Plotting and Labelling Data and Images using PGPLOT

A central requirement of any data analysis package is the possibility of visualisation of data. PDL deals with this in a slightly different manner than some other packages in that no built-in graphics library is used, instead it uses other freely available external packages. In this chapter we will focus on the main 2D plotting package, PGPLOT.

Here we will cover the use of the `PDL::Graphics::PGPLOT` package which uses the freely available PGPLOT subroutine package written by Tim Pearson. This is a very powerful package and `PDL::Graphics::PGPLOT` does not provide easy access to everything in the PGPLOT package, although it hopefully does most of what you will need.

For advanced use you might have to use some PGPLOT commands directly, see *Using PGPLOT commands directly* for a discussion of this. But even if you don't you are recommended to at least keep a copy of the PGPLOT documentation lying around. It is available from *http://www.astro.caltech.edu/~tjp/pgplot/*.

The goals of this section is to familiarise the reader with the PDL interface to PGPLOT and show how complicated datasets can be easily manipulated and displayed. The focus will be on interactive use to facilitate learning, but at the end we will turn to an object-oriented interface that might be more suited for scripts.

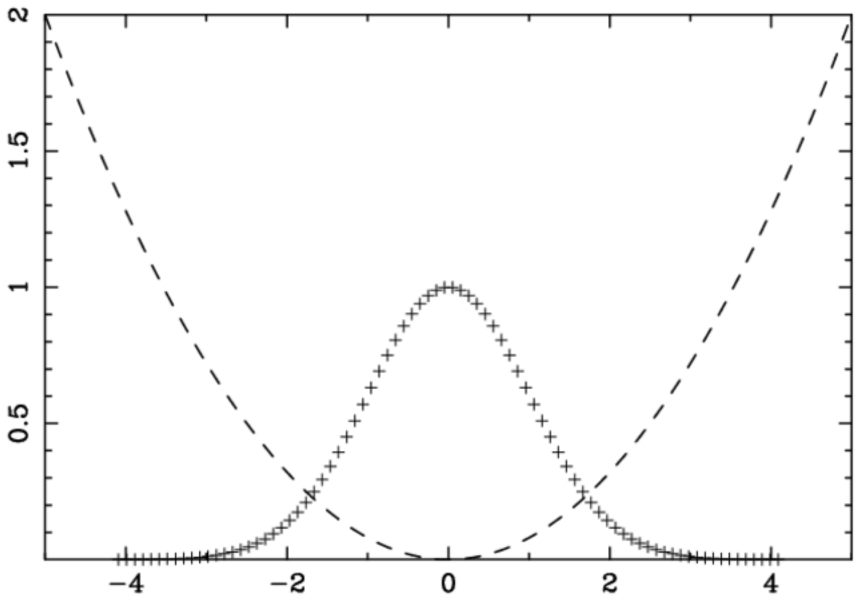
To use `PDL::Graphics::PGPLOT` it is necessary to have the PGPLOT package installed, and in addition have the Perl PGPLOT module (written by Karl Glazebrook and available through CPAN) installed and working. In the following we will assume that you have this all set up.

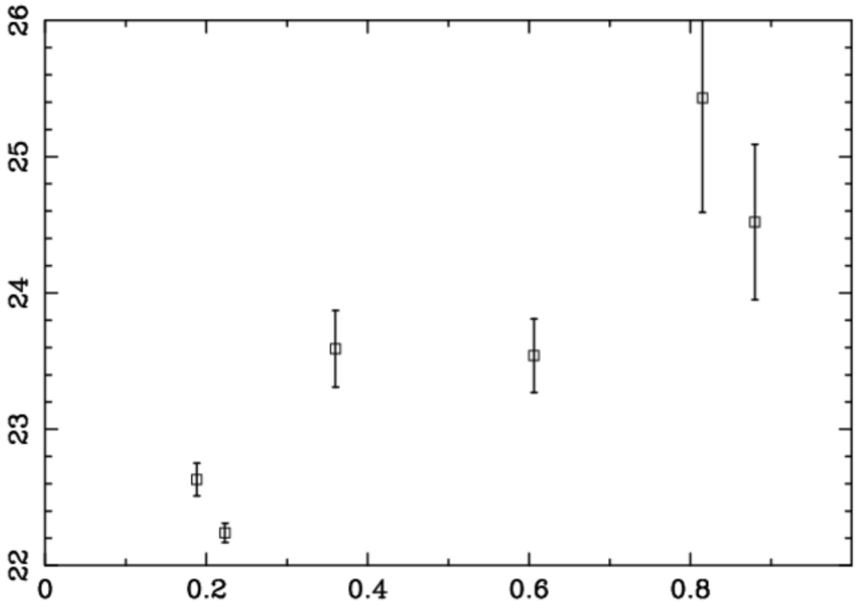
Introducing PDL::Graphics::PGPLOT

2-dimensional graphics in PDL is normally performed by the `PDL::Graphics::PGPLOT` module. The `PDL::Graphics::PGPLOT` package must be `use`'ed to give access to the commands. This introduction will be based on interactivity and use of `perldl`

```
pdl> use PDL::Graphics::PGPLOT;
```

That is what you need to get running. We will now play around with a couple of commands before we turn to a systematic overview in the next two sections. We will concentrate on the `line` and `points` commands which draws continuous lines and individual plotting symbols respectively. The final result should look similar to Figure 1.





The first step is to start `perldl` and use the `PDL::Graphics::PGPLOT` package (some output is suppressed)

```
> perldl
Type 'help' for online help
Type 'demo' for online demos
Loaded PDL v2.4.3
pdl> use PDL::Graphics::PGPLOT
```

Now we need to open a graphics device - there are quite a few that are supported by PGPLOT, here we will use a normal plot window that can be re-used:

```
pdl> dev('/xs')
```

You should now have a large plot window on your screen, if you had some problems try to do `dev('?')` which will give you a list of available devices and allow you to choose one.

We first need to define a variable to have something to plot. The first plan is to simply plot a parabola and a Gaussian (bell) function as in the left panel in Figure 1, so we need an x-variable that is both positive and negative.

```
pdl> $x=zeroes(100)->xlinvals(-5, 5)
```

This creates a 100 element piddle starting at -5 and ending at 5. We can then very easily draw a parabola:

```
pdl> line $x, $x*$x/12.5, {LINESTYLE=>'Dashed', Colour=>red}
```

which should draw a nice parabola with a dashed red line. As should be clear the `line` command draws a line and takes the x and y coordinates of the points on the line as arguments and options to the command are given as an anonymous hash.

We now want to plot a Gaussian on top of this, but if we were just to issue another plot command it would by default erase the screen, so instead we call the `hold` function to stop that from happening:

```
pdl> hold
```

We can then continue plotting, now using symbols instead of a line:

```
pdl> points $x, exp(-$x*$x/2), {Symbol => 'Plus'};
```

Again, note that the function `points` function plots symbols instead of lines. PGPLOT has a large array of symbols, normally accessed using numbers, but the most common have text aliases defined.

The only thing left for us now is to ensure that the next plot will start afresh. Since we issued the `hold` command all subsequent plots will overplot the existing ones and since we do not want that anymore, we therefore have to `release` the device to the next set of plot commands:

```
pdl> release;
```

As a second example we will show how you can create plots with error bars. We will just carry on so the previous plot will be erased (enjoy it while you can). We first have to define some variables for the plot, so we need the *x* and *y* variables and the error on *y*.

```
pdl> $x = pdl(0.88, 0.223, 0.815, 0.606, 0.188, 0.360)
pdl> $y = pdl(24.52, 22.24, 25.43, 23.54, 22.63, 23.59)
pdl> $dy = pdl(0.57, 0.07, 0.84, 0.27, 0.12, 0.28)
```

In the previous example we let PGPLOT decide on the plotting ranges we were going to use, but now we want some more control over it. To do so we set it up using the `env` command:

```
pdl> env(0, 1, 22, 26)
```

which sets the X-axis to go from 0 to 1 and the Y-axis from 22 to 26.

That is really all that is needed before plotting the error bars:

```
pdl> errb $x, $v, $dv,  {Symbol => 'Square'};
```

And here we go! It almost looks like science. Of course in real life error-bars might not be symmetric (although you often wish they were), and we will explain how to do this later when we discuss `errb` in more detail below.

An overview of 2D plotting commands

Before we proceed to an overview of all commands in `PDL::Graphics::PGPLOT` it is necessary to define a couple of terms: The first is the concept of **device** - this is what the plotting commands work on, often this will be a *screen* device which shows resulting output on the screen in a window, but it can also be output to a file in some sort of format. Then inside each device there is a *plotting area* within which plotting commands gives a noticeable result.

Another important concept is *holding* of plots. When a plot is held, any subsequent plot commands will plot on top of the existing plot. To explicitly hold a plot you issue the command `hold` and to release it again you use `release`.

Finally most commands described in the following take a set of **options**. These are values that can be set to modify the default behaviour of the plotting routine and are very useful so we will first discuss the standard options and how options are specified.

Options in plot commands

As mentioned above and seen in the brief introduction to the PGPLOT interface earlier, we use options to modify the behaviour of plot commands. Below we will often see examples of **specific** options, those that are only recognised by a particular plot command. However in addition there are **general** options that are recognised by many or all plot commands. These are normally the options you use most so it is important to know these.

But first, how do you specify an option? If you read through the walk-through above you have probably already realised that they are set as keys in a hash:

```
line x, y {Colour => 3}
```

However due to the way they are implemented in the code (using the `PDL::Options` package) the hash is more flexible than normal Perl hashes. Firstly the options are case-insensitive and secondly some have synonyms defined so that for instance `Color` and `Colour` are both accepted to avoid bad feelings on one side of the Atlantic. Finally most, if not all, options can be shortened so that `Lines` will be interpreted as `LineStyle`. This is mostly useful when working on the `perldl` command line however as it is error-prone in scripts (imagine that someone later implemented a `Lines` option which did something totally different, like draw 10 parallell lines, yeah, quite likely).

