# PCOT design notes

James Finnis (jcf1@aber.ac.uk)

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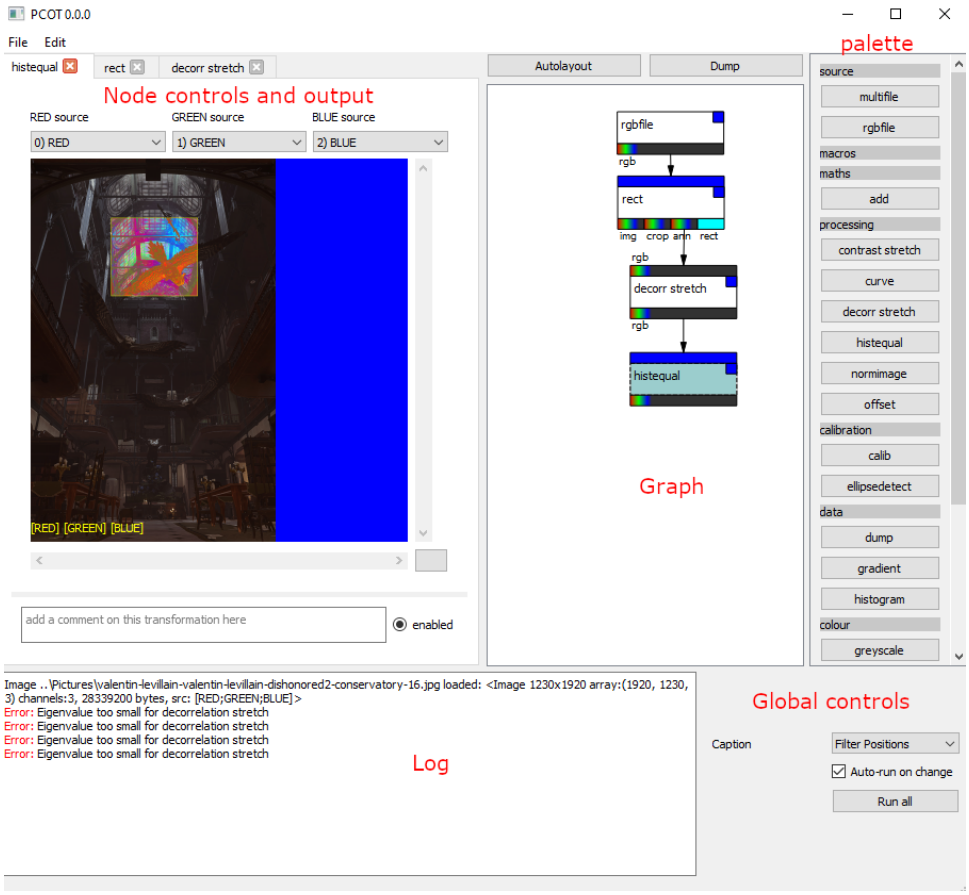
## Contents



# 1 Introduction

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

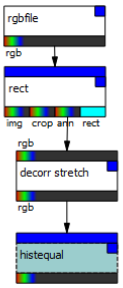
PCOT is based around a directed graph of nodes which perform transformations of data. For this reason, the nodes are sometimes called "transforms" and are represented by the `XForm` class in the code. Usually the data in question is an image, or rather an "image cube": these have an arbitrary number 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

## 1.1 Notes on type checking

Python is dynamically typed, but there are a lot of "type annotations" in the code. Unfortunately, Python's import rules mean there's also some odd stuff going on. Annotations like

```
class XFormType:
    ## @var name
    # name of the type
    name: str
    ## @var group
    # the palette group to which it belongs
    group: str
    ## @var ver
    # version number
    ver: str
    ## @var hasEnable
    # does it have an enable button?
```

are straightforward (and note the Doxygen annotations): we have three string fields (`name`, `group` and `ver`) and a boolean field (`hasEnable`). The next annotation, however, is a link to a class defined further down the file, which in turn has a field which is `XFormType`: a cyclic dependency. In such cases, the standard PEP 0484 tactic is to use a string literal — the type checker will resolve this successfully and give appropriate warnings:

```
    ## @var instances
    # all instances of this type in all graphs
    instances: List['XForm']
```

defines `instances` as a list of `XForm`.

