Writing a graphical application for scientific programming using TraitsUI

A step by step guide for a non-programmer

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Building interactive Graphical User Interfaces (GUIs) is a hard problem, especially for somebody who has not had training in IT. TraitsUI is a python module that provides a great answer to this problem. I have found that I am incredibly productive when creating graphical application using traitsUI. However I had to learn a few new concepts and would like to lay them down together in order to make it easier for others to follow my footsteps.

This document is intended to help a non-programmer to use traits, traitsUI and pyface to write an interactive graphical application. The reader is assumed to have some basic python scripting knowledge (see ref[1] for a basic introduction). Knowledge of numpy/scipy[2] helps understanding the data processing aspects of the examples, but may not be paramount. Some examples rely on matplotlib[3] . This document is **not** a replacement for user manuals and references of the different packages (traitsUI[4], scipy, matplotlib). It provides a "cookbook" approach, and not a reference.

This tutorial provides step-by-step guide to building a medium-size application. The example chosen is an application used to do control of a camera, analysis of the retrieved data and display of the results. This tutorial focuses on building the general structure and flow-control of the application, and on the aspects specific to traitsUI programming. Interfacing with the hardware or processing the data is left aside. The tutorial progressively introduces the tools used, and in the end present the skeleton of a real application that has been developed for real-time controlling of an experiment, monitoring through a camera, and processing the data. The tutorial goes into more and more intricate details that are necessary to build the final application. Each section is in itself independent of the following ones. The complete beginner trying to use this as an introduction should not expect to understand all the details in a first pass.

The author's experience while working on several projects in various physics labs is that code tends to be created in an 'organic' way, by different people with various levels of qualification in computer development, and that it rapidly decays to a disorganized and hard-to-maintain code base. This tutorial tries to prevent this by building an application shaped for modularity and readability.

1 From objects to dialogs using traitsUI

Creating user interfaces directly through a toolkit is a time-consuming process. It is also a process that does not integrate well in the scientific-computing work-flow, as, during the elaboration of algorithms and data-flow, the objects that are represented in the GUI are likely to change often.

Visual computing, where the programmer creates first a graphical interface and then writes the callbacks of the graphical objects, gives rise to a slow development cycle, as the work-flow is centered on the GUI, and not on the code.

TraitsUI provides a beautiful answer to this problem by building graphical representations of an object. Traits and TraitsUI have their own manuals (http://code.enthought.com/traits/) and the reader is encouraged to refer to these for more information.

We will use TraitsUI for *all* our GUIs. This forces us to store all the data and parameters in objects, which is good programming style. The GUI thus reflects the structure of the code, which makes it easier to understand and extend.

In this section we will focus on creating dialogs that allow the user to input parameters graphically in the program.

1.1 Object-oriented programming

Software engineering is a difficult field. As programs, grow they become harder and harder to grasp for the developer. This problem is not new and has sometimes been know as the "tar pit". Many attempts have been made to mitigate the difficulties. Most often they consist in finding useful abstractions that allow the developer to manipulate larger ideas, rather than their software implementation.

Code re-use is paramount for good software development. It reduces the number of code-lines required to read and understand and allows to identify large operations in the code. Functions and procedures have been invented to avoid copy and pasting code, and hide the low-level details of an operation.

Object-oriented programming allows yet more modularity and abstraction.

1.1.1 Objects, attributes and methods

Suppose you want your program to manipulate geometric objects. You can teach the computer that a point is a set of 3 numbers, you can teach it how to rotate that point along a given axis. Now you want to use spheres too. With a bit more work your program has functions to create points, spheres, etc. It knows how to rotate them, to mirror them, to scale them. So in pure procedural programming you will have procedures to rotate, scale, mirror, each one of your objects. If you want to rotate an object you will first have to find its type, then apply the right procedure to rotate it.

Object-oriented programming introduces a new abstraction: the object. It consists of both data (our 3 numbers, in the case of a point), and procedures that use and modify this data (e.g., rotations). The data entries are called "attributes" of the object and the procedures "methods". Thus with object oriented programming an object "knows" how to be rotated.

A point object could be implemented in python with:

```python
from numpy import cos, sin

class Point(object):
    """ 3D Point objects """
    x = 0.
    y = 0.
    z = 0.

    def rotate_z(self, theta):
        """ rotate the point around the Z axis """
```

```
        self.x =  cos(theta) * self.x + sin(theta) * self.y
        self.y = -sin(theta) * self.x + cos(theta) * self.y
```

This code creates a *Point* class. Points objects can be created as instances of the Point class:

```
>>> p = Point()
>>> p.x = 1
>>> p.rotate_z(pi)
>>> p.x
-1.0
>>> p.y
1.2246467991473532e-16
```

When manipulating objects, the developer does not need to know the internal details of their procedures. As long as the object has a *rotate* method, the developer knows how to rotate it.

> ***Note***: *Beginners often use objects as structures: entities with several data fields useful to pass data around in a program. Objects are much more then that: they have methods. They are 'active' data structures that know how to modify themselves. Part of the point of object-oriented programming is that the object is responsible for modifying itself through its methods. The object therefore takes care of its internal logic and the consistency between its attributes.*
>
> *In python, dictionaries make great structures and are more suited for such a use than objects.*

1.1.2 Classes and inheritance

Suppose you have already created a *Point* class that tells your program what a point is, but that you also want some points to have a color. Instead of copy-and-pasting the *Point* class and adding a color attribute, you can define a new class *ColoredPoint* that inherits all of the *Point* class's methods and attributes:

```
class ColoredPoint(Point):
    """ Colored 3D point """
    color = "white"
```

You do not have to implement rotation for the *ColoredPoint* class as it has been inherited from the *Point* class. This is one of the huge gains of object-oriented programming: objects are organized in classes and sub-classes, and method to manipulate objects are derived from the objects parent-ship: a *ColoredPoint* is only a special case of *Point*. This proves very handy on large projects.

Note: *To stress the differences between classes and their instances (objects), classes are usually named with capital letters, and objects only with lower case letters.*

1.2 An object and its representation

Objects are code entities that can be easily pictured by the developer. The TraitsUI python module allows the user to edit objects attributes with dialogs that form a graphical representation of the object.