The following listing of standard options is based on the on-line documentation which you can access yourself inside `perldl` as

```
pdl> help PDL::Graphics::PGPLOT::Window
```

or using the `pdldoc` command

```
bash$ pdldoc PDL::Graphics::PGPLOT::Window
```

It is not envisaged that the standard option set will be significantly expanded from that listed here, but the on-line documentation should reflect any changes if they take place.

`Arrow`

This option allows you to set the arrow shape, and optionally size for arrows for the `vect` routine. The arrow shape is specified as a hash with the key `FS` to set fill style,

`Angle`

sets the opening angle of the arrow head, `Vent` to set how much of the arrow head is cut out and `Size` to set the arrowsize.

The following code:

```
pdl> $opt = {Arrow => {FS=>1, Angle=>60, Vent=>0.3, Size=>5}};
```

will set up an options hash for a broad arrow of five times the normal size.

Alternatively the arrow can be specified as a set of numbers corresponding to an extention to the syntax for the PGPLOT command `pgsah` . The equivalent to the above is

```
pdl> $opt = {Arrow => pdl([1, 60, 0.3, 5])};
```

For the latter the arguments must be in the given order, and if any are not given the default values of 1, 45, 0.3 and 1.0 respectively will be used.

`Arrowsize`

The arrowsize can be specified separately using this option to the options hash. It is useful if an arrowstyle has been set up and one wants to plot the same arrow with several sizes. Please note that it is **not** possible to set arrowsize and character size in the same call to a plotting function. This should not be a problem in most cases.

```
pdl> $opt = {ARROWSIZE => 2.5};
```

`Axis`

Set the axis type (see the `env` command below in *Setting up the plot area*). It can either be specified as a number, or by a name as in the following table

```
Name        Number  Explanation
----        ------  -----------

Empty       -2      draw no box, axes or labels
Box         -1      draw box only
Normal       0      draw box and label it with coordinates
Axes         1      same as Normal, but also draw X=0, Y=0 axes
Grid         2      same as Axes, but also draw grid lines
LogX        10      draw box and label X-axis logarithmically
LogY        20      draw box and label Y-axis logarithmically
LogXY       30      draw box and label both axes logarithmically
```

The reason why this command is accepted by most commands is that when a command is called before a plot area is set up it will implicitly call `env` which interprets this option.

`AxisColour`

Set the axis colour using the same syntax as for the `Colour` option below.

`Border`

Normally the plot limits are chosen so that the plotted points just fit inside the plot area; with this option you can increase (or decrease) the limits by either a relative (ie a fraction of the original axis width) or an absolute amount. Either specify a hash array, where the keys are `Type` (set to '`Relative` ' or '`Absolute` ') and `Value` (the amount to change the limits by), or set to 1, which is equivalent to `Border => { Type => 'Rel', Value => 0.05}`.

`Charsize`

Set the character/symbol size as a multiple of the standard size. `$opt = {Charsize => 1.5}`

`Colour`

Set the colour to be used for the subsequent plotting - it has `Color` as a synonym. This can be specified as a number, and the most used colours can also be specified with name, according to the following table:

0	White	4	Blue	8	Orange
1	Black	5	Cyan	14	Dark gray
2	Red	6	Magenta	16	Light Gray
3	Green	7	Yellow		

However there is a much more flexible mechanism to deal with colour. The colour can be set as a 3 or 4 element anonymous array (or piddle) which gives the RGB colours. If the array has four elements the first element is taken to be the colour index to change. For normal work you might want to simply use a 3 element array with R, G and B values and let the package deal with the details. The R,G and B values go from 0 to 1.

In addition the package will also try to interpret non-recognised colour names using the default X11 lookup table, normally using the `rgb.txt` that came with PGPLOT.

For more details on the handling of colour it is best that the user consults the PGPLOT documentation. Further details on the handling of colour can be found in the documentation for the internal routine `_set_colour`.

`Filltype`

Set the fill type to be used by `poly`, `circle`, `ellipse` and `rectangle`. The fill can either be specified using numbers or name, according to the following table, where the recognised name is shown in capitals-it is case-insensitive, but the whole name must be specified.

1	Solid
2	Outline
3	Hatched
4	CrossHatched

`$opt = {Filltype => 'Solid'}` (see below for an example of hatched fill)

`Font`

Set the character font. This can either be specified as a number following the PGPLOT numbering or name as follows (name in capitals):

1	Normal
2	Roman
3	Italic
4	Script

Note that in a string, the font can be changed using the escape sequences `\fn` , `\fr` , `\fi` and `\fs` respectively. See the documentation in *Text and legends* for more information regarding escape sequences.

`$opt = {Font => 'Roman'};` gives the same result as `$opt = { Font=> 2 };`

`Hatching`

Set the hatching to be used if either filltype 3 or 4 is selected (see above). The specification is similar to the one for specifying arrows. The arguments for the hatching is either given using a hash with the key `Angle` to set the angle that the hatch lines will make with the horizontal, `Separation` to set the spacing of the hatch lines in units of 1% of `min(height,width)` of the view surface, and `Phase` to set the offset the hatching. Alternatively this can be specified as a 1x3 piddle `$hatch=pdl[$angle, $sep, $phase]`.

```
$opt = {Filltype => 'Hatched', Hatching => {Angle=>30,
```

`Separation=>4}};` Can also be specified as

```
$opt = {Fill=> 'Hatched', Hatch => pdl [30,4,0.0]};
```

For another example of hatching, see the command `poly` in *Drawing lines and plotting points* below.

`Justify`

A boolean value which, if true, causes both axes to drawn to the same scale. If you want more information about this option you are advised to consule the PGPLOT documenation for the `pgenv` command.

`Linestyle`

Set the line style. This can either be specified as a number following the PGPLOT numbering or as a name as shown in the following table.

```
1   Solid
2   Dashed
3   Dot-dash
4   Dotted
5   Dash-dot-dot
```

Thus the following two specifications both specify the line to be dotted:

```
$opt = {Linestyle => 4};
$varopt = {Linestyle => 'Dotted'};
```

The names are not case sensitive, but the full name is required.

`Linewidth`

Set the line width. It is specified as a integer multiple of 0.13 mm.

```
$opt = {Linewidth => 10}; # A rather fat line
```

`PlotPosition`

The position of the plot on the page relative to the view surface in normalised coordinates as an anonymous array. The array should contain the lower and upper X-limits and then the lower and upper Y-limits. To place two plots above each other with no space between them you could do

```
$win->env(0, 1, 0, 1, {PlotPosition => [0.1, 0.5, 0.1, 0.5]});
$win->env(5, 9, 0, 8, {PlotPosition => [0.1, 0.5, 0.5, 0.9]});
```

`Symbol`

The plot symbol to use, with the default being 17 which gives a small filled circle. This is an option for `points` and `errb` at the moment, but could be used for others too. It is either given a piddle with the same number of elements as the plot variable, a name (or number) specifying the symbol to use according to the following (recognised name in capital letters):

```
0   Square      4   Circle      9   Sun
1   Dot         5   Cross       11  Diamond
2   Plus        7   Triangle    12  Star
3   Asterisk    8   Earth       17  Default
```

PGPLOT has support for a much larger number of symbols. The reader is advised to consult the PGPLOT documentation for further information or write a short program that loops through all symbols. Note however that there are a **lot**. For instance symbol 2830 is a cyrillic character - the system used is the Hershey system for symbols. In addition you can draw regular polygons with *n*-sides by setting the symbol to *-n*, so that `$opt = {Symbol => -n };` but be aware that *-1* and *-2* draws a dot with the diameter set to the current linewidth.

`Title`

The title on top of the plot box.

`XTitle`

The title for the X-axis of the plot.

`YTitle`

The title along the Y-axis.

Hard-copies and plot options

The default options for screen display are not ideal for hard-copies (typically PostScript). Thus there is a separate set of options for certain properties when the output device is a hard-copy one. Here we will quickly summarize these

`HardLW`

The line width used on hard-copy devices. The default is 4.

`HardCH`

The character size used on hard-copy devices. The default is 1.4.

`HardFont`

The default font used on hard-copy devices. It defaults to 2.

`HardAxisColour`

The default colour to draw the axis with on a hard-copy device. This is particularly important since light green (default screen colour) is not very visible on paper. The default is 1 (black). The setting of colours work as with `Colour`

`HardColour`

The default plot colour on hard-copy devices, it defaults to 1 (black).

These options should be set either in the call to `dev` (see *Setting up the plot area*) or redefined using the method outlined in the next section.

Setting default values for options

You might not be happy with the default settings for the various options and want to set a different value permanently instead of specifying it with every call to `dev` , `env` or some other command. There is some support for this, but it is limited in that it is not case-insens itive nor does it have synonyms (except for colour/color) so the options **must** be written as above. (You will be notified if you did something wrong).

That said it is fairly easy to use. You would normally set this in your `.perldlrc` file (see '`help\InsetSpace ~perldl`' in the perldl shell or '`pdldoc pdl`'). The relevant function is `set_pgplot_options` which takes a hash as argument with the options and their values, as in the following example:

```
use PDL::Graphics::PGPLOTOptions ('setpgplotoptions');
setpgplotoptions('Device' => '/xs', 'LineWidth' => 10);
```

Note that some settings might affect more than you like. In particular the `LineWidth` and `LineStyle` options will also affect the axis and axis labels drawn. However, character size, device default plot symbol, border and other options can be conveniently be specified in this way.

Setting up the plot area

The first step for the budding plot maker is to set up the drawing area. This involves selecting what device you want to create the plots on and then setting the region you want to plot in .