Another oddity you may see in some of the files is this (from the top of `xform.py` like the previous example):

```
if TYPE_CHECKING:
    import graphscene
    import PyQt5.QtWidgets
```

These lines are only run when type checking, and are used to ensure that appropriate classes are imported for type hints like this:

```
    ## @var rect
    # the main rectangle for the node in the scene
    rect: ['graphscene.GMainRect']
    ## @var inrects
    # input connector rectangles
    inrects: List[Optional['graphscene.GConnectRect']]
    ## @var outrects
    # output connector rectangles
    outrects: List[Optional['graphscene.GConnectRect']]
    ## @var helpwin
    # an open help window, or None
    helpwin: Optional['PyQt5.QtWidgets.QMainWindow']
```

Without the `TYPE_CHECKING` guard the program will not run, because these imports are actually cyclic. However, they are only needed at compile time, so the `if`-statement is added to stop the import at run time. Note the quotes: they are there to stop Python trying to resolve the symbols at run time.

# 2 The data model

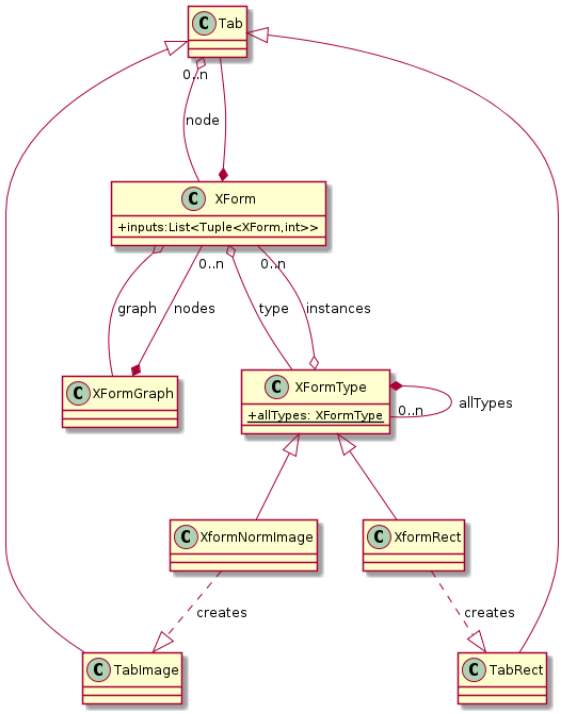
The data model consists of two parts — the data itself (largely image cube data) and the graph. By far the most important kind of data from the point of view of this document is the image data, which ties into the user interface in complex ways. Other forms of data do exist, but these are much simpler.

## 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.




xform.png

**Figure 3:** `XForm` and graph model

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;
- 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 type's `perform()` method.

## 2.2 Performing the graph

The graph needs to be "performed" — its nodes executed — whenever the data changes, which is generally whenever the graph is edited or a node control changed in a tab. This is done by calling `changed()` on the node's tab, which calls `changed()` on the tab's node's graph, passing in the node. Here is the relevant code in `ui.tabs.Tab`:

```
def changed(self):
    self.node.graph.changed(self.node)
```

The `XFormGraph.changed()` method takes a node, and either calls `performNodes()` on the main graph passing in that node, or, if the node is inside a macro prototype graph (q.v.), copies the prototype graph to all its instances and runs `performNodes()` for all those instances (see Sec. 2.7.1 for why this is a problem).

The `XFormGraph.performNodes()` method itself takes a single argument and performs either the entire graph or a portion of the graph starting at a particular node. If the argument is None, the internal list of all nodes in the graph is traversed looking for nodes with no inputs and these are performed. If the argument is not None that node is performed. Nodes are performed by calling their `perform()` method. This will recursively run the child nodes, but only when they are ready to run.

### 2.2.1 Performing a node

The `XForm.perform()` method will run a node, and recursively run all child nodes, although there are some complexities here (mainly to accommodate macros). It will not perform the node if it has already run in this call to `performNodes()` or if it is not ready to run (some inputs do not yet have values):

**if** node has not already run **and** node is ready to run **then**
  clear all outputs
  run the node type singleton's `perform()` method on the node
  mark node as having run
  **for all** $t$ in open tabs for this node **do**
    $t$`.onNodeChanged()`
  **end for**
  **for all** $c$ in child nodes **do**
    perform node $c$
  **end for**
**end if**

A node is ready to run if it has no inputs which do not yet have values set. This is determined by checking the outputs of the nodes from which the inputs come to see if they have yet been set with values. The `performNodes()` method is called from only two places:

- `XFormGraph.changed(node)`: when the graph or a node in a graph has been changed. This is the most frequent call, and is typically called with a node to avoid running the whole graph. The node is passed down into `performNodes()`).
- `XFormMacro.perform(node)`: when a node which contains a macro instance is being performed (see Sec. 2.7 for more details).