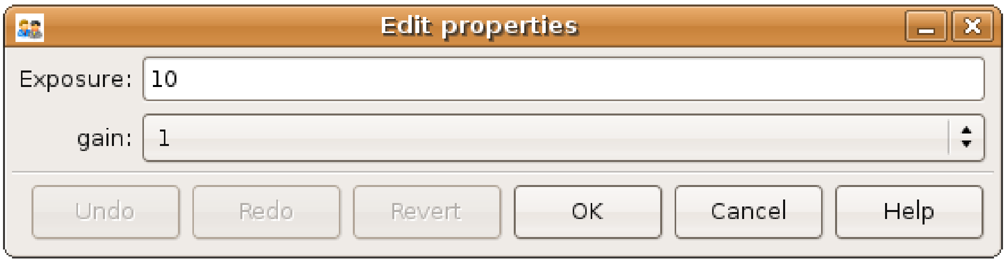
In our example application, each process or experimental device is represented in the code as an object. These objects all inherit from the *HasTraits*, class which supports creating graphical representations of attributes. To be able to build the dialog, the *HasTraits* class enforces that the types of all the attributes are specified in the class definition.

The *HasTraits* objects have a *configure_traits()* method that brings up a dialog to edit the objects' attributes specified in its class definition.

Here we define a camera object (which, in our real world example, is a camera interfaced to python through the ctypes[5] module), and show how to open a dialog to edit its properties :

```
from enthought.traits.api import *
from enthought.traits.ui.api import *

class Camera(HasTraits):
    """ Camera object """

    gain = Enum(1, 2, 3,
        desc="the gain index of the camera",
        label="gain", )

    exposure = CInt(10,
        desc="the exposure time, in ms",
        label="Exposure", )

    def capture(self):
        """ Captures an image on the camera and returns it """
        print "capturing an image at %i ms exposure, gain: %i" % (
                self.exposure, self.gain )

if __name__ == "__main__":
    camera = Camera()
    camera.configure_traits()
    camera.capture()
```

The *camera.configure_traits()* call in the above example opens a dialog that allows the user to modify the camera object's attributes:



This dialog forms a graphical representation of our camera object. We will see that it can be embedded in GUI panels to build more complex GUIs that allow us to control many objects.

We will build our application around objects and their graphical representation, as this mapping of the code to the GUI helps the developer to understand the code.

1.3 Displaying several objects in the same panel

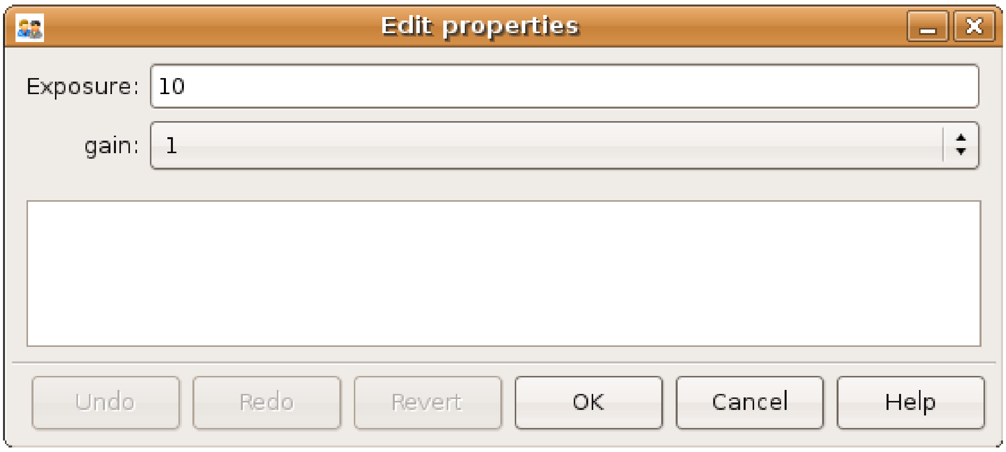
We now know how to build a dialog from objects. If we want to build a complex application we are likely to have several objects, for instance one corresponding to the camera we want to control, and one describing the experiment that the camera monitors. We do not want to have to open a new dialog per object: this would force us to describe the GUI in terms of graphical objects, and not structural objects. We want the GUI to be a natural representation of our objects, and we want the Traits module to take care of that.

The solution is to create a container object, that has as attributes the objects we want to represent. Playing with the View attribute of the object, we can control how the representation generated by Traits looks like (see the TraitsUI manual):

```
from enthought.traits.api import *
from enthought.traits.ui.api import *

class Camera(HasTraits):
    gain = Enum(1, 2, 3, )
    exposure = CInt(10, label="Exposure", )

class TextDisplay(HasTraits):
    string = String()

    view= View( Item('string', show_label=False, springy=True, style='custom' ))

class Container(HasTraits):
    camera = Instance(Camera)
    display = Instance(TextDisplay)

    view = View(
                Item('camera', style='custom', show_label=False, ),
                Item('display', style='custom', show_label=False, ),
```

```
              )

container = Container(camera=Camera(), display=TextDisplay())
container.configure_traits()
```

The call to *configure_traits()* creates the following dialog, with the representation of the *Camera* object created is the last example on top, and the *Display* object below it:



The *View* attribute of the *container* object has been tweaked to get the representation we are interested in: traitsUI is told to display the *camera* item with a *'custom'* style, which instructs it to display the representation of the object inside the current panel. The *'show_label'* argument is set to *False* as we do not want the name of the displayed object ('camera', for instance) to appear in the dialog. See the traitsUI manual for more details on this powerful feature.

The *camera* and *display* objects are created during the call to the creator of the *container* object, and passed as its attributes immediately: *"container = Container(camera=Camera(), display=TextDisplay())"*

1.4 Writing a "graphical script"

If you want to create an application that has a very linear flow, popping up dialogs when user input is required, like a "setup wizard" often used to install programs, you already have all the tools to do it. You can use object oriented programming to write your program, and call the objects *configure_traits* method each time you need user input. This might an easy way to modify an existing script to make it more user friendly.

The following section will focus on making interactive programs, where the user uses the graphical interface to interact with it in a continuous way.

2 From graphical to interactive

In an interactive application, the program responds to user interaction. This requires a slight paradigm shift in our programming methods.

2.1 Object-oriented GUIs and event loops

In a GUI application, the order in which the different parts of the program are executed is imposed by the user, unlike in a numerical algorithm, for instance, where the developer chooses the order of execution of his program. An event loop allows the programmer to develop an application in which each user action triggers an event. Interactions with objects generate calls to their methods. These calls are placed on an "event stack". The event loop process each call on the event queue one after the other, thus emptying the event queue. The flow of the program is still sequential (two code blocks never run at the same time in an event loop), but the execution order is chosen by the user, and not by the developer.

