    dphi = pi/1000.0
    phi = numpy.arange(0.0, 2*pi + 0.5*dphi, dphi, 'd')
    mu = phi*n_mer
    x = numpy.cos(mu)*(1+numpy.cos(n_long*mu/n_mer)*0.5)
    y = numpy.sin(mu)*(1+numpy.cos(n_long*mu/n_mer)*0.5)
    z = numpy.sin(n_long*mu/n_mer)*0.5

    l = plot3d(x, y, z, numpy.sin(mu), tube_radius=0.025, colormap='Spectral')
    return l
```

11.1.4 surf

surf(**args, **kwargs*)

Plots a surface using regularly spaced elevation data supplied as a 2D array.

Function signatures:

```
surf(s, ...)
surf(x, y, s, ...)
surf(x, y, f, ...)
```

If 3 positional arguments are passed the last one must be an array s, or a callable, f, that returns an array. x and y give the coordinnates of positions corresponding to the s values.

z is the elevation matrix.

x and y can be 1D or 2D arrays (such as returned by numpy.ogrid or numpy.mgrid), but the points should be located on an orthogonal grid (possibly non-uniform). In other words, all the points sharing a same index in the s array need to have the same x or y value. For arbitrary-shaped position arrays (non-orthogonal grids), see the mesh function.

If only 1 array s is passed the x and y arrays are assumed to be made from the indices of arrays, and an uniformly-spaced data set is created.

Keyword arguments:

opacity The overall opacity of the vtk object.

colormap type of colormap to use.

color the color of the vtk object. Overides the colormap, if any, when specified.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

transparent make the opacity of the actor depend on the scalar.

figure Figure to populate.

warp_scale scale of the z axis (warped from the value of the scalar). By default this scale is calculated to give a pleasant aspect ratio to the plot. You can overright this behavoir by specifying a float value.

name the name of the vtk object created.

vmin vmin is used to scale the colormap If None, the min of the data will be used

mask boolean mask array to suppress some data points.

representation the representation type used for the surface. Must be 'surface' or 'wireframe' or 'points'. Default: surface

Example:

```
def test_surf():
    """Test surf on regularly spaced co-ordinates like MayaVi."""
    def f(x, y):
        sin, cos = numpy.sin, numpy.cos
        return sin(x+y) + sin(2*x - y) + cos(3*x+4*y)

    x, y = numpy.mgrid[-7.:7.05:0.1, -5.:5.05:0.05]
    s = surf(x, y, f)
    #cs = contour_surf(x, y, f, contour_z=0)
    return s
```

11.1.5 mesh

mesh(**args, **kwargs*)

Plots a surface using grid-spaced data supplied as 2D arrays.

Function signatures:

```
mesh(x, y, z, ...)
```

x, y, z are 2D arrays giving the positions of the vertices of the surface. The connectivity between these points is implied by the connectivity on the arrays.

For simple structures (such as orthogonal grids) prefer the surf function, as it will create more efficient data structures.

Keyword arguments:

opacity The overall opacity of the vtk object.

scale_factor scale factor of the glyphs used to represent the vertices, in fancy_mesh mode. Must be a float. Default: 0.05

colormap type of colormap to use.

color the color of the vtk object. Overides the colormap, if any, when specified.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

tube_radius radius of the tubes used to represent the lines, in mesh mode. If None, simple lines are used.

transparent make the opacity of the actor depend on the scalar.

figure Figure to populate.

name the name of the vtk object created.

vmin vmin is used to scale the colormap If None, the min of the data will be used

scale_mode the scaling mode for the glyphs ('vector', 'scalar', or 'none').

mask boolean mask array to suppress some data points.

scalars optional scalar data.

mode the mode of the glyphs. Must be '2darrow' or '2dcircle' or '2dcross' or '2ddash' or '2ddiamond' or '2dhooked_arrow' or '2dsquare' or '2dthick_arrow' or '2dthick_cross' or '2dtriangle' or '2dvertex' or 'arrow' or 'cone' or 'cube' or 'cylinder' or 'point' or 'sphere'. Default: sphere

representation the representation type used for the surface. Must be 'surface' or 'wireframe' or 'points' or 'mesh' or 'fancymesh'. Default: surface

resolution The resolution of the glyph created. Forspheres, for instance, this is the number ofdivisions along theta and phi.

tube_sides number of sides of the tubes used to represent the lines. Must be an integer. Default: 6

Example:

```
def test_mesh():
    """A very pretty picture of spherical harmonics translated from
    the octaviz example."""
    pi = numpy.pi
    cos = numpy.cos
    sin = numpy.sin
    dphi, dtheta = pi/250.0, pi/250.0
    [phi,theta] = numpy.mgrid[0:pi+dphi*1.5:dphi,0:2*pi+dtheta*1.5:dtheta]
    m0 = 4; m1 = 3; m2 = 2; m3 = 3; m4 = 6; m5 = 2; m6 = 6; m7 = 4;
    r = sin(m0*phi)**m1 + cos(m2*phi)**m3 + sin(m4*theta)**m5 + cos(m6*theta)**m7
    x = r*sin(phi)*cos(theta)
    y = r*cos(phi)
    z = r*sin(phi)*sin(theta);

    return mesh(x, y, z, colormap="bone")
```

11.1.6 contour3d

contour3d(**args, **kwargs*)

Plots iso-surfaces for a 3D volume of data suplied as arguments.

Function signatures:

```
contour3d(scalars, ...)
contour3d(scalarfield, ...)
```

Keyword arguments:

opacity The overall opacity of the vtk object.

name the name of the vtk object created.

color the color of the vtk object. Overides the colormap, if any, when specified.

colormap type of colormap to use.

contours Integer/list specifying number/list of contours. Specifying 0 shows no contours. Specifying a list of values will only give the requested contours asked for.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

figure Figure to populate.

transparent make the opacity of the actor depend on the scalar.

vmin vmin is used to scale the colormap If None, the min of the data will be used

Example:

```
def test_contour3d():
    dims = [64, 64, 64]
    xmin, xmax, ymin, ymax, zmin, zmax = [-5,5,-5,5,-5,5]
    x, y, z = numpy.ogrid[xmin:xmax:dims[0]*1j,
                          ymin:ymax:dims[1]*1j,
                          zmin:zmax:dims[2]*1j]
    x = x.astype('f')
    y = y.astype('f')
    z = z.astype('f')

    sin = numpy.sin
    scalars = x*x*0.5 + y*y + z*z*2.0

    obj = contour3d(scalars, contours=4, transparent=True)
    return obj, scalars
```

11.1.7 points3d

`points3d`(**args, **kwargs*)

Plots glyphs (like points) at the position of the supplied data.

Function signatures:

```
points3d(scalardata, ...)
points3d(x, y, z...)
points3d(x, y, z, s, ...)
points3d(x, y, z, f, ...)
```

If only one positional argument is passed, it should be VTK data object with scalar data.

If only 3 arrays x, y, z all the points are drawn with the same size and color

If 4 positional arguments are passed the last one can be an array s or a callable f that gives the size and color of the glyph.

Keyword arguments:

opacity The overall opacity of the vtk object.

scale_factor the scaling applied to the glyphs. The size of the glyph is by default in drawing units. Must be a float. Default: 1.0

colormap type of colormap to use.

color the color of the vtk object. Overides the colormap, if any, when specified.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

transparent make the opacity of the actor depend on the scalar.

name the name of the vtk object created.

vmin vmin is used to scale the colormap If None, the min of the data will be used

scale_mode the scaling mode for the glyphs ('vector', 'scalar', or 'none').

mode the mode of the glyphs. Must be '2darrow' or '2dcircle' or '2dcross' or '2ddash' or '2ddiamond' or '2dhooked_arrow' or '2dsquare' or '2dthick_arrow' or '2dthick_cross' or '2dtriangle' or '2dvertex' or 'arrow' or 'cone' or 'cube' or 'cylinder' or 'point' or 'sphere'. Default: sphere

figure Figure to populate.

resolution The resolution of the glyph created. Forspheres, for instance, this is the number ofdivisions along theta and phi.

Example:

```
def test_points3d():
    t = numpy.linspace(0, 4*numpy.pi, 20)
    cos = numpy.cos
    sin = numpy.sin

    x = sin(2*t)
    y = cos(t)
    z = cos(2*t)
    s = 2+sin(t)

    points3d(x, y, z, s, colormap="copper", scale_factor=.25)
```

11.1.8 flow

flow(**args, **kwargs*)

Creates streamlines following the flow of a vector field.

Function signatures:

```
flow(u, v, w, ...)
flow(x, y, z, u, v, w, ...)
flow(x, y, z, f, ...)
```

If only 3 arrays u, v, w are passed the x, y and z arrays are assumed to be made from the indices of vectors.

If the x, y and z arrays are passed they are supposed to have been generated by *numpy.mgrid*. The function builds a scalar field assuming the points are regularly spaced.

If 4 positional arguments are passed the last one must be a callable, f, that returns vectors.

Keyword arguments:

opacity The overall opacity of the vtk object.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

colormap type of colormap to use.

seedtype the widget used as a seed for the streamlines. Must be 'line' or 'plane' or 'point' or 'sphere'. Default: sphere

color the color of the vtk object. Overides the colormap, if any, when specified.

linetype the type of line-like object used to display the streamline. Must be 'line' or 'ribbon' or 'tube'. Default: line

vmax vmax is used to scale the colormap If None, the max of the data will be used

transparent make the opacity of the actor depend on the scalar.

name the name of the vtk object created.

vmin vmin is used to scale the colormap If None, the min of the data will be used

scalars optional scalar data.

figure Figure to populate.

Example:

```
def test_flow():
    dims = [32, 32, 32]
    xmin, xmax, ymin, ymax, zmin, zmax = [-5,5,-5,5,-5,5]
    x, y, z = numpy.mgrid[xmin:xmax:dims[0]*1j,
                          ymin:ymax:dims[1]*1j,
                          zmin:zmax:dims[2]*1j]
    x = x.astype('f')
    y = y.astype('f')
    z = z.astype('f')

    sin = numpy.sin
    cos = numpy.cos
    u = cos(x/2.)
    v = sin(y/2.)
    w = sin(x*z/4.)

    obj = flow(x, y, z, u, v, w, linetype='tube')
    return u, v, w, obj
```

11.1.9 contour_surf

contour_surf(**args, **kwargs*)

Plots a the contours of asurface using grid spaced data supplied as 2D arrays.

Function signatures:

```
contour_surf(s, ...)
contour_surf(x, y, s, ...)
contour_surf(x, y, f, ...)
```

If only one array s is passed the x and y arrays are assumed to be made of the indices of s. s is the elevation matrix.

Keyword arguments:

opacity The overall opacity of the vtk object.

colormap type of colormap to use.

color the color of the vtk object. Overides the colormap, if any, when specified.

extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the x, y, z arrays extents.

vmax vmax is used to scale the colormap If None, the max of the data will be used

transparent make the opacity of the actor depend on the scalar.

warp_scale scale of the warp scalar

name the name of the vtk object created.

vmin vmin is used to scale the colormap If None, the min of the data will be used

contours Integer/list specifying number/list of contours. Specifying 0 shows no contours. Specifying a list of values will only give the requested contours asked for.

figure Figure to populate.

Example:

```
def test_contour_surf():
    """Test contour_surf on regularly spaced co-ordinates like MayaVi."""
    def f(x, y):
        sin, cos = numpy.sin, numpy.cos
        return sin(x+y) + sin(2*x - y) + cos(3*x+4*y)

