PCOT design notes

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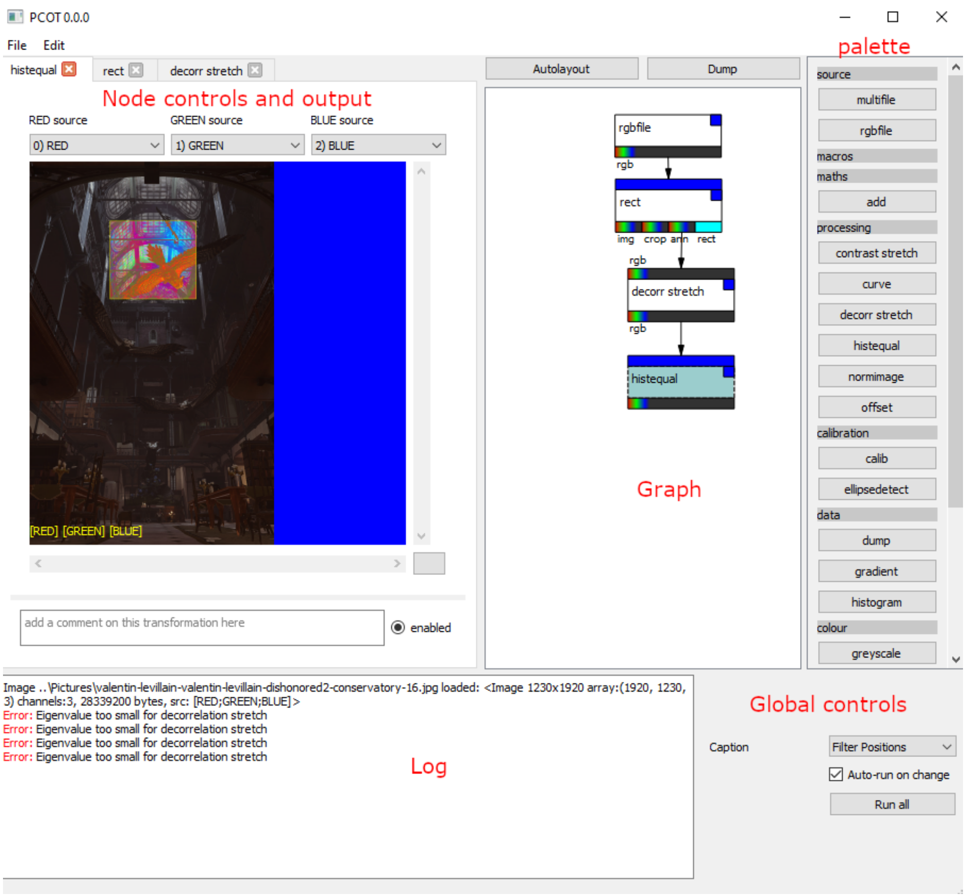
1 Introduction

These notes provide some architectural details for PCOT to help maintainers. I'll try to keep them up to date.

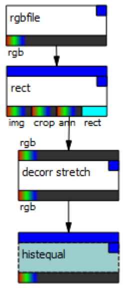
PCOT is based around a directed graph of nodes which perform transformations of data. For this reason, the nodes are sometimes called "transforms" and are represented by the `XForm` class in the code. Usually the data in question is an image, or rather an "image cube": these have an arbitrary number of channels, not just the typical RGB or greyscale. However, the data can be anything at all — it depends on the node. There is some typechecking when constructing the graph: for exampel, you can't connect a "rectangle" output to an "image" input. The entire application is shown in Fig. 1. On the right is a "palette" from which nodes can be selected to add to the graph, while on the left is an area which can show controls for each node in the graph, while in the centre-right is the graph itself. This is shown in more detail in Fig. 2.



app.png

Figure 1: The PCOT application

This will take an RGB image from a file, perform a decorrelation stretch, and then a histogram equalisation on the three channels. It will only do this to a rectangular portion of the image (defined by the `rect` node), annotating the region with some text defined in the `rect` node's controls. The control region is currently showing the output of the histogram equalisation.



graph.png

Figure 2: An example graph

2 The data model

The data model consists of two parts — the data itself (largely image cube data) and the graph. By far the most important kind of data from the point of view of this document is the image data, which ties into the user interface in complex ways. Other forms of data do exist, but these are much simpler.