A complex GUI is made of a large numbers of graphical elements, called widgets (e.g., text boxes, check boxes, buttons, menus). Each of these widgets has specific behaviors associated with user interaction (modifying the content of a text box, clicking on a button, opening a menu). It is natural to use objects to represent the widgets, with their behavior being set in the object's methods. Interacting with these objects adds "callbacks" to the event queue.

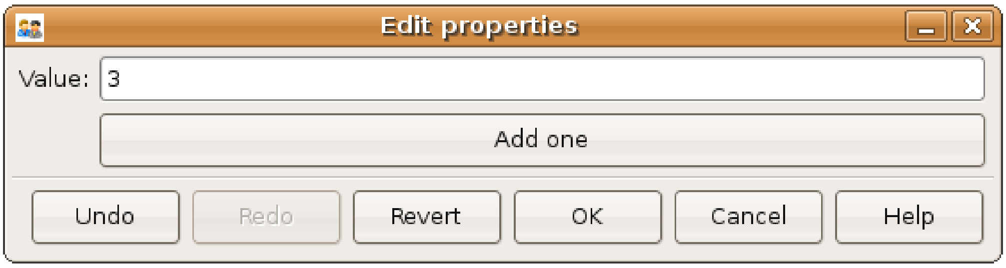
Creating dialogs with traitsUI allows the developer to not worry about widgets, but to deal only with objects and their attributes. This is a fabulous gain as the widgets no longer appear in the code, but only the attributes they are associated to. A *HasTraits* object has an *edit_traits()* method that creates a graphical panel to edit its attributes. This method creates and returns the panel, but does not start its event loop. The panel is not yet "alive", unlike with the *configure_traits()* method. A call to the *start_event_loop()* method of the *GUI* object provided in the pyface module is required to start the event loop.

Here is a very simple example of an interactive application built with traitsUI:

```
from enthought.traits.api import *
from enthought.pyface.api import GUI
from enthought.traits.ui.api import View, Item, ButtonEditor

class Counter(HasTraits):
    value =  Int()
    add_one = Button()

    def _add_one_fired(self):
        self.value +=1

    view = View('value', Item('add_one', show_label=False ))
```

```
Counter().edit_traits()
GUI().start_event_loop()
```

This creates a dialog with one integer represented, and a button, representing the *add_one* event. Clicking on the button adds the *_add_one_fired()* method to the event queue, and this method gets executed as soon as the GUI is ready to handle it. Most of the time that is almost immediately.



Note*: For older versions of pyface, you may need to remove ".api" part from the line that imports the pyface object GUI above:*

```
from enthought.pyface import GUI
```

2.2 Embedding TraitsUI in pyface panels

If we want to have a graphical application in which we represent several objects, and allow them to interact via their methods, we need a container for the panels created by TraitsUI.

These panels are actually made of widgets coming from the wxPython toolkit. They can thus be inserted in wxPython applications. Pyface is an abstraction layer on top of wxPython that provides objects very well suited to combine panels into complex applications without getting into the details of the creation of the wxPython objects.

To create a panel that can be embedded in a larger wxPython GUI from a HasTraits object, we need to use its *edit_traits()* method. Using the *'kind="subpanel"'* keyword argument forces the dialog to be embedded as a sub-panel of its parent window, and not appear as a separate window.

A simple example of an event loop driven application built in a pyface component:

```
from enthought.traits.api import *
from enthought.pyface.api import SplitApplicationWindow, GUI
from enthought.traits.ui.api import View, Item, ButtonEditor

class TextDisplay(HasTraits):
    string = String()
```

```python
    view= View( Item('string', show_label=False, springy=True, style='custom' ))

class Camera(HasTraits):
    capture = Button()
    display = Instance(TextDisplay)

    view = View(Item('capture', show_label=False), )

    def _capture_fired(self):
        self.display.string += "Captured fired\n"

class MainWindow(SplitApplicationWindow):
    display = Instance(TextDisplay)
    camera = Instance(Camera)

    def _create_lhs(self, parent):
        self.display = TextDisplay()
        return self.display.edit_traits(parent = parent,
                                        kind="subpanel").control

    def _create_rhs(self, parent):
        self.camera = Camera(display=self.display)
        return self.camera.edit_traits(parent=parent,
                                       kind="subpanel").control

if __name__ == '__main__':
    MainWindow().open()
    GUI().start_event_loop()
```

The resulting application is created:

The above code creates 2 classes for the contents of the experiment: a *Camera* class and a *TextDisplay* class. These two classes are sub-classes of the *HasTraits* class, which means they have automatically generated GUIs that represent them. A *MainWindow* class is created, inheriting from the *SplitApplicationWindow* class. This class is a pyface component that creates a window split in two panels, each of which we use to host the *HasTraits* objects.

Each panel is created through the *_create_lhs()* and *_create_rhs()* methods of the *SplitApplicationWindow* that are called during the call to its *open()* method. We use these methods to trap the dialogs created by the Traits module from a *Camera* and a *TextDisplay*.

All in all, once the main window is created, it has a *Camera* object and a *TextDisplay* as attributes, and has their representation in each of its panels. The *TextDisplay* class is nothing but a container for a string. Its representation is a text box displaying the string. The *Camera* class has a *capture Button*. When the button is pressed, the event is fired, and the *_capture_fired* method is called. This method adds a line to the *string* attribute of the *TextDisplay* object. As that string is represented in a text box, the line appears immediately.

To allow the *Camera* object to modify an attribute of the *TextDisplay* object, the latter is stored as an attribute of the former: *camera.display* is nothing but a reference to the *display* object that is created in the initialization call of the *camera* object: *"Camera(display=self.display)"*.

Using *Button* traits and a clever set of objects interacting with each others, complex interactive applications can be built. These applications are governed by the events generated by the user, in contrast to script-like applications (batch programming). Executing a long operation in the event loop blocks the reactions of the user-interface, as other events callbacks are not processed as long as the long operation is not finished. In the next section we will see how we can execute several operations in the same time.

3 Breaking the flow in multiple threads

3.1 What are threads ?

A standard python program executes in a sequential way. Consider the following code snippet :

```
do_a()
do_b()
do_c()
```

do_b() is not called until *do_a()* is finished. Even in event loops everything is sequential. In some situation this can be very limiting. Suppose we want to capture an image from a camera and that it is a very lengthy operation. Suppose also that no other operation in our program requires the capture to be complete. We would like to have a different "timeline" in which the camera capture instructions can happen in a sequential way, while the rest of the program continues in parallel.

Threads are the solution to this problem: a thread is a portion of a program that can run concurrently with other portions of the program.