The destination for your plot commands is set with the `dev` command, and with different arguments to `dev` you can send plots to various output devices such as:

GIF files - `dev('giffile.gif/gif')`

Postscript files - `dev('filename.ps/ps')`

Colour Postscript files - `dev('filename.ps/cps')`

X-windows plotting windows - `dev('/xs')`

If you wish to have several plotting panels per page you can specify the number in the x and y directions as further arguments to `dev` so that to get four panels you would write `dev('/xs', 2, 2)`.

For more detailed control over the created device, you can specify various options. The main four options you might use are:

`Aspect`

The aspect ratio of a newly created output device. If your device is a graphics window under a window system, this might or might not be applied when the window is created, but it should be updated as soon as you plot to it. The default value is 0.618, i.e. the golden ratio.

`WindowWidth`

The width of the created output window. The width is specified in units of inches, which is reasonably easy to deal with when printing out, but if your device is a graphics window it is all a bit more unclear since different setups might have different ideas of what an inch corresponds to in pixels.

`WindowXSize`

The X-size of the plot window, specified as `WindowWidth` and combined with `Aspect` if `WindowYSize` is not set.

`WindowYSize`

As above but for the Y-size.

`NX` and `NY`

These two options set the number of panels in the X and Y direction respectivel y and are alternatives to specifying the numbers of panels directly in the call to `dev` as `dev(<device>, <nx>, <ny>)`.

The options are specified in an anonymous hash so that:

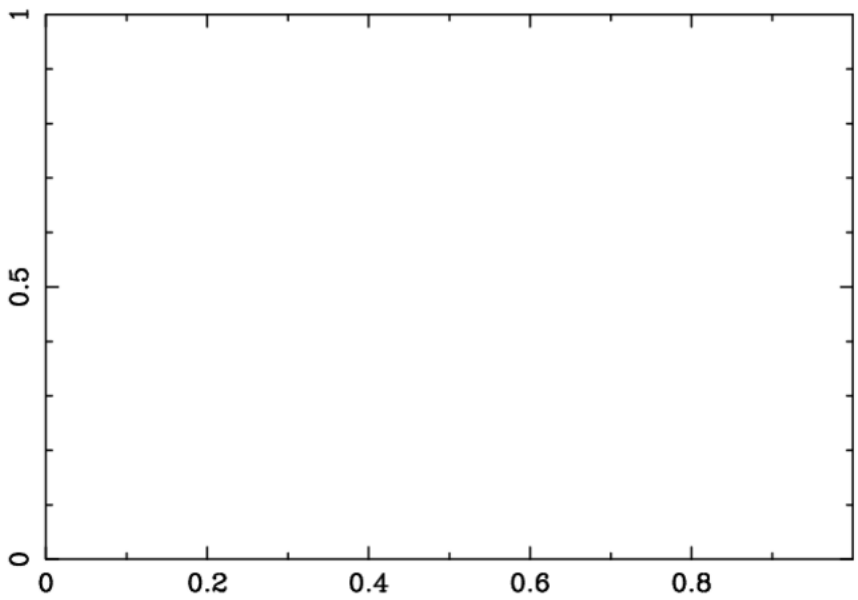
```
pdl> dev('/xs', {NX => 4, NY => 2})
```

will create a plot window with four panels in the X-direction and 2 in the Y-direction, with a default aspect ration and size. Alternatively the same window could have a specified width and aspect ratio by specifying those options as

```
    pdl> dev('/xs', {NX => 4, NY => 2, Aspect => 1, WindowWidth =>
5})
```

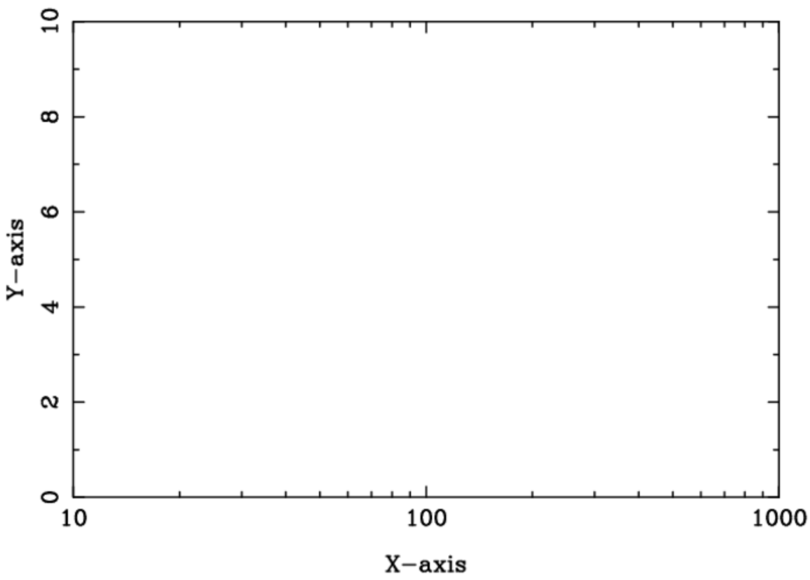
However dev does not actually draw anything for you, it merely selects the output device. To set up a plot you either call a plot command directly, or if you want more control over the axis ranges you use the command `env`. This useful command takes the upper and lower limits in X and Y as input:

```
env(0, 1, 0, 1);
```



sets up a plotting area with both axes going from 0 to 1. If a logarithmic axis is desired this can be achieved by passing an option to the env command, we can also use this to set the axis labels:

```
    env(1, 1000, 0, 1, {Axis => 'LOGX', Xtitle => 'X-axis', Ytitle =>
 'Y-axis'});
```

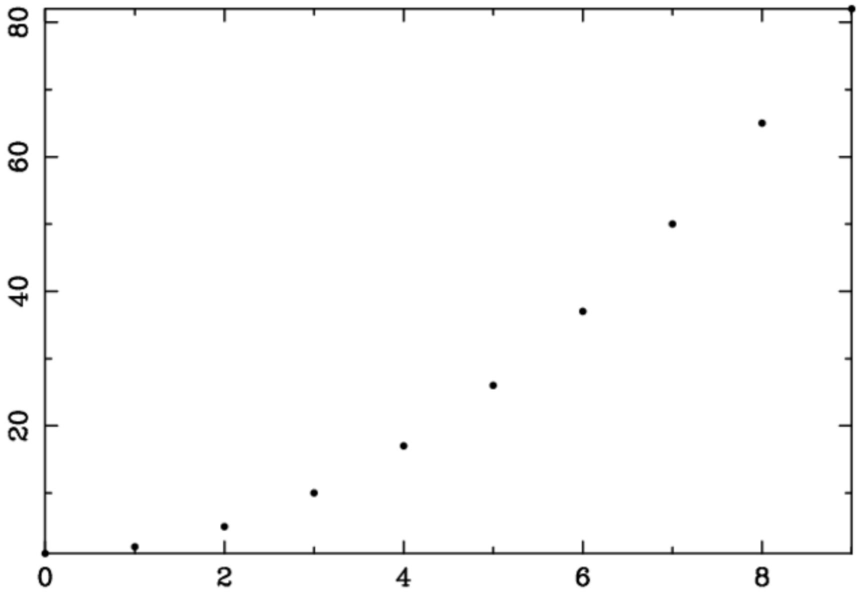


Further information on the `Axis` option can be found in *Options in plot commands*.

It is important to realise that when you call env explicitly it automatically holds the plot for you, so subsequent plot commands will plot on top of the plotting area, and if you want to make a new plot you need either to call env again or call release explicitly.

Drawing lines and plotting points

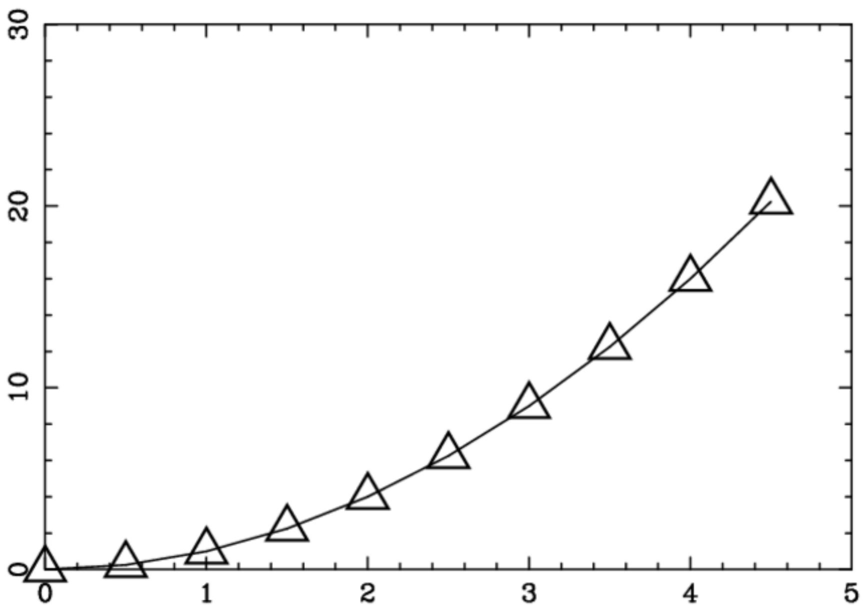
The most important commands in the graphics package are probably the line drawing and point plotting commands line and points . The most basic command is points which plots particular symbols at given x and y values:




```
pdl> $x = sequence(10)
pdl> $y = $x*$x + 1
pdl> points $x, $y
```

The action of the points command can be modified by adding options. The most important is Symbol which changes the plot symbol and Charsize which changes the size of plot symbols; in addition the Plotline option is a toggle which if set causes a line to be drawn through the plots:

```
    pdl> points $x, $y, {Symbol => 'Triangle', Plotline => 1, Charsize =>
5}
```