    x, y = numpy.mgrid[-7.:7.05:0.1, -5.:5.05:0.05]
    s = contour_surf(x, y, f)
    return s
```

11.2 Figure handling functions

11.2.1 figure

figure(*name=None, bgcolor=None, fgcolor=None, engine=None*)

Creates a new scene or retrieves an existing scene. If the mayavi engine is not running this also starts it.

Keyword arguments

name The name of the scene.

bgcolor The color of the background (None is default).

fgcolor The color of the foreground (None is default).

engine The mayavi engine that controls the figure.

11.2.2 savefig

savefig(*filename, size=None, figure=None, **kwargs*)

Save the current scene. The output format are deduced by the extension to filename. Possibilities are png, jpg, bmp, tiff, ps, eps, pdf, rib (renderman), oogl (geomview), iv (OpenInventor), vrml, obj (wavefront)

If an additional size (2-tuple) argument is passed the window is resized to the specified size in order to produce a suitably sized output image. Please note that when the window is resized, the window may be obscured by other widgets and the camera zoom is not reset which is likely to produce an image that does not reflect what is seen on screen.

Any extra keyword arguments are passed along to the respective image format's save method.

11.2.3 gcf

gcf(*engine=None*)

Return a handle to the current figure.

You can supply the engine from which you want to retrieve the current figure, if you have several mayavi engines.

11.2.4 clf

clf (*figure=None*)
Clear the current figure.

You can also supply the figure that you want to clear.

11.2.5 draw

draw (*figure=None*)
Forces a redraw of the current figure.

11.3 Figure decoration functions

11.3.1 zlabel

zlabel (*text, object=None*)
Creates a set of axes if there isn't already one, and sets the z label

Keyword arguments

object The object to apply the module to, if not the whole scene is searched for a suitable object.

11.3.2 ylabel

ylabel (*text, object=None*)
Creates a set of axes if there isn't already one, and sets the y label

Keyword arguments:

object The object to apply the module to, if not the whole scene is searched for a suitable object.

11.3.3 scalarbar

scalarbar (*object=None, title=None, orientation=None*)
Adds a colorbar for the scalar color mapping of the given object.

If no object is specified, the first object with scalar data in the scene is used.

Keyword arguments:

object Optional object to get the scalar color map from

title The title string

orientation Can be 'horizontal' or 'vertical'

11.3.4 colorbar

colorbar (*object=None, title=None, orientation=None*)
Adds a colorbar for the color mapping of the given object.

If the object has scalar data, the scalar color mapping is represented. Elsewhere the vector color mapping is represented, if available. If no object is specified, the first object with a color map in the scene is used.

Keyword arguments:

object Optional object to get the color map from

title The title string

orientation Can be 'horizontal' or 'vertical'

11.3.5 xlabel

xlabel (*text, object=None*)

Creates a set of axes if there isn't already one, and sets the x label

Keyword arguments:

object The object to apply the module to, if not the whole scene is searched for a suitable object.

11.3.6 vectorbar

vectorbar (*object=None, title=None, orientation=None*)

Adds a colorbar for the vector color mapping of the given object.

If no object is specified, the first object with vector data in the scene is used.

Keyword arguments

object Optional object to get the vector color map from

title The title string

orientation Can be 'horizontal' or 'vertical'

11.4 Camera handling functions

11.4.1 roll

roll (*roll=None*)

Sets or returns the absolute roll angle of the camera

11.4.2 view

view (*azimuth=None, elevation=None, distance=None, focalpoint=None*)

Sets the view point for the camera.

view(azimuth=None, elevation=None, distance=None, focalpoint=None)

azimuth: angle in the horizontal plane elevation: elevation angle of the camera relative to the vertical distance: distance to the focal point focalpoint: (x, y, z) position of the focal point. If some parameters are not passed, they are left unchanged. The function tries to guess the roll angle appropriate for the view. see also: roll.

11.5 Other functions

11.5.1 axes

axes (**args, **kwargs*)

Creates axes for the current (or given) object.

Keyword arguments:

opacity The overall opacity of the vtk object.
name the name of the vtk object created.
color the color of the vtk object. Overides the colormap, if any, when specified.
zlabel the label of the z axis
ranges [xmin, xmax, ymin, ymax, zmin, zmax] Ranges of the labels displayed on the axes. Default is the object's extents.
xlabel the label of the x axis
extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the object's extents.
ylabel the label of the y axis

11.5.2 show

show (*func=None*)

Start interacting with the figure.

By default, this function simply creates a GUI and starts its event loop if needed.

If it is used as a decorator, then it may be used to decorate a function which requires a UI. If the GUI event loop is already running it simply runs the function. If not the event loop is started and function is run in the toolkit's event loop. The choice of UI is via *ETSConfig.toolkit*.

11.5.3 text

text (**args, **kwargs*)

Adds a text on the figure.

Function signature:

```
text(x, y, text, ...)
```

x, and y are the position of the origin of the text on the 2D projection of the figure.

Keyword arguments:

opacity The overall opacity of the vtk object.
name the name of the vtk object created.
color the color of the vtk object. Overides the colormap, if any, when specified.
width width of the text.

11.5.4 set_engine

set_engine (*self, engine*)

Sets the mlab engine.

11.5.5 show_engine

show_engine ()

This function is depreciated, please use show_pipeline.

11.5.6 get_engine

get_engine (*self*)
Returns an engine in agreement with the options.

11.5.7 outline

outline (**args, **kwargs*)
Creates an outline for the current (or given) object.

Keyword arguments:

opacity The overall opacity of the vtk object.
name the name of the vtk object created.
color the color of the vtk object. Overides the colormap, if any, when specified.
extent [xmin, xmax, ymin, ymax, zmin, zmax] Default is the object's extents.

11.5.8 show_pipeline

show_pipeline (*self, engine=None*)
Show a dialog with the mayavi pipeline. This dialog allows to edit graphicaly the properties of the different objects on the scenes.

11.5.9 title

title (**args, **kwargs*)
Creates a title for the figure.

Function signature:

```
title(text, ...)
```

Keyword arguments:

opacity The overall opacity of the vtk object.
name the name of the vtk object created.
color the color of the vtk object. Overides the colormap, if any, when specified.
height height of the title, in portion of the figure height
size the size of the title

11.5.10 orientationaxes

orientationaxes (**args, **kwargs*)
Applies the OrientationAxes mayavi module to the given VTK data object.

Keyword arguments:

opacity The overall opacity of the vtk object.
name the name of the vtk object created.
color the color of the vtk object. Overides the colormap, if any, when specified.
zlabel the label of the z axis
xlabel the label of the x axis
ylabel the label of the y axis

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