Programming with threads is difficult as instructions are no longer executed in the order they are specified and the output of a program can vary from a run to another, depending on subtle timing issues. These problems are known as "race conditions" and to minimize them you should avoid accessing the same objects in different threads. Indeed if two different threads are modifying the same object at the same time, unexpected things can happen.

3.2 Threads in python

In python a thread can be implemented with a *Thread* object, from the threading[6] module. To create your own execution thread, subclass the *Thread* object and put the code that you want to run in a separate thread in its *run* method. You can start your thread using its *start* method:

```python
from threading import Thread
from time import sleep

class MyThread(Thread):
    def run(self):
```

```
        sleep(2)
        print "MyThread done"

my_thread = MyThread()

my_thread.start()
print "Main thread done"
```

The above code yields the following output:

```
Main thread done
MyThread done
```

3.3 Getting threads and the GUI event loop to play nice

Suppose you have a long-running job in a TraitsUI application. If you implement this job as an event placed on the event loop stack, it is going to freeze the event loop while running, and thus freeze the UI, as events will accumulate on the stack, but will not be processed as long as the long-running job is not done (remember, the event loop is sequential). To keep the UI responsive, a thread is the natural answer.

Most likely you will want to display the results of your long-running job on the GUI. However, as usual with threads, one has to be careful not to trigger race-conditions. Naively manipulating the GUI objects in your thread will lead to race conditions, and unpredictable crash: suppose the GUI was repainting itself (due to a window move, for instance) when you modify it.

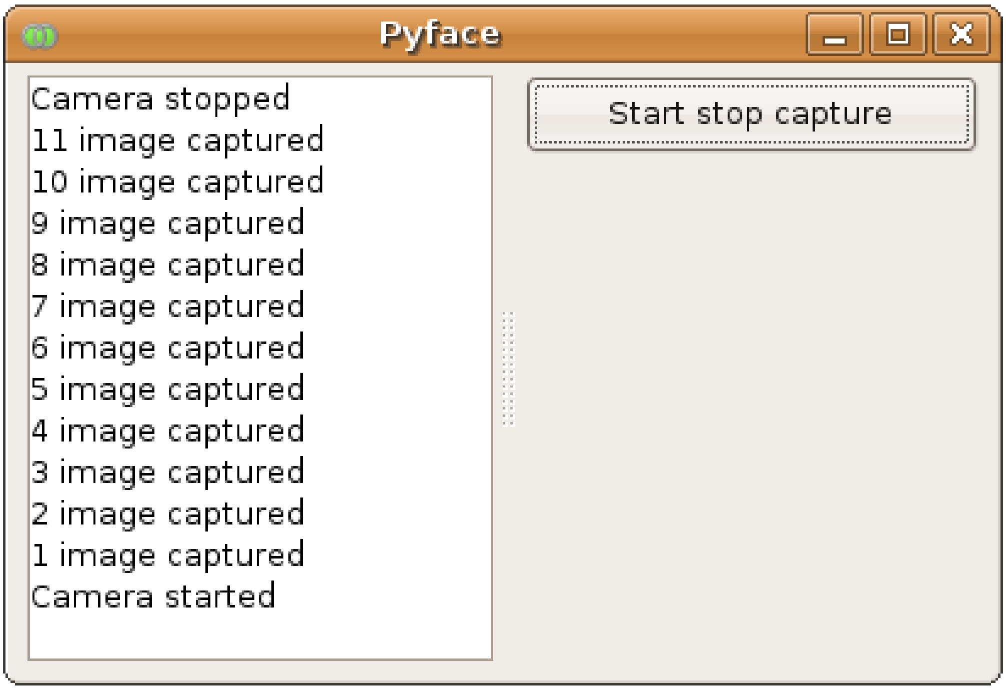
In a pyface application, if you start a thread, GUI event will still be processed by the GUI event loop. To avoid collisions between your thread and the event loop, the proper way of modifying a GUI object is to insert the modifications in the event loop, using the *GUI.invoke_later()* call. That way the GUI will apply your instructions when it has time.

Recent versions of the TraitsUI module (post October 2006) propagate the changes you make to a *HasTraits* object to its representation in a thread-safe way. However it is important to have in mind that modifying an object with a graphical representation is likely to trigger race-conditions as it might be modified by the graphical toolkit while you are accessing it. Here is an example of code inserting the modification to traits objects by hand in the event loop:

```
from threading import Thread
from time import sleep
from enthought.traits.api import *
from enthought.pyface.api import SplitApplicationWindow, GUI
from enthought.traits.ui.api import View, Item, ButtonEditor

class TextDisplay(HasTraits):
    string = String()
```

```python
    view= View( Item('string',show_label=False, springy=True, style='custom' ))

    def add_line(self, string):
        GUI.invoke_later(setattr, self, 'string', string + "\n" + self.string)

class CaptureThread(Thread):
    def run(self):
        self.display('Camera started')
        n_img = 0
        while not self.wants_abort:
            sleep(.5)
            n_img += 1
            self.display('%d image captured' % n_img)
        self.display('Camera stopped')

class Camera(HasTraits):
    start_stop_capture = Button()
    display = Instance(TextDisplay)
    capture_thread = Instance(CaptureThread)

    view = View( Item('start_stop_capture', show_label=False ))

    def _start_stop_capture_fired(self):
        if self.capture_thread and self.capture_thread.isAlive():
            self.capture_thread.wants_abort = True
        else:
            self.capture_thread = CaptureThread()
            self.capture_thread.wants_abort = False
            self.capture_thread.display = self.display.add_line
            self.capture_thread.start()

class MainWindow(SplitApplicationWindow):
    display = Instance(TextDisplay)
    camera = Instance(Camera)

    def _create_lhs(self, parent):
        self.display = TextDisplay()
        return self.display.edit_traits(parent = parent,
                            kind="subpanel").control
    def _create_rhs(self, parent):
        self.camera = Camera(display=self.display)
        return self.camera.edit_traits(parent = parent,
                            kind="subpanel").control


if __name__ == '__main__':
    MainWindow().open()
    GUI().start_event_loop()
```

This creates an application with a button that starts or stop a continuous camera acquisition loop.



When the "Start stop capture" button is pressed the *_start_stop_capture_fired* method is called. It checks to see if a *CaptureThread* is running or not. If none is running, it starts a new one. If one is running, it sets its *wants_abort* attribute to true.

The thread checks every half a second to see if its attribute *wants_abort* has been set to true. If this is the case, it aborts. This is a simple way of ending the thread through a GUI event.