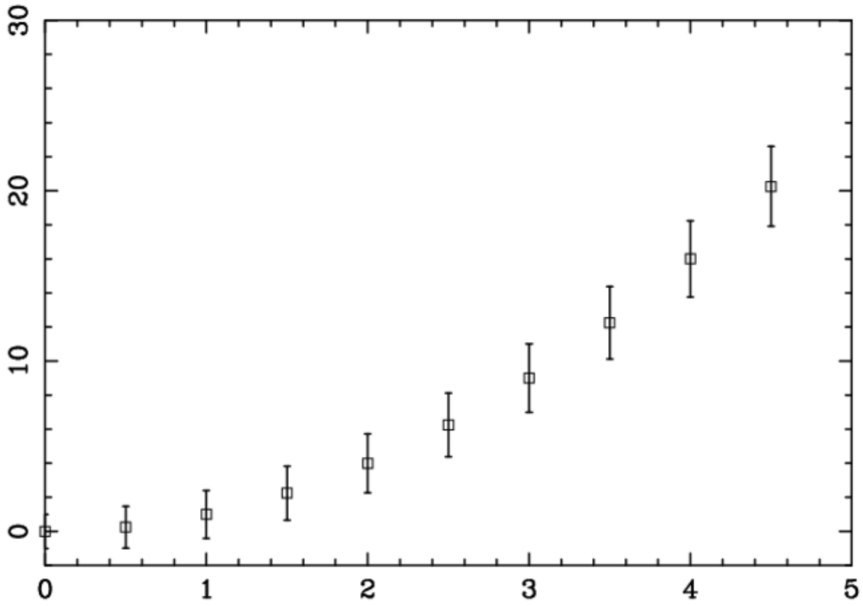


The string `Triangle` is equivalent to symbol number 7 and in general symbols will have to be accessed using the numerical system, but there are textual equivalents for many commonly used symbols (see *Options in plot commands*). The `points` command does also accept a piddle as the symbol value, in which case it should have the same length as `$x` and `$y` and each point will be plotted with the corresponding symbol value.

Plotting error-bars

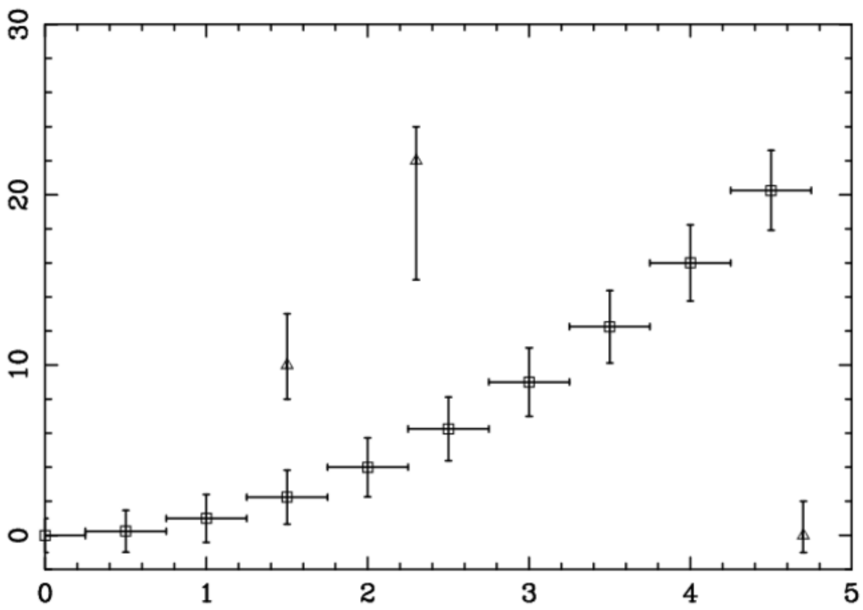
Closely related to `points` is the routine for plotting symbols with error-bars, `errb` . This can be called in a variety of ways to allow for various ways of giving errorbars and whether horizontal or vertical errorbars are required. A typical call is:

```
pdl> env(0, 5, -2, 30)
pdl> $x=sequence(10)/2.0; $y=$x*$x
pdl> $dy = sqrt($x+1);
pdl> errb $x, $y, $dy, { Symbol => â€™Squareâ€™}
```



which plots squares with symmetrical vertical error-bars. To get error bars in the horizontal direction one gives these before the y-errors. Likewise it is possible to get asymmetric error-bars by giving the upper and lower limits of the error bars separately for the X and Y variables as in the following example:

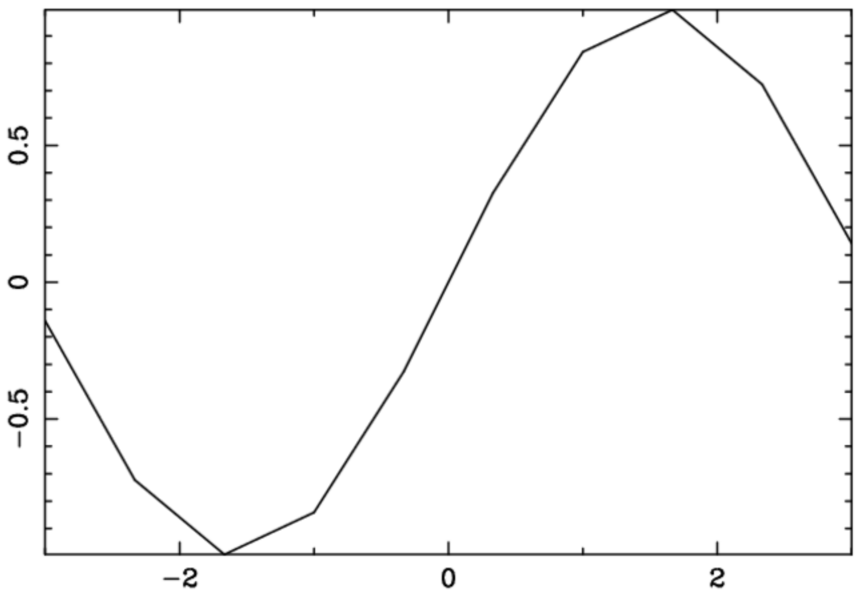
```
pdl> $x2 = pdl(1.5, 2.3, 4.7)
pdl> $y2 = pdl(10, 22, 0)
pdl> $dx = $x2->zeroes(); # No X-errors
pdl> $yu= pdl(12,29,1)-$y2
pdl> $yl= $y2 - pdl(7, 20, -2)
pdl> errb $x2, $y2, $dx, $dx, $yl, $yu, {Symbol => â€™Triangleâ€™}
```



Drawing lines

We saw above that we could draw lines between points by setting the `PlotLine` option to `points`, however there are much better ways to draw lines. The basic line-drawing command is `line` which draws a straight line between each point.

```
pdl> $x = zeroes(10)->xlinvals(-3, 3)
pdl> line $x, sin($x)
```

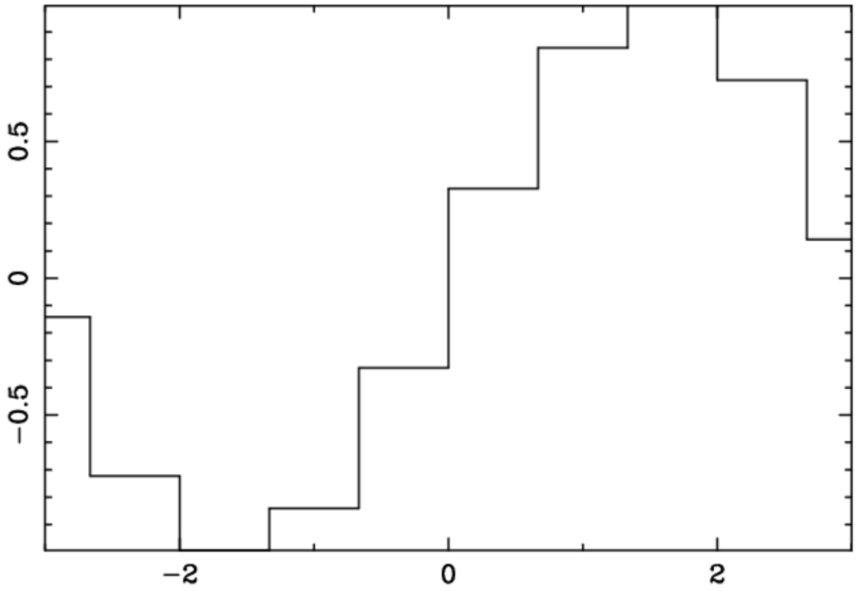


The style, width and colour of the line can be changed with the options `Style`, `LineWidth` and `Colour` / `Color` respectively as outlined in *Options in plot commands*.

Plotting histograms

A very similar command is `bin` which is useful for plotting histograms. This command draws horizontal lines between *x(i)* and *x(i+1)* with the value *y(i)*.

```
pdl> $x = zeroes(10)->xlinvals(-3, 3)
pdl> bin $x, sin($x)
```

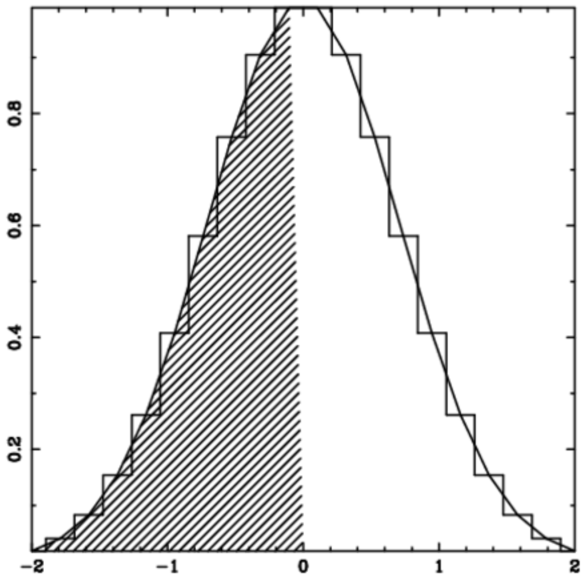


By default the routine assumes that the X-values are the start points of the bin, if instead your values are for the centers of the bins, you need to set the option `Centre`/`Center` to a true value. In addition the appearance of the lines can be modified using the same options as for the `line` command.