2.1 Graph and nodes

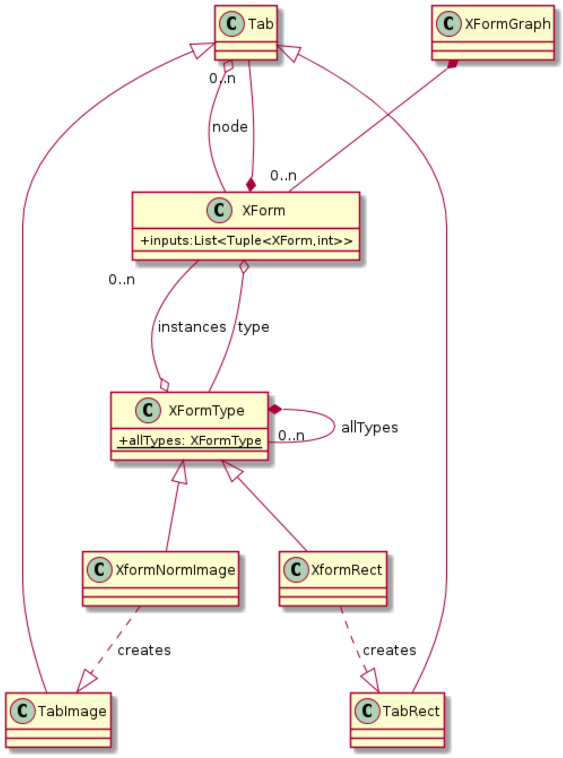
The graph is a directed graph of nodes represented by the `XFormGraph` class. Each node is an instance of `XForm` (short for "transform node"). The function of each node is determined by its `type` field, which references an `XFormType` singleton. See Fig. 3 for an overview.

2.1.1 XFormType and type registration

Each node type is represented by a subclass of `XFormType`, and each subclass has a singleton to which nodes of that type link. For example, the *rect* node's behaviour is specified by the `XformRect` class, which has a singleton instance. All `XForm` nodes which are *rect* nodes have a `type` field pointing to this singleton.

The singletons are automatically created and registered when the class is defined, through the `@xformtype` decorator. This does the following:

- Creates an instance of the class;
- Creates an MD5 hash of the class' source code which is stored inside the type singleton for version control;



xform.png

Figure 3: `XForm` and graph model

- Changes the semantics of the class constructor so that it always returns the instance we just created (thus making the class a singleton).

The base constructor for `XFormType` adds the singleton to a dictionary class variable `allTypes`, so we can always obtain the singleton object and create new nodes which perform that node type.

2.1.2 XFormType methods

In order to perform a node's action, the type classes must contain the following methods:

- `init(node:XForm)` : initialise any extra data inside the node required to perform this type's behaviour
- `perform(node:XForm)` : perform this node's behaviour — read any inputs, manipulate the data, set the outputs.
- `createTab(node:XForm, window:MainWindow)` : create a UI tab to edit/view this node.

Several other methods may optionally be overridden.

2.1.3 Linkage

XForm node objects are linked together by their inputs. Each XForm contains an inputs list indexed by input number. The length of this list is determined by the number of inputs the type object specifies. Each entry is a $(node, output)$ tuple where *node* is a reference to another XForm and *output* is the index of an output on that XForm.

Methods are provided in XForm for connecting and disconnecting nodes (also checking for cycles and providing basic type checking), and getting inputs and setting outputs inside the the type's perform() method.

2.2 Image data

Most classes making up the image data model are described in the pancamimage.py file, including the main ImageCube class. Some additional classes describing where images can come from are in channelsource.py. The model is shown in outline in Fig. 4 although some links to channel sources and mapping from nodes are omitted; these will be explained later.