Using different threads lets the operations avoid blocking the user interface, while also staying responsive to other events. In the real-world application that serves as the basis of this tutorial, there are 2 threads and a GUI event loop.

The first thread is an acquisition loop, during which the program loops, waiting for a image to be captured on the camera (the camera is controlled by external signals). Once the image is captured and transfered to the computer, the acquisition thread saves it to the disk and spawns a thread to process the data, then returns to waiting for new data while the processing thread processes the data. Once the processing thread is done, it displays its results (by inserting the display events in the GUI event loop) and dies. The acquisition thread refuses to spawn a new processing thread if there still is one running. This makes sure that data is never lost, no matter how long the processing might be.

There are thus up to 3 set of instructions running concurrently: the GUI event loop, responding to user-generated events, the acquisition loop, responding to hardware-generated events, and the processing jobs, doing the numerical intensive work.

In the next section we are going to see how to add a home-made element to pyface and traits, in order to add new possibilities to our application.

4 Adding a matplotlib figure to our application

This section gives a few guidelines on how to build your own pyface widgets. It involves a bit of wxPython code that may be hard to understand if you do not know wxPython. The reason it appears in this tutorial is that I wanted a matplotlib widget. It is not necessary to fully understand the code of this section to be able to read on.

I should stress that there already exists a plotting module that provides pyface widgets for plotting, and that is very well integrated with traits: chaco[7].

4.1 Pyface: a GUI elements module

Pyface is a fantastic abstraction above the GUI toolkit library (wxPython, in our case) as it allows, in combination with traitsUI, the programmer not to worry about low-level details of placement or creation of graphical elements.

Pyface provides a set of classes that the developer can use to create objects that will populate graphical interfaces. The graphical elements are called "widgets".

Building a Pyface interface involves creating classes that put together these basic building blocks:

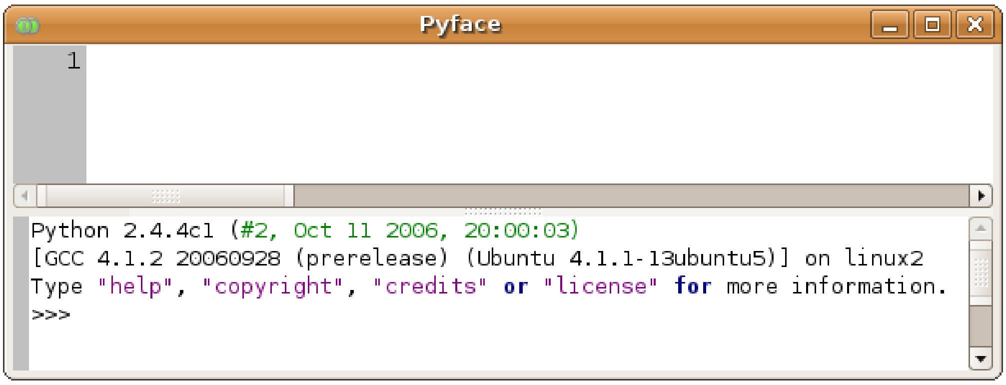
- Everything that has a representation on the screen is a widget and inherits from the *Widget* class.
- Everything that opens and closes is a window, and inherits from the *Window* class (which is a subclass of *Widget*).
- A widget has a control, which is passed to its parent when it is created, and can have one or more contents, created at initialization through method like *_create_contents*, or *_create_lhs* that return the content's control.

To create a user interface, a window is populated with widgets, for instance a *SplitApplicationWindow* has two widgets, and is represented by a window divided in two.

```
from enthought.traits.api import Any, Instance, Float, Str
from enthought.pyface.api import SplitApplicationWindow, PythonShell, GUI, \
            PythonEditor

class MainWindow(SplitApplicationWindow):

    shell = Instance(PythonShell)
    editor =  Instance(PythonEditor)

    ratio = Float(0.5)
```

```
    direction = Str('horizontal')

    def _create_lhs(self, parent):
        self.editor = PythonEditor(parent)
        return self.editor.control

    def _create_rhs(self, parent):
        shell = self.shell = PythonShell(parent)
        return self.shell.control

window = MainWindow()
window.open()
window.size = (600, 200)
GUI().start_event_loop()
```

The resulting window is divided in two, with a python editor instance in the upper part, and a python shell instance in the lower part:



By combining *SplitWidget* objects, within traitsUI created panels, complex UIs can be created, but this is out of the scope of this article.

4.2 Making a pyface widget from a MatPlotLib plot

To use pyface, the developer does not need to know its internals. However pyface does not provide a widget for every need. If we want to insert a powerful tool for plotting we have to get our hands a bit dirty and create our own pyface widget.

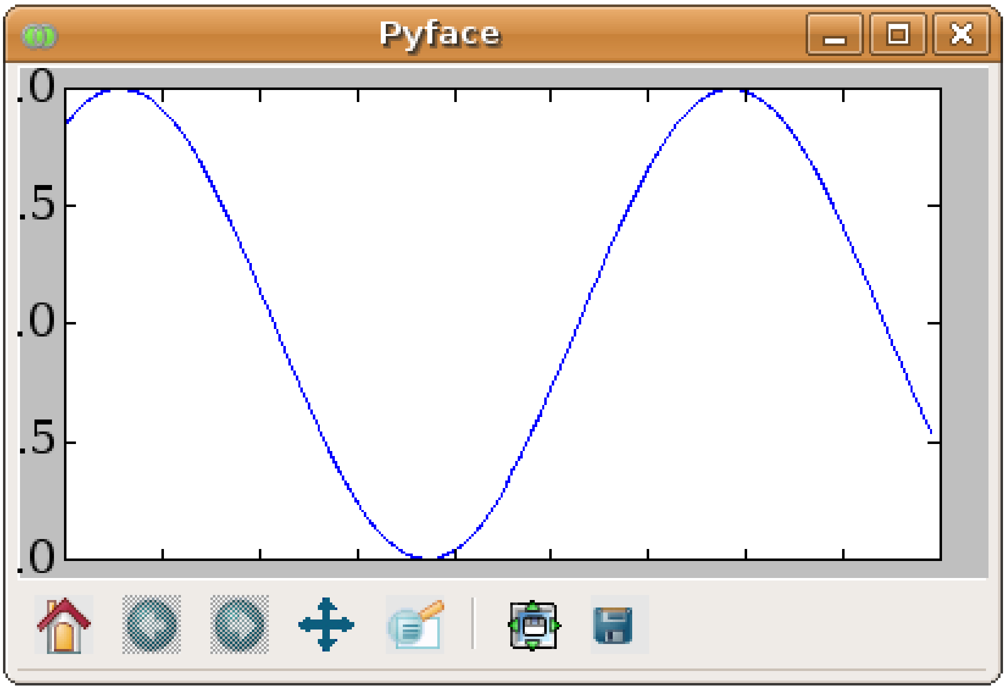
This involves some wxPython coding, as we need to translate a wxPython object in a pyface widget by providing the standard pyface methods. The pyface widget has a *control* attribute, that corresponds to the *control* attribute of a normal wxPython object. It is also a HasTrait derived object.