Drawing polygons

Finally the `poly` command is like `line` but fills the polygon defined by `$x` and `$y` with the chosen fillstyle (defaults to solid fill). If you display this you should consider putting `FillStyle => 'Outline'` in your `.perldlrc` file as explained in *Setting default values for options*, or you can set it explicitly as in the following example:

```
pdl> $x=zeroes(20)->xlinvals(-2,2);
pdl> $y=exp(-$x*$x);
pdl> $xpoly = append($x->where($x <= 0), pdl(0));
pdl> $ypoly = append($y->where($x <= 0), pdl(0));
pdl> poly $xpoly, $ypoly, {FillType => â€™Hatchedâ€™};
```

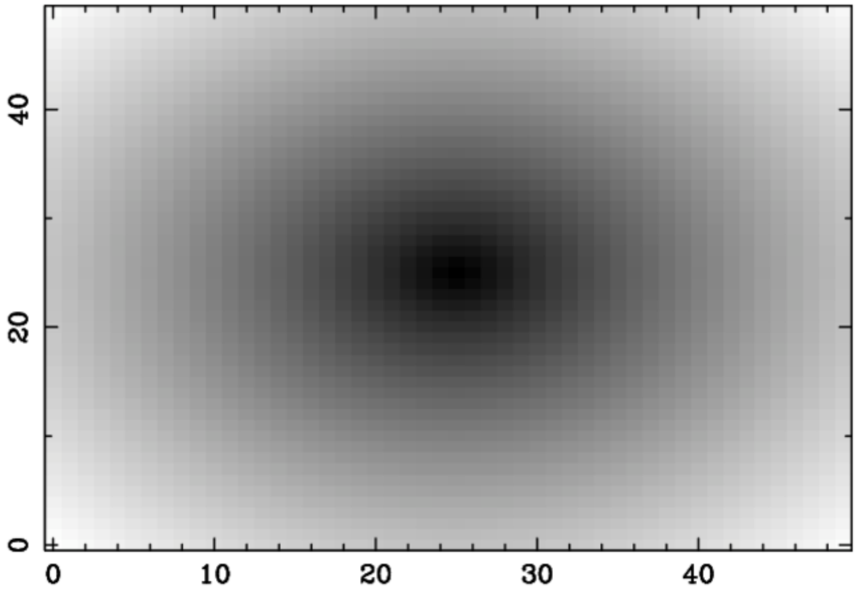


In this example it is worth noting the added complications to ensure that the polygon is closed. In addition we have used the option `FillType` to change the style of fill used. This can be finely adjusted if necessary, for further examples see *PDL::Graphics::PGPLOT* and the discussion of `FillType` in *Options in plot commands*.

Displaying images

PGPLOT was originally designed for astronomy and as such it has good support for the display of 2D-data. In PDL this support has been simplified and there is now only one command for image display, `imag` , which internally chooses between different PGPLOT display commands. The simplest use of `imag` is to let it act on a 2D piddle so:

```
pdl> $a = rvals(50,50, {Center => [ 25, 25]});
pdl> imag $a;
```



However, most likely you will find that the shape is not circularly symmetric because the aspect ratio of your graphics window is different from 1. How then can we correct this? The easiest solution is probably to make sure that your graphics device has aspect ratio 1 by giving the `Aspect` option to the `dev` command (see *Setting up the plot area*).

That isn't always an option though, and an alternative approach is to use the option `Pix` to the `imag` command. This lets you adjust the aspect ratio of the image pixels. You can in addition specify the number of image pixels per screen unit with the option `Pitch` so that to display the previous image with square pixels and 2 image pixels per screen pixel you use:

```
pdl> imag $a, { Pix => 1, Pitch => 2 }
```

You can also use `Unit` to specify the unit used for scaling and `Scale` for the reciprocal of `Pitch`, see the PDL::Graphics::PGPLOT documentation for details. The `Pix` option only adjusts the coordinate ranges and this might not always be what you require. In such situations a solution might be to create a square plot window directly as mentioned earlier.

In addition you might want to specify a stretch of the gray-scale of the image. This can be obtained first by specifying the max and min values of the displayed image (everything above is set to the max value and everything below to the min value). This is set with the `Min` and `Max` options. Additionally it is possible to adjust the image transfer function using the option `ITF`. Allowed values are `Linear`, `Log` and `Sqrt`.

You can also add a colour bar (colour wedge in PGPLOT parlance) to the image display. This is accomplished either using the `draw_wedge` (see below) command directly or by setting the `DrawWedge` option to true in your call to `imag` . If you want to pass options to the `draw_wedge` command, you can do that with the `Wedge` option. See below for further details.

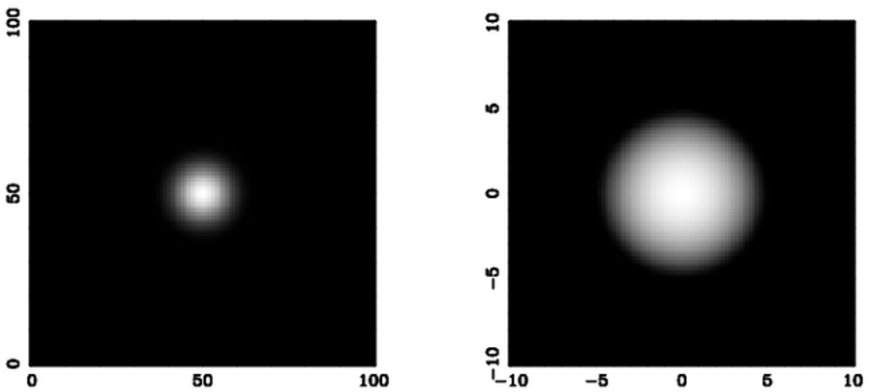
Transforms

Finally a very useful feature of PGPLOT that is relevant both to images and also the contour plots (see below) is the concept of a transform matrix. This is a *6* element vector, *T(i)* which maps input pixels into display pixels so that pixel *i,j* is mapped to:

```
X(ij) = T0 + T1(i) + T2(j)
Y(ij) = T3 + T4(i) + T5(j)
```

It is always simplest to refer to this equation the first few times one sets up a transform vector.You use this whenever your pixel positions in the real world were different from that represented by your input image array.

```
use PDL;
use PDL::Graphics::PGPLOT;
# Create two plot areas in the X-directions dev('/xs', 2, 1);
# Create a Gaussian around the center of the image
$a = rvals(101, 101, {Center => [50, 50]});
$y = exp(-$a*$a/50.);
# Display with a linear transfer function
imag $y;
# This transform vector maps the extreme points to
my $tr = pdl(-10, 1.0/5.0, 0, -10, 0, 1.0/5.0);
# Finally display the image with the transform and
# a logarithmic transfer function.
imag $y, {Transform => $tr, ITF => 'Log'};
```



Here we are contrasting two different ways of displaying the same image. On the left is the default display of a Gaussian, whereas on this right is the result when mapping the pixels to a range from *-10* to *10* with a logarithmic transfer function. Here we show the use of the `ITF` and and `Transform` options. Note that using `Transform` in conjunction with `Pix` is going to lead to unwanted results!

Colour bar/wedge

It is often desireable to annotate an image with a colour wedge showing the range of values in the image. This is accomplished with the `draw_wedge` function in PDL::Graphics::PGPLOT (but you can avoid calling this directly by setting the `DrawWedge` option in your call to `imag` , see above). This function should normally give a decent result without the user setting any options except the `Label` option which sets the annotation, but occasionally it is necessary to change its behaviour and that is done by setting the following options:

`Side`

What side the wedge will appear on, the default is the right side and it is specified as a single character, 'B' for bottom, 'L', 'T' and 'R' for left, top and right respectively.

`Displacement`

The distance away from the axis. Default=2.

`Width`

The width of the wedge. Default=3

`Foreground`

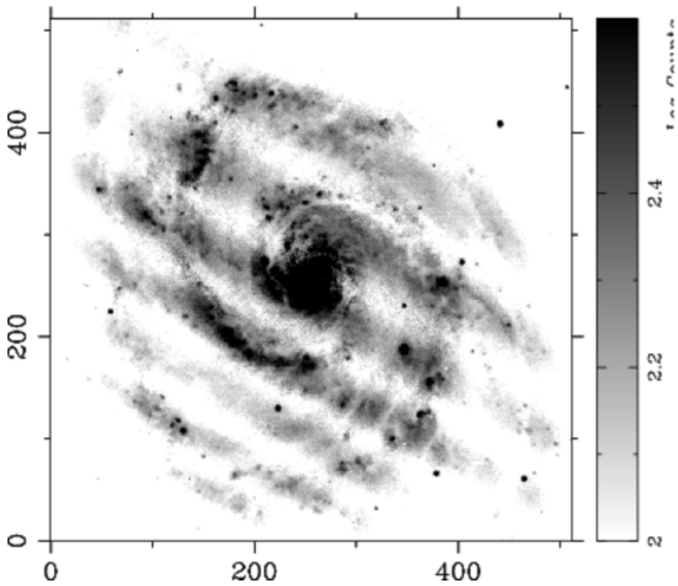
The value to set the foreground colour to. This can be referred to as `Fg` as well. The default is the max value used by `imag` when drawing the image.