The `XFormGraph.changed()` method is called from several places:

- `XFormGraph.runAll()` : called when a graph is explicitly run.
- `XForm.disconnect()` and `XForm.connect()`: when connections between nodes are made or broken.
- `XForm.setEnabled()`: when a node is enabled or disabled.
- `Tab.changed()`: when a tab signals that a node it controls has had a parameter change.
- `XFormGraph.deserialise()`: when a graph has been loaded.

## 2.3 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.

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].

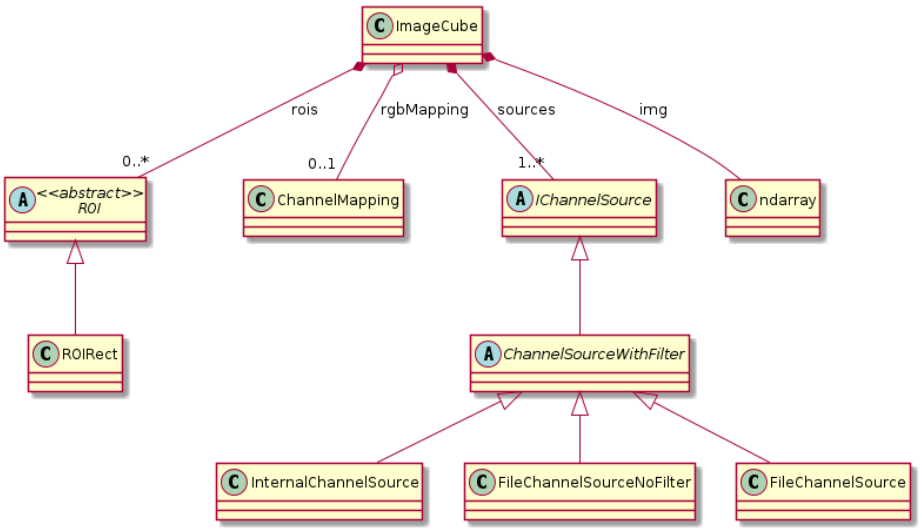



image.png

**Figure 4:** Outline UML class diagram of image model

> 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.

## 2.4 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:

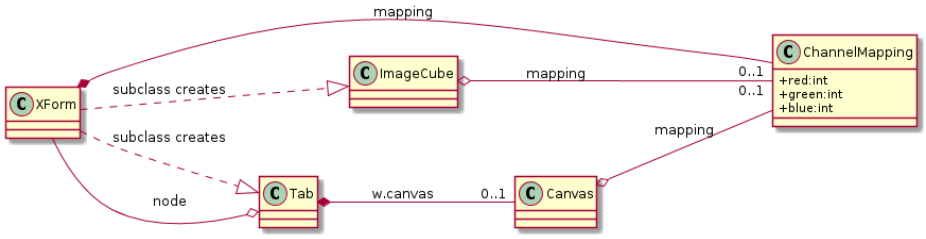
- an **identifier string** for the source from which the channel was acquired (typically a filename or data ID);
- a **filter** and methods for obtaining the filter name, filter position and an actual filter reference (for extra data such as centre wavelength) (note that much of this information will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

## 2.5 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.




rgb.png

**Figure 5:** RGB mapping classes

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

- 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.