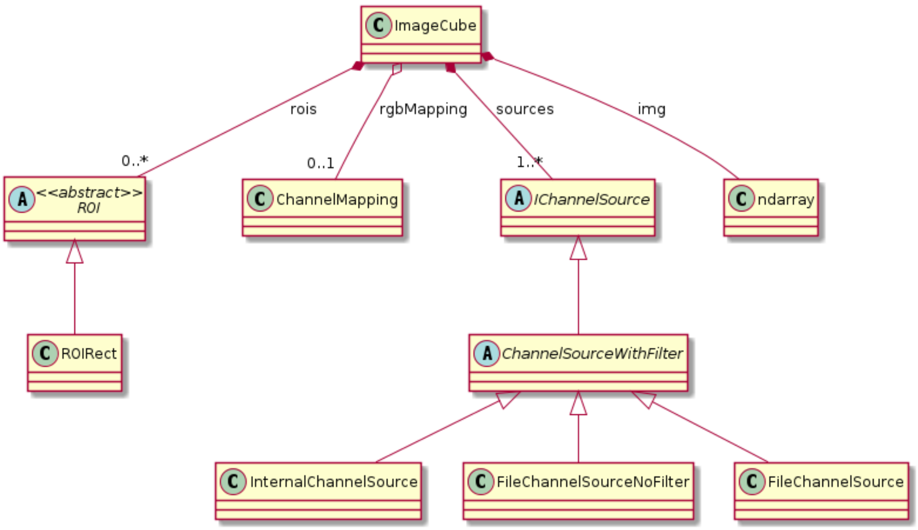


image.png

Figure 4: Outline UML class diagram of image model

The main class is ImageCube: this encapsulates a numpy array img which is the actual image data cube in the form of a $w \times h \times depth$ array. The data type is 32-bit floating point, and images are typically normalized to the range [0,1].

> In this document I have a tendency to refer to image data as both "image" and "image cube." Both terms refer to the same thing: an array of floating point image data, with 1 or more channels of information. There is no upper limit on the number of channels in an image (or image cube) beyond system memory.

2.3 IChannelSource and its implementations

Each `ImageCube` has a number of channels, and for each channel there must be a corresponding entry in the `sources` list. This describes where that channel came from, so that (typically) filter information can be preserved, where appropriate, through the graph. The sources for each channel are a set of `IChannelSource` objects. For example, if an image was loaded through the RGB loader, it might have three "fake" channel sources for red, green and blue. Thus the sources will be

```
[ {RED}, {GREEN}, {BLUE} ]
```

i.e. a list of three sets, each with a single source. If the image is then converted to greyscale, this could become

```
[ {RED,GREEN,BLUE}, {RED,GREEN,BLUE}, {RED,GREEN,BLUE} ]
```

because each channel now contains information from the red, green and blue channels in the source file. The `RED`, `GREEN` and `BLUE` values refer in this case to `FileChannelSourceNoFilter` objects which contain "fake" filter information and a filename identifier. Each `IChannelSource` contains methods for accessing:

- an **identifier string** for the source from which the channel was acquired (typically a filename or data ID);
- a **filter** and methods for obtaining the filter name, filter position and an actual filter reference (for extra data such as centre wavelength) (note that much of this information will be "fake" for images loaded from plain RGB files);
- methods for getting string descriptors for this source.

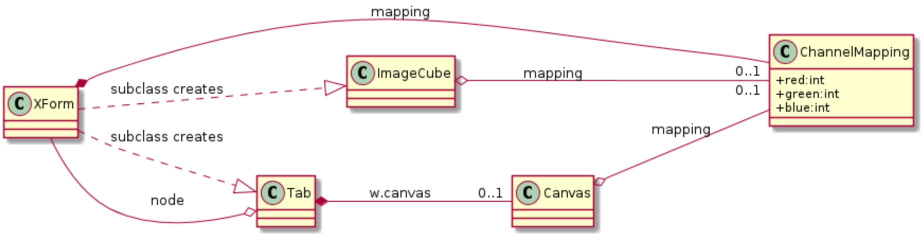
Nodes generate and process this information in different ways. For example, a *gradient* node takes a single channel and converts it into an RGB image with a colour gradient: here, the output image's sources are "internal RGB" sources with no identifier or sensible filter data because the output's colour is entirely artificial. In contrast, a the *curve* for performing a sigmoid function on all channels of an image will give the output image the same sources as the input image.

Sources are used to keep track of each channel as it moves through the graph so they can be processed and displayed appropriately: Fig. 1 shows a typical node in the "node controls and output" section. This section, as it does in many nodes, contains a "canvas" displaying an image. Above the canvas are three combo boxes which select the channels in the image cube to display on the canvas, and these are typically labelled by a string generated from the source data for each channel (along with the index). Sources are also used to select channels to combine and manipulate in those nodes which do so.