`Background`

The value to set the background colour to. This can be referred to as `Bg` as well. The default is the min value used by `imag` when drawing the image.

`Label`

The label used to annotate the wedge.



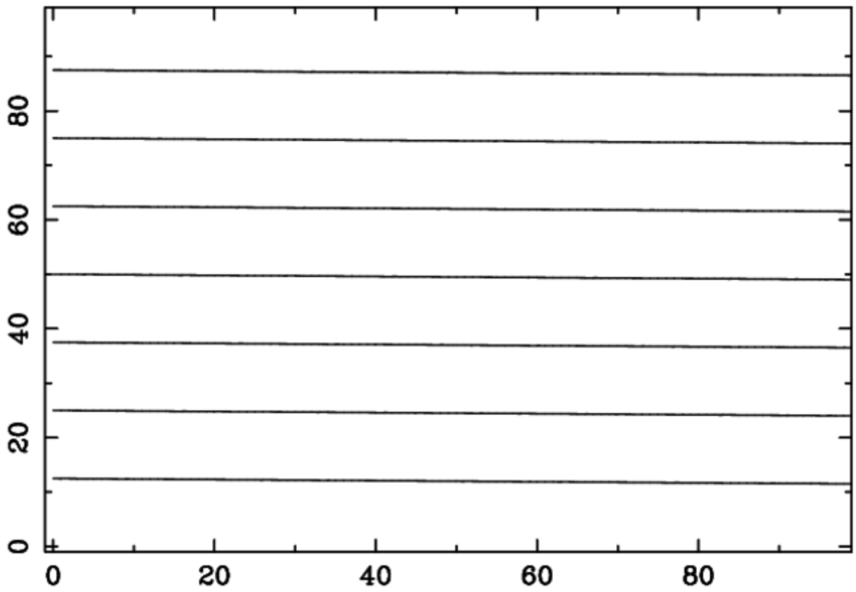

```
    dev '/xs', {WindowWidth => 6, Aspect => 1};
    $im = rfits('Frei/n4013lJ.fits');
    $im += abs(min($im)-1);
    $im = log10($im);
    imag($im, {PlotPosition => [0.1, 0.85, 0.175, 0.925], Min => 2.6, Max
=> 2.0 });
    draw_wedge({Wedge => {Width => 4, Label => 'Log Counts', Displacement
=> 1}});
```

Note that you will sometimes need to directly set the plot size to avoid clipping in the display. A full example that shows the use of `draw_wedge` can be seen in the Figure above where we display a galaxy and display a look-up table next to it.

Contour plots and vector fields

Contour plots are very similar to image displays and display lines at particular levels of the image. The function to create contour plots is `cont` which at the simplest level only takes a 2D array as its argument.

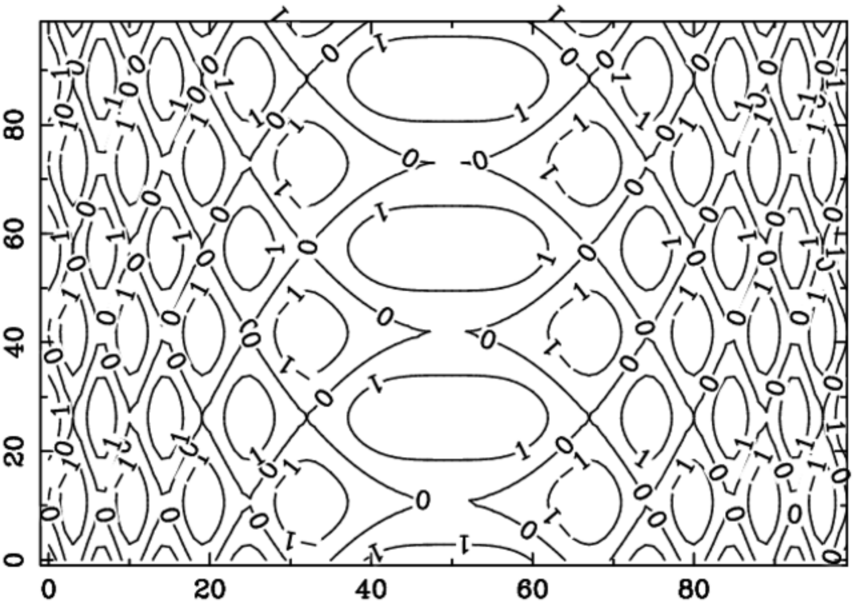
```
$a = sequence(100,100); cont $a;
```



That might be all you need, but most likely you would like to specify contour levels, label contours and maybe draw them in different colours.

You use the option `Contours` to give the wanted contour levels as a piddle and `Labels` to give an anonymous array of strings for labels as shown in the example below:

```
    use PDL; use PDL::Graphics::PGPLOT;
    dev(â€™/xsâ€™);
    $y = ylinvals(zeroes(100,100), -5, 5);
    $x = xlinvals(zeroes(100,100), -5, 5);
    $z = cos($x**2)+sin($y*2);
    cont $z, {Contours => pdl(-1, 0, 1), Labels => [â€™-1â€™, â€™0â€™,
â€™1â€™]};
```



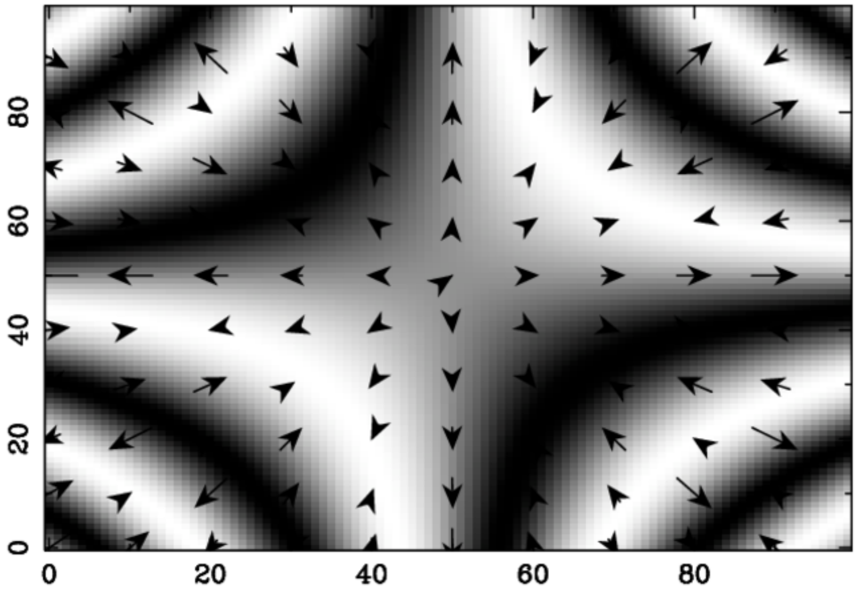
In addition it is possible to colour the labels differently from the contour lines (`LabelColour`), to specify the number of contours instead of their values (`NContours`) and to draw negative contours as dashed lines and positive as solid lines by setting the option `Follow` to a value *>0*.

Overlaying a contour plot on top of an image is as easy as displaying the image, call `hold` and display the contour plot. The reader might want to try a colour version of the example above (`$z` as in the example):

```
pdl> ctab('Fire');
pdl> imag $z; hold;
pdl> cont $z, {Contours => pdl(-1,0,1)};
```

The final 2D plot command we will deal with here is the command for plotting a vector field, `vect`. This command takes two arrays as arguments. The first gives the horisontal component and the second the vertical component of the vector field. The length of the vectors can be set using the `SCALE` option and the position relative to the pixel centers with the option `POS`.

What is important to note with a command like `vect` is that you can use the `Transform` option to map a smaller vector array to a larger image. This is often useful because a vector field with *256 x 256* arrows on top of a similarly sized image will quickly be unreadable. The result of using this technique is shown below together with the code that produced the plot.



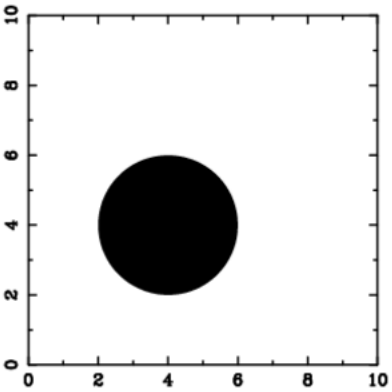

```
pdl> $x = xlinvals(zeroes(100,100), -5, 5)
pdl> $y = ylinvals(zeroes(100,100), -5, 5)
pdl> $z = sin($x*$y/2)
pdl> imag $z;
pdl> hold;
# Show the partial derivatives wrt.  x & y as vectors
pdl> $xcomp = $x*cos($x*$y/2)/2
pdl> $ycomp = $y*cos($x*$y/2)/2
# We want to show only every tenth vector for clarity
pdl> $s = '0:-1:10,0:-1:10';
# Finally we need to map the final 10x10 array to the 100x100 image
pdl> $tr = pdl(0,10,0,0,0,10)
pdl> vect $xcomp->slice($s), $ycomp->slice($s), {Transform=>$tr}
```

Drawing simple shapes

In addition to the simple commands described above, there are a few convenient commands for drawing simple shapes such as circles, ellipses and rectangles. These are fairly straightforward commands with similar options and invocations so we will go through them fairly quickly. A common issue with these commands as with the `poly` command is that they draw filled shapes, if you want outlined shapes to be drawn you have to set the `Filltype` option to `Outline`.