The simplest implementation of a pyface widget is to wrap a wxPython panel. The initialization code creates the *control* attribute. A few more attributes may be handy to provide control of the object wrapped. Here is an example of wrapping a matplotlib figure, and its toolbox, so that it can easily be used by a pyface application.

```
import wx

import matplotlib
# We want matplotlib to use a wxPython backend
matplotlib.use('WXAgg')
from matplotlib.backends.backend_wxagg import FigureCanvasWxAgg as FigureCanvas
from matplotlib.figure import Figure
from matplotlib.backends.backend_wx import NavigationToolbar2Wx

# The try/except block is here to accomodate different version of the
# enthought library
try:
    from enthought.traits.api import Any, Instance, Float, Str
    from enthought.pyface.api import Widget
except ImportError:
    from enthought.pyface import Widget
    from enthought.traits import Any, Instance, Float, Str


class MPLWidget(Widget):
    """ A MatPlotLib PyFace Widget """
    # Public traits
    figure = Instance(Figure)
    axes = Instance('matplotlib.axes.Axes')
    mpl_control = Instance(FigureCanvas)

    # Private traits.
    _panel = Any
    _sizer = Any
    _toolbar = Any

    def __init__(self, parent, **traits):
        """ Creates a new matplotlib widget. """
        # Calls the init function of the parent class.
        super(MPLWidget, self).__init__(**traits)
        self.control = self._create_control(parent)

    def _create_control(self, parent):
        """ Create the toolkit-specific control that represents the widget. """
        # The panel lets us add additional controls.
        if isinstance(parent,wx.Panel):
            self._panel = parent
        else:
            self._panel = wx.Panel(parent, -1, style=wx.CLIP_CHILDREN)
        self._sizer = wx.BoxSizer(wx.VERTICAL)
        self._panel.SetSizer(self._sizer)
        # matplotlib commands to create a figure, and add an axes object
        self.figure = Figure()
```

```python
        self.axes = self.figure.add_axes([0.05, 0.04, 0.9, 0.92])
        self.mpl_control = FigureCanvas(self._panel, -1, self.figure)
        self._sizer.Add(self.mpl_control, 1, wx.LEFT | wx.TOP | wx.GROW)
        self._toolbar = NavigationToolbar2Wx(self.mpl_control)
        self._sizer.Add(self._toolbar, 0, wx.EXPAND)
        self._sizer.Layout()
        self.figure.canvas.SetMinSize((10,10))
        return self._panel

if __name__ == "__main__":
    # Create a window to demo the widget
    from enthought.pyface.api import ApplicationWindow, GUI

    class MainWindow(ApplicationWindow):
        figure = Instance(MPLWidget)
        def _create_contents(self, parent):
            self.figure = MPLWidget(parent)
            return self.figure.control

    window = MainWindow()
    from pylab import arange, sin
    x = arange(1, 10, 0.1)
    window.open()
    window.figure.axes.plot(x, sin(x))
    GUI().start_event_loop()
```

This code first creates a pyface widget containing a matplotlib figure, and then a window to host it:



The *MPLWidget* object created in the above example can be imported in a traitsUI application and combined with the power of traits. This object exposes a matplotlib canvas through its canvas attribute. The matplotlib user guide[3] details how this object can be used for plotting.

5 Putting it all together: a sample application

The real world problem that motivated the writing of this tutorial is an application that retrieves data from a camera, processes it and displays results and controls to the user. We now have all the tools to build such an application. This section gives the code of a skeleton of this application. This application actually controls a camera on a physics experiment (Bose-Einstein condensation), at the university of Toronto.

The reason I am providing this code is to give an example to study of how a full-blown application can be built. This code can be found in the tutorial's zip file (it is the file application.py).

- The camera will be built as an object. Its real attributes (exposure time, gain...) will be represented as the object's attributes, and exposed through traitsUI.
- The continuous acquisition/processing/user-interaction will be dealt with appropriate threads, as discussed in section 2.3.
- The plotting of the results will be done through the MPLWidget object.

5.1 The imports

The MPLWidget is imported from last example.

```
from threading import Thread
from time import sleep
from enthought.traits.api import *
from enthought.pyface.api import SplitApplicationWindow, GUI
from enthought.traits.ui.api import View, Item, ButtonEditor, Group
from mplwidget import MPLWidget
from scipy import *
```

5.2 User interface objects

These objects store information for the program to interact with the user via traitsUI.

```
class Experiment(HasTraits):
    """ Object that contains the parameters that control the experiment,
        modified by the user.
    """
    width = Float(30, label="Width", desc="width of the cloud")
    x = Float(50, label="X", desc="X position of the center")
    y = Float(50, label="Y", desc="Y position of the center")


class Results(HasTraits):
    """ Object used to display the results.
    """
    width = Float(30, label="Width", desc="width of the cloud")
    x = Float(50, label="X", desc="X position of the center")
    y = Float(50, label="Y", desc="Y position of the center")

    view = View( Item('width', style='readonly'),
                 Item('x', style='readonly'),
                 Item('y', style='readonly'),
               )
```

The camera object also is a real object, and not only a data structure: it has a method to acquire an image (or in our case simulate acquiring), using its attributes as parameters for the acquisition.

```
class Camera(HasTraits):
    """ Camera objects. Implements both the camera parameters controls, and
        the picture acquisition.
    """
    exposure = Float(1, label="Exposure", desc="exposure, in ms")
    gain = Enum(1, 2, 3, label="Gain", desc="gain")
```

```python
    def acquire(self, experiment):
        X, Y = indices((100, 100))
        Z = exp(-((X-experiment.x)**2+(Y-experiment.y)**2)/experiment.width**2)
        Z += 1-2*rand(100,100)
        Z *= self.exposure
        Z[Z>2] = 2
        Z = Z**self.gain
        return(Z)
```

5.3 Threads and flow control

There are three threads in this application:

- *The GUI event loop, the only thread running at the start of the program.*
- *The acquisition thread, started through the GUI. This thread is an infinite loop that waits for the camera to be triggered, retrieves the images, displays them, and spawns the processing thread for each image recieved.*
- *The processing thread, started by the acquisition thread. This thread is responsible for the numerical intensive work of the application. it processes the data and displays the results. It dies when it is done. One processing thread runs per shot acquired on the camera, but to avoid accumulation of threads in the case that the processing takes longer than the time lapse between two images, the acquisition thread checks that the processing thread is done before spawning a new one.*

```python
class AcquisitionThread(Thread):
    """ Acquisition loop. This is the worker thread that retrieves images
        from the camera, displays them, and spawns the processing job.
    """
    wants_abort = False

    def process(self, image):
        """ Spawns the processing job.
        """
        try:
            if self.processing_job.isAlive():
                self.display("Processing to slow")
                return
        except AttributeError:
            pass
        self.processing_job = ProcessingJob()
        self.processing_job.image = image
        self.processing_job.results = self.results
        self.processing_job.start()
```

```
    def run(self):
        """ Runs the acquisition loop.
        """
        self.display('Camera started')
        n_img = 0
        while not self.wants_abort:
            n_img += 1
            img =self.acquire(self.experiment)
            self.display('%d image captured' % n_img)
            self.image_show(img)
            self.process(img)
            sleep(1)
        self.display('Camera stopped')

class ProcessingJob(Thread):
    """ This thread gets spawned each time data is acquired.
    """
    def run(self):
        im = self.image
        X, Y = indices(im.shape)
        x = sum(X*im)/sum(im)
        y = sum(Y*im)/sum(im)
        width = sqrt(abs(sum(((X-x)**2+(Y-y)**2)*im)/sum(im)))
        GUI.invoke_later(setattr, self.results, 'x', x)
        GUI.invoke_later(setattr, self.results, 'y', y)
        GUI.invoke_later(setattr, self.results, 'width', width)
```

5.4 The GUI elements

The GUI of this application is separated in two (and thus created by a sub-class of *SplitApplicationWindow*).

On the left a plotting area, made of an *MPLWidget* object, displays the images acquired by the camera.

On the right a panel hosts the TraitsUI representation of a *ControlPanel* object. This object is mainly a container for our other objects, but it also has an *Button* for starting or stopping the acquisition, and a string (represented by a textbox) to display informations on the acquisition process. The view attribute is tweaked to produce a pleasant and usable dialog. Tabs are used as it help the display to be light and clear.

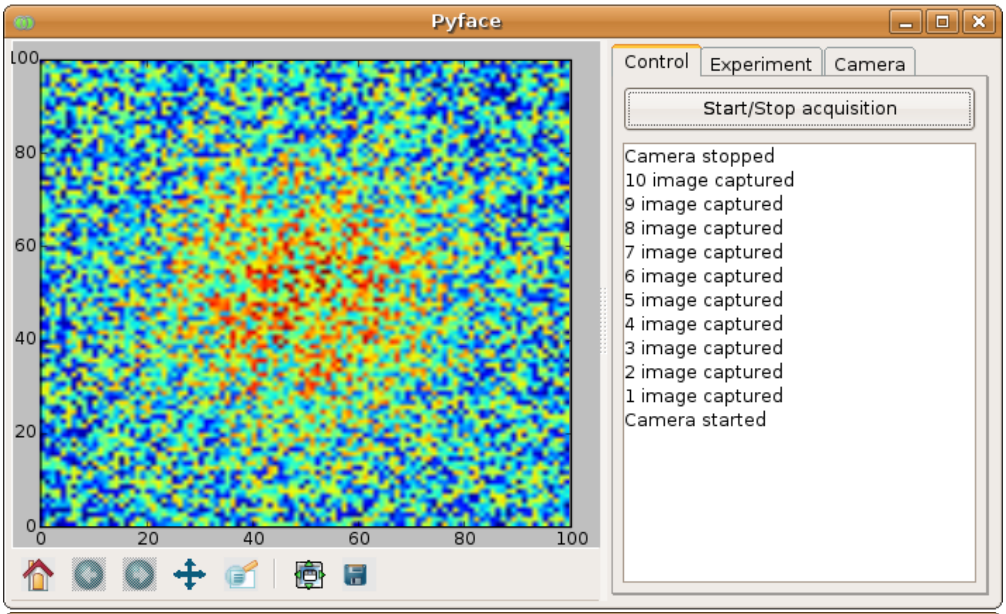
```
class ControlPanel(HasTraits):
    """ This object is the core of the traitsUI interface. Its view is
        the right panel of the application, and it hosts the method for
        interaction between the objects and the GUI.
    """
    experiment = Instance(Experiment)
    camera = Instance(Camera)
```