2.4 RGB channel mappings

The previous section briefly mentions the three RGB mapping combo boxes at the top of the canvas component in the node controls in Fig 1. In canvases — components which display images — a multi-channel image cube must be displayed as RGB data. The combo boxes control how this is done, and the data is made persistent in a slightly complicated way, as shown in Fig. 5.

The relationships will hopefully become clearer when I come to describe how nodes work in more detail, but for now:



rgb.png

Figure 5: RGB mapping classes

- A `ChannelMapping` object consists of three integers giving the indices of the channels in an image cube to display in the red, green and blue channels on screen.
- An `XForm` (i.e. a node) may need to show an image on a canvas. If so, it will use the `mapping` field in `XForm` to store a mapping. This is provided as a convenience, not all node classes will use it, and some may need to create more if they display more than one image.
- When an `XForm` creates an image for display or passes one through, it sets the mapping of the image to the mapping of the node. This is used in the `rgb()` method to generate the RGB representation.
- When an `XForm` is opened for modification, it creates a subclass of `Tab`. This will contain a `Canvas`, which is given a reference to the mapping inside the `XForm`. It needs this so that the mapping can be modified even when no image is present.

This may seem rather redundant, but

- We need the mapping to be owned by the node, so it can be serialised and persists when there is no image and no open tab.
- We need to have a reference to the mapping in the canvas, so it can be manipulated by the combo boxes even when no image is present.
- Finally, we need a reference to the mapping in the image so that `rgb()` can be called on the image when it is input into another node. This is used in nodes like *inset*, which operate entirely on RGB representations — it's much neater if these are the RGB representations output by the nodes which feed in.

2.5 Regions of interest

Regions of interest belong to images, and modify how nodes process those images. They are added to images by region of interest nodes such as *rect*. Figs. 1 and 2 show this in action:

- A file is read in, producing an image cube
- A *rect* node adds a region of interest to this image. The outputs are:
  - the image with the rectangle added to its list of ROIs;

- the image cropped to the bounding box of the list of ROIs (at the moment, just this rectangle)'
- an RGB representation of the image (according to the previous node's canvas RGB mapping); annotated with the rectangle and some text, and also an ROI added describing the rectangle;
- the rectangle datum itself.

- a *decorr stretch* takes the annotated RGB representation output and imposes a decorrelation stretch — but only on the regions of interest in the image (in this case, inside the rectangle)
- a *histequal* node performs a histogram equalisation, again honouring the regions of interest which have been passed through the previous node unchanged.

As shown in Fig. 4, each image contains a list of `ROI` objects, each of which is an instantiation of a subclass of `ROI`.

To honouring regions of interest inside a node's `perform()` method:

- `ImageCube.subimage()` will return a `SubImageCubeROI` object. This encapsulates a numpy array containing the image bounded to a rectangle around the regions of interest and a boolean mask (again as a numpy array) specifying which pixels in this rectangle are actually in regions of interest.
- The manipulation can now be performed on the `img` field of this "subimage," but only on those pixels whose values are true in the corresponding `mask` field.
- The modified pixels can be "spliced" into the original image cube, creating a new image cube, using the `modifyWithSub` method.

This example shows the operation of the decorrelation stretch:

```
def perform(self,node):
    img = node.getInput(0)
    if img is None:
        node.img = None
    elif not node.enabled:
        node.img = img
    elif img.channels != 3:
        ui.error("Can't decorr stretch images with other than 3 channels")
    else:
        subimage = img.subimage()
        newimg = decorrstretch(subimage.img, subimage.mask)
        node.img = img.modifyWithSub(subimage, newimg)
    if node.img is not None:
        node.img.setMapping(node.mapping)
    node.setOutput(0, node.img)
```

There are several checks for whether the node is actually enabled, and whether there is an image present to stretch, but the core lines are these:

```
subimage = img.subimage()
newimg = decorrstretch(subimage.img, subimage.mask)
node.img = img.modifyWithSub(subimage, newimg)
```

The `decorrstretch` takes two arguments: the numpy array containing the pixels which bound the ROIs, and the mask for those pixels in that array which are in the ROIs. It returns an image of the same size, which is then spliced back into the original image. The new image returned will have the same channel sources, the same ROIs and the same RGB mapping.

> Much of the ROI system is work in progress, particularly combining multiple ROIs. This documentation might change.

2.6 Macros