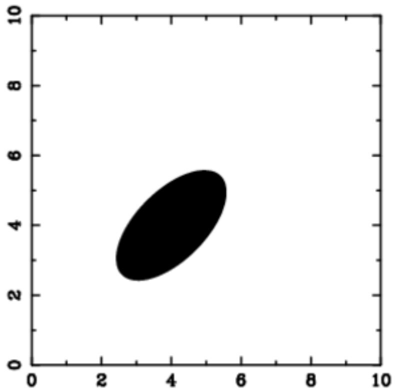
The circle command is probably the simplest, it draws a circle (which may or may not look like a circle depending on the aspect ratio of your display - see *Setting up the plot area*. The user specifies the radius and the x and y position of the center:

```
pdl> dev â€™/xsâ€™, {Aspect => 1, WindowWidth => 5}
pdl> env 0, 10, 0, 10
pdl> $radius=2; ($x, $y) = (4, 4)
pdl> circle $x, $y, $radius, {LineWidth => 3}
```



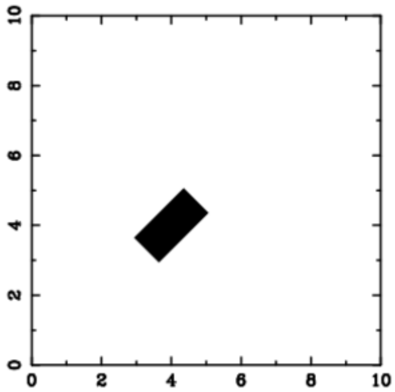
The `ellipse` function is like the `circle` function but it requires the user to specify the minor and major axis and the angle between the major axis and the horisontal. For ease of use it is probably better to specify these as options, but if you remember the order you can also give them directly as arguments to the function (*x*-position, *y*-position, major axis, minor axis, angle):

```
    pdl> dev â€™/xsâ€™, {Aspect => 1, WindowWidth => 5}
    pdl> env 0, 10, 0, 10
    pdl> ellipse 4, 4, {MajorAxis => 2, MinorAxis => 1, Theta =>
atan2(1,1)}
```



And finally the `rectangle` command draws rectangles where you can give the position of the centre, the length of the sides and the angle with the horisontal. The operation is very similar to the `ellipse` command with the length of the sides of the rectangle taking place of the major and minor axis.

```
pdl> dev â€™/xsâ€™, {Aspect => 1, WindowWidth => 5}
pdl> env 0, 10, 0, 10
pdl> rectangle 4, 4, {XSide => 2, YSide => 1, Angle => atan2(1,1)}
```



Note that `Angle` and `Theta` are synonyms.

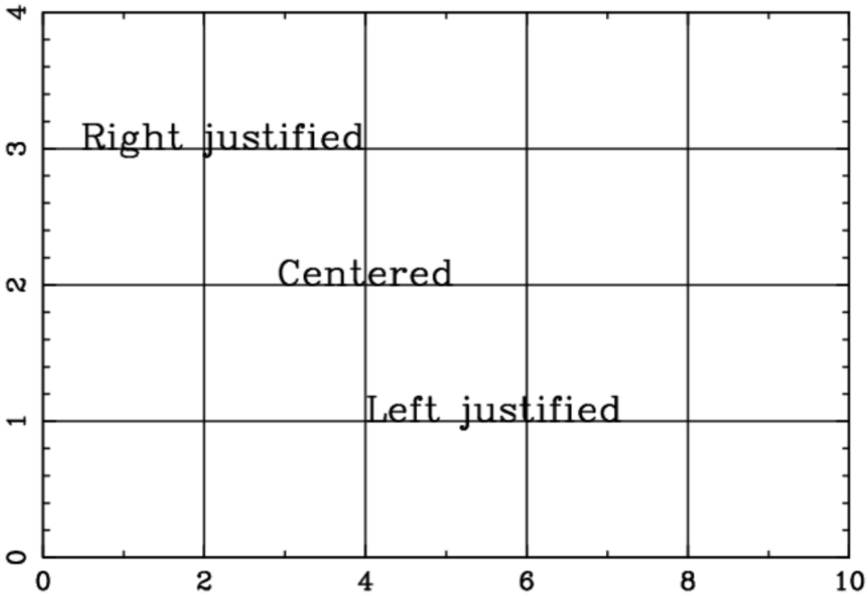
In addition you can set the sides to be similar by setting the `Side` option to the length you require. The lengths are all specified in data-coordinates (which is why you should do a plot or call `env` before using any of these commands).

For other shapes or when these are not sufficiently flexible you should use the `poly` command which is called by both `rectangle` and `ellipse` .

Text and legends

The main command for drawing text on the plotting surface is the `text` command which at its basic level just draws a string from the given *x* and *y* position:

```
pdl> dev â€™/xsâ€™
pdl> env 0,10,0,10, {Axis => â€™GRIDâ€™}
pdl> text â€™Left justifiedâ€™, 4, 1
pdl> text â€™Centeredâ€™, 4, 2, { Justification => 0.5}
pdl> text â€™Right justfiedâ€™, 4, 3, { Justification => 1.0}
```



Here we have included grid-lines to show the effect of the different justifications. Note that `Justify` is a synonym for `Justification`, and that you need to give numerical values for the position. Normally the text background is transparent as shown here, but you can also set an opaque background by setting the `BackgroundColour` option to a colour name or value (see also the next section).

In addition to the justification option one can also change the angle of the text using the `Angle` option and specify the text and/or *x* and *y* as options (the best advice is to either do all or none).

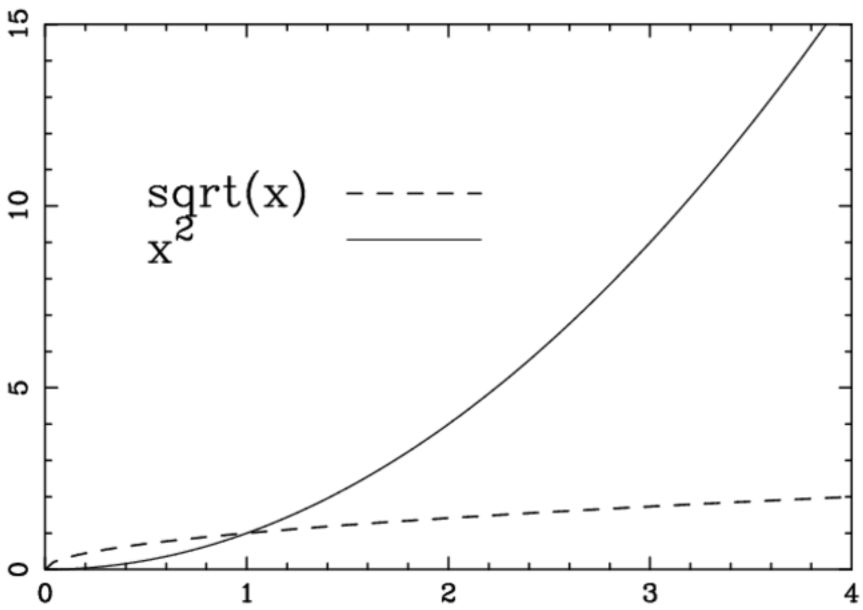
```
pdl> text {XPos => 1, YPos=> 4, Angle => 25, Text => 'Tilted'}
```

Non-alphanumeric symbols

PGPLOT has extensive support for non-alphanumeric characters in text strings and also offers reasonable control over the display of superscripts, subscripts etc. This is all achieved using *escape sequences*. In PGPLOT these are all signaled by the character `\` . Thus `\u` starts a superscript or ends a subscript - it signals a shift "up". Likewise `\d` starts a subscript or ends a superscript. Consult the PGPLOT documentation for a full list.

Labelling your figures in PGPLOT

The only additional text-related function in the PDL::Graphics::PGPLOT interface is the `legend` command which draws a legend in the plot window. This is a more complex routine which can be a time-saver as soon as you have learned how to use it. It takes the same arguments as the `text` command with the exception that the text argument is an anonymous array of labels for the legend, and that a fourth argument is accepted which specifies the width of the box in which the legend will be drawn. If this is not set or it is set to the string `Automatic` it will be adjusted to contain the legend with the default font-size (or that set by the user via the `CharSize` option).




```
pdl> $x = sequence(100) / 5; $y1 = sqrt($x); $y2 = $x**2;
pdl> env(0, 4, 0, 15);
pdl> line $x, $y1, {LineStyle => 'Dashed', Colour => 'Red'}
pdl> line $x, $y2, {LineWidth => 3, Colour => 'Blue'}
pdl> legend ['sqrt(x)', 'x \backslash u2'], 0.5, 10,
                {LineStyle => ['Dashed', undef],
                LineWidth => [undef, 3], Colour => ['Red', 'Blue'] }
              # ,Width => 1.0 } makes x**2 legend disappear, why?
```

The idea of the `legend` command is that you give the line-styles, line-widths, colours or symbols you want to illustrate as anonymous arrays to the `LineStyle`, `LineWidth`, `Colour` and `Symbol` options. Not very clear? Well, maybe an example will help.

The figure above is an example of `legend` in use. Two lines are drawn, a red dashed line and a blue thick line. To annotate this plot using `legend` you give the text annotations as an (anonymous) array of strings, the x and y position of the legend box and an anonymous hash containing information about the legends to draw as shown in the example. The options used to specify a particular draw style are the same as the ones used in the call to `line` and will undergo the same translations-note however that you can specify a value of `undef` which requests that the current default for the linestyle/linewidth/colour etc. is used. The `Width` option is used to set the width of the legend box and is given in data coordinates. The idea is that you will create the plot, see where you want the legends to go and then set the x and y width to the appropriate settings and redoing the plot, possibly using the replay mechanism, see *Recording and playing back plot commands*.

The legend command has several options, the main of which are illustrated above. The remaining options are useful for tweaking the appearance, and a full list is as follows:

`Text`

The text, this is an alternative to specifying it as the first argument to the function.

`XPos`

The X-position of the text, again as an alternative to specifying it as the second argument.

`YPos`

The Y-position of the text, again as an alternative to specifying it as the third argument.