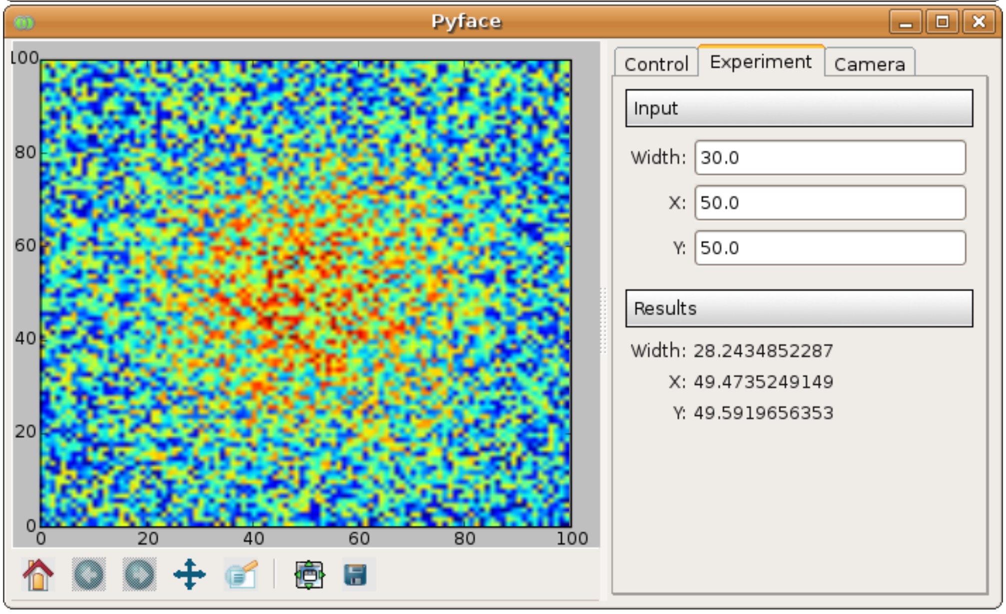
```
    mplwidget = Instance(MPLWidget)
    results = Instance(Results)
    start_stop_acquisition = Button("Start/Stop acquisition")
    results_string =  String()
    acquisition_thread = Instance(AcquisitionThread)
    view = View(Group(
                Group(
                  Item('start_stop_acquisition', show_label=False ),
                  Item('results_string',show_label=False,
                                  springy=True, style='custom' ),
                  label="Control"),
                Group(
                  Group(
                    Item('experiment', style='custom', show_label=False),
                    label="Input",),
                  Group(
                    Item('results', style='custom', show_label=False),
                    label="Results",),
                label='Experiment'),
                Item('camera', style='custom', show_label=False),
               layout='tabbed'),
               )

    def _start_stop_acquisition_fired(self):
        """ Callback of the "start stop acquisition" button. This starts
            the acquisition thread, or kills it/
        """
        if self.acquisition_thread and self.acquisition_thread.isAlive():
            self.acquisition_thread.wants_abort = True
        else:
            self.acquisition_thread = AcquisitionThread()
            self.acquisition_thread.display = self.add_line
            self.acquisition_thread.acquire = self.camera.acquire
            self.acquisition_thread.experiment = self.experiment
            self.acquisition_thread.image_show = self.image_show
            self.acquisition_thread.results = self.results
            self.acquisition_thread.start()

    def add_line(self, string):
        """ Adds a line to the textbox display in a thread-safe way.
        """
        GUI.invoke_later(setattr, self, 'results_string',
                              (string + "\n" + self.results_string)[0:1000] )

    def image_show(self, image):
        """ Plots an image on the canvas in a thread safe way.
        """
        self.mplwidget.axes.images=[]
```

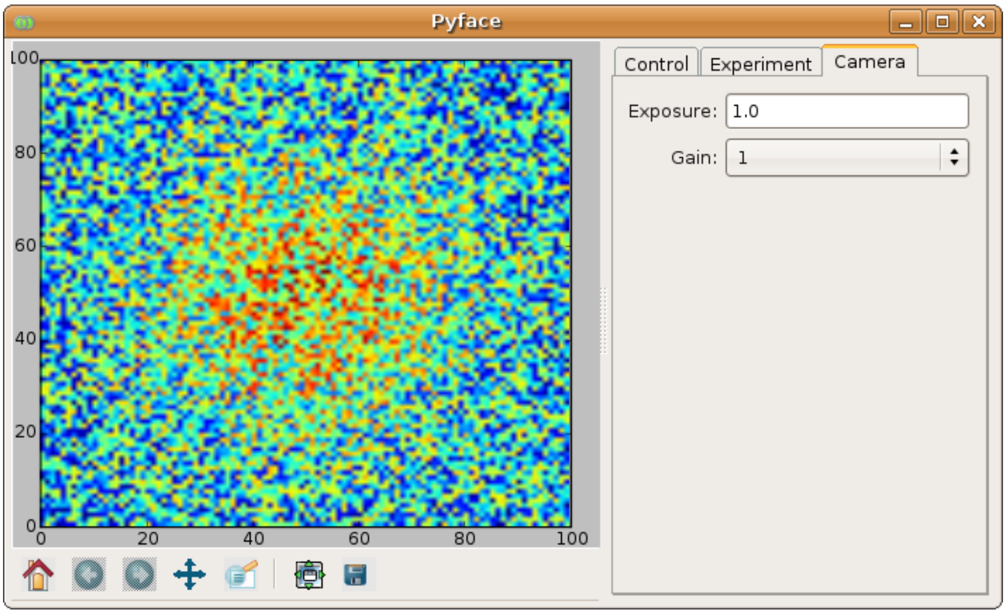
```
        self.mplwidget.axes.imshow(image, aspect='auto')
        GUI.invoke_later(self.mplwidget.figure.canvas.draw)


class MainWindow(SplitApplicationWindow):
    """ The main window, here go the instructions to create and destroy
        the application.
    """
    mplwidget = Instance(MPLWidget)
    panel = Instance(ControlPanel)
    ratio = Float(0.6)

    def _create_lhs(self, parent):
        self.mplwidget = MPLWidget(parent)
        return self.mplwidget.control

    def _create_rhs(self, parent):
        self.panel = ControlPanel(camera=Camera(), experiment=Experiment(),
                        mplwidget=self.mplwidget, results=Results())
        return self.panel.edit_traits(parent = parent, kind="subpanel").control

    def _on_close(self, event):
        if ( self.panel.acquisition_thread
                    and self.panel.acquisition_thread.isAlive() ):
            self.panel.acquisition_thread.wants_abort = True
            while self.panel.acquisition_thread.isAlive():
                sleep(0.1)
        self.close()

if __name__ == '__main__':
    gui = GUI()
    window = MainWindow()
    window.size = (700, 400)
    window.open()
    gui.start_event_loop()
```

When the acquisition loop is created and running, the mock camera object produces noisy gaussian images, and the processing code estimates the parameters of the gaussian.

Here are screenshots of the three different tabs of the application:


Pyface
Control
Experiment
Camera
Start/Stop acquisition
Camera stopped
10 image captured
9 image captured
8 image captured
7 image captured
6 image captured
5 image captured
4 image captured
3 image captured
2 image captured
1 image captured
Camera started


Pyface
Control
Experiment
Camera
Input
Width: 30.0
X: 50.0
Y: 50.0
Results
Width: 28.2434852287
X: 49.4735249149
Y: 49.5919656353



Conclusion

I have summarized here all what most scientists need to learn in order to be able to start building applications with traitsUI. Using the traitsUI module to its full power requires you to move away from the procedural type of programming most scientists are used to, and think more in terms of objects and flow of information and control between them. I have found that this paradigm shift, although a bit hard, has been incredibly rewarding in terms of my own productivity and my ability to write compact and readable code.

Good luck!

Acknowledgments

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References

[1] python tutorial: http://docs.python.org/tut/tut.html

[2] The scipy website: http://www.scipy.org

[3] The matplotlib website: http://matplotlib.sourceforge.net

[4] The traits and traitsUI user guide: http://code.enthought.com/traits

[5] ctypes: http://starship.python.net/crew/theller/ctypes/

[6] threading: http://docs.python.org/lib/module-threading.html

[7] chaco: http://code.enthought.com/chaco/