## 2.6 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.

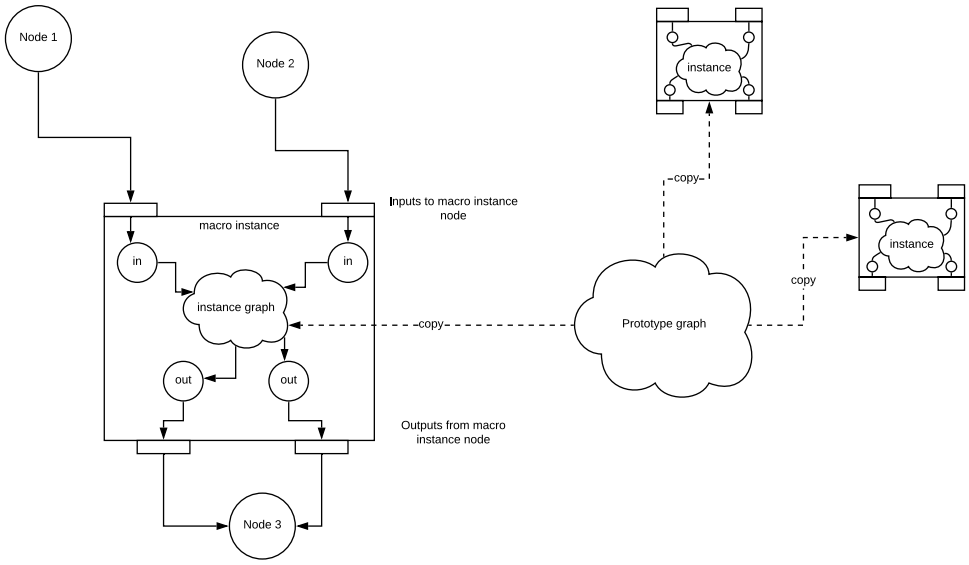
> Much of the ROI system is work in progress, particularly combining multiple ROIs. This documentation might change.

## 2.7 Macros

Macros are one of the more complex parts of the PCOT data model, so it's important that they are documented here. First, a quick description of how they work from a user standpoint.

Users can create a new macro, which will open a window with a new graph in it. This is distinguished from the main window by its slightly different background colour. The user can create and manipulate transform nodes inside this graph, as usual. This is the **prototype graph** for the macro. The user should create special input and output nodes inside this graph to allow data to flow into and out of the macro.

When a new macro is created, a button for that macro appears in the "palette" on the right of the app window. Clicking on this button will create an **instance** of the macro inside the main graph. This is a node which contains a copy of the prototype graph — it must be a copy, because multiple instances of the macro with different data may exist. When the user edits the prototype graph (including the parameters of any nodes within it) the changes are copied to the instance graphs for that macro. Consider the situation in Fig. 6. This contains three instance nodes of a




macroobjs.pdf

**Figure 6:** An example of a graph containing macros

single macro. I have "zoomed in" on one of the instances, showing that it is connected to three other nodes: two on its inputs, one on its outputs. When this main graph runs, the following happens:

- Node 1 is able to run, does so, and sets its output
- The macro instance cannot yet run
- Node 2 is able to run, does so, and sets its output
- The macro instance can now run:
  - The macro instance node copies its input data into the input nodes contained within the instance graph
  - The input nodes in the instance graph are run
  - The nodes dependent on those input nodes are run (i.e. the instance graph proper)
  - The output nodes in the instance graph are run, copying their inputs into the macro instance node's outputs
  - the instance now has now completed its run
- Node 3 can now run, reading its inputs from the macro instance node.

### 2.7.1 Macro inefficiencies

As noted above in Sec. 2.2, all the nodes in all instance graphs are run whenever the prototype graph is changed. This is very inefficient and may cause considerable delays. It's done simply by forcing all `XFormMacro` nodes which are instances of the macro to perform themselves. Here is the relevant part of `XFormGraph.changed()`:

```
# distribute changes in macro prototype to instances.
# what we do here is go through all instances of the macro.
# We copy the changed prototype to the instances, then run
# the instances in the graphs which contain them (usually the
# main graph).
# This could be optimised to run only the relevant (changed) component
# within the macro, but that's very hairy.

for inst in self.proto.instances:
    inst.instance.copyProto()
    inst.graph.performNodes(inst)
```

Here, `inst` is an XFormMacro node inside the graph which contains the macro, it is not the instance graph inside the `inst` node. Thus `inst.graph` will be the main graph (for an non-nested macro). The `self` value, however, is the macro prototype graph, because this method was called on an object inside that graph. This code therefore calls `performNodes()` on the main graph to run the XFormMacro node inside that graph.

In an ideal world, this process — calling `changed()` — would identify the instance node which corresponds to the prototype node which was changed, and only run that inside the instance graph for the macro. The child nodes of the instance node would then need to be run.