`Width`

The width of the (invisible) box the legend is drawn inside. This can also be specified as the fourth argument to the `legend` command. If this is set to the string `Automatic` the width is calculated from the character size used.

`Height`

This can be used as an alternative constraint on size, giving the height of the legend box. If both `Width` and `Height` are specified the smallest size is used (characters are not compressed or stretched to fit).

`TextFraction`

The fraction of the box set aside for text. The default is 0.5 which usually is ok. Note that this option used to be called `Fraction` , which still is available as a synonym.

`TextShift`

This option allows for fine control of the spacing between the text and the start of the line/symbol. It is given in fractions of the total width of the legend box. The default value is 0.1.

`VertSpace`

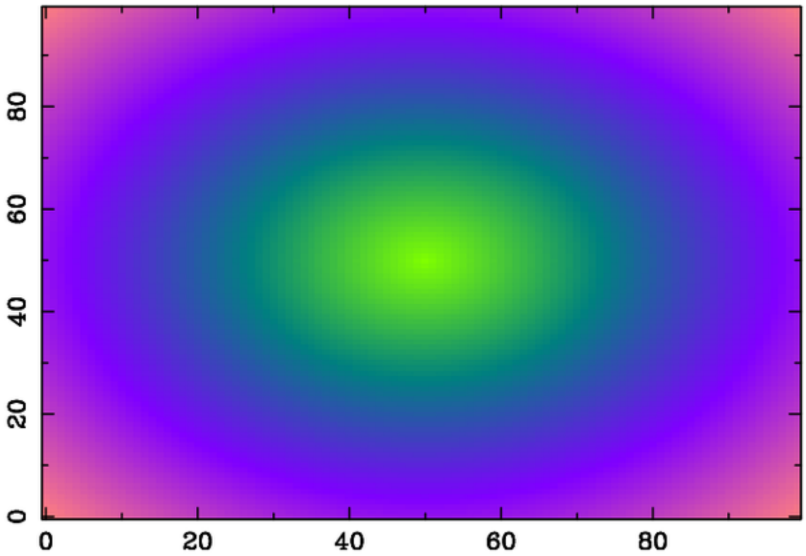
By default the text lines are separated by one character height (in the sense that if the separation were 0 then they would lie on top of each other). The `VertSpace` option allows you to increase (or decrease) this gap in units of the character height; a value of 0.5 would add half a character height to the gap between lines, and -0.5 would remove the same distance. The default value is 0. This option has `VSpace` as a synonym (more natural for the TeX-heads out there).

Using colour

PGPLOT has a two disjoint sets of colours. One set determines the colour table used when displaying images and is initialised to a grayscale, and the other is a set of 15 colours used to colour all other plotting objects. The latter set is accessible through the `Colour` option described in *Options in plot commands* Here we will concentrate on accessing the lookup-table for image display.

The command used to change the colour table is `ctab`, which in its generic form takes six arguments specifying the intensity levels, red, green and blue colour components, contrast and brightness levels. The contrast and brightness are optional so that we can say:

```
pdl> $int = pdl([0, 0.33, 0.66, 1.0])
pdl> $r = pdl([0.5, 0, 0.5, 1])
pdl> $b = pdl([0.0, 0.5, 1.0, 0.5])
pdl> $g = pdl([1.0, 0.5, 0.0, 0.5])
pdl> ctab($int, $r, $g, $b);
pdl> $a = rvals(100, 100)
pdl> imag $a
```



...which should display a circularly symmetric figure with green in the centre, going through blue to red-ish where $a is at a maximum.

It is however normally sufficient to use the colour tables made available by `PDL::Graphics::LUT`. This package makes available a large number of standard colour tables which can be accessed using the following commands:

`lut_names`

This returns a perl list of the available colour tables.

`lut_ramps`

As above, but returns a list of the names of the available intensity ramps.

`lut_data`

And finally the data in the tables can be accessed with this function which takes as arguments the name of the colour table, and optionally a scalar determining if the colour table is to be reversed and the name of an intensity ramp (default is a linear intensity ramp). The function returns four piddles with intensity and RGB values which can immediately be passed to `ctab`.

Note that these commands do not set the colour table for you, you will still need to call `ctab` to do that.

Thus to set one of the colour tables in the `PDL::Graphics::LUT` package, you do:

```
    pdl> use PDL::Graphics::LUT;
    pdl> print "Available tables: ".join(', ', lut_names());
    Available tables: aips0, backgr, bgyrw, blue, blulut, color, green,
    heat, idl11, idl12, idl14, idl15, idl2, idl4, idl5, idl6, isophot,
light,
    manycol, pastel, rainbow, rainbow1, rainbow2, rainbow3,
    rainbow4, ramp, random, random1, random2, random3,
    random4, random5, random6, real, red, smooth, smooth1,
    smooth2, smooth3, staircase, stairs8, stairs9, standard
    pdl> ctab( lut_data \series default ('rainbow1'));
```

```
pdl> imag rvals(100,100);
```

which should give you a colour table that goes from black through green, blue and yellow to red.

All the colour tables with their names overlaid can be generated with this script:

```
use PDL::Graphics::PGPLOT;
use PDL::Graphics::LUT;
dev("/xs",3,15);
foreach(lut_names()){
    print"$_\n";
    ctab(lut_data($_));
    imag sequence(250,1);
    text $_,20,-0.2,{CHARSIZE=>20,LINEWIDTH=>20,COLOUR=>0};
    text $_,20,-0.2,{CHARSIZE=>20,LINEWIDTH=>1,COLOUR=>1};
}
```

And the resultant figure is shown below:

Threading in PDL::Graphics::PGPLOT

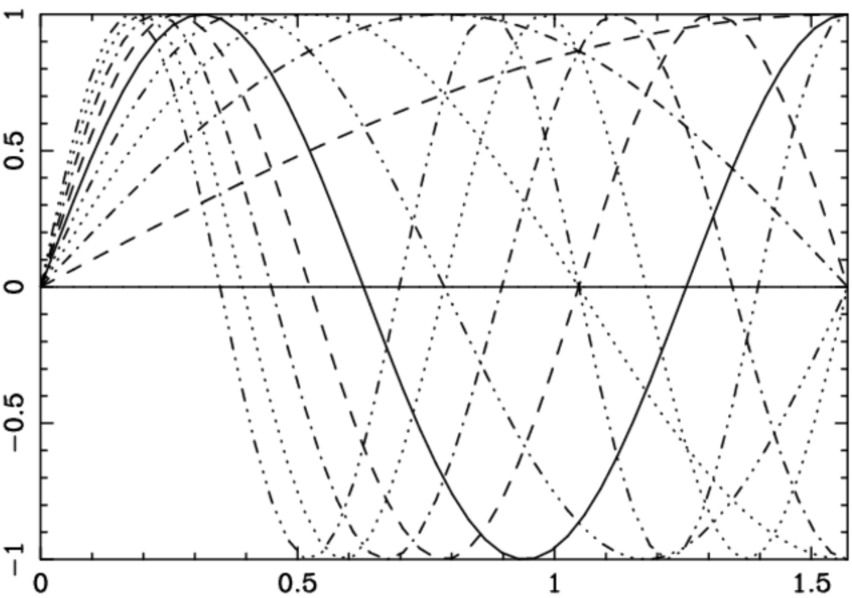
The plot commands do not always lend themselves to easy threading because it can sometimes be difficult to know what the user intends to do when (say) an array of images is passed to the `imag` command. Are they to be displayed in several plot panels, are they to be plotted on top of each other, seamlessly plotted next to each other? But even more complex is the question of treatment of options and how to deal with these if there are less options than for instance, lines to draw (a common occurence if you wanted to draw a **lot** of lines).

That said the `PDL::Graphics::PGPLOT` interface does have limited support for threading in the `line` and `points` functions. These call the `tline` and `tpoints` internally, and work just like `line` and `points` except that they expect the input *y*-piddle to be 2D, with each line in the array plotted against the *x*-piddle.

The way the options are treated is the most interesting. To set options for a set of lines, give an anonymous array as argument to that option with a value for each line. If you give more options than there are lines, the surplus is ignored. However if you give less, the options are repeated from the start. Although possibly a bit confusing this is very powerful because you can get a large number of combinations of colour and linestyle. For instance if you give 4 colours and 5 linestyles, you get a total of 20 distinct combinations and should you give 3 linewidths as well you will suddenly have 80 different styles to work with with very little typing. Note however that you need to make sure that the numbers you give are relativel y prime - otherwise you will get much less possibility, just think of the situation where you have 4 linestyles and 4 colours, they will just loop in harmony and result in only 4 combinations.

Anyway, let us see how it all works in practice by creating a plot of sine curves with different frequencies. This is a simple example where we want to colour all even frequencies with red and all odd with blue and vary the line-styles as well:

```
    pdl> $pi=4*atan2(1,1);
    pdl> $x=zeroes(50)->xlinvals(0, $pi)
    pdl> $freq = sequence(10)
    pdl> $y = sin($freq*transpose($x))
    pdl> line $x, $y, {Colour => [â€™Redâ€™, â€™Blueâ€™],
Linestyle=>[0,1,2,3,4,5]}
```



Recording and playing back plot commands

Have you ever created a good-looking plot on the command line of an interactive data program, be it PDL, IDL, Matlab, Octave or any other package, and wished that you could make a quick Postscript copy of it only to find that you need to redo all the commands? I certainly have. In the newer versions of PDL this is thankfully not the case anymore. These have a recording facility built in. However this is not enabled by default (for reasons described later in this section), you need to turn it on yourself. The way to do this is to set the `$PDL::Graphics::PGPLOT::RECORDING` variable to a true value:

```
    pdl> $PDL::Graphics::PGPLOT::RECORDING = 1
```

You can turn this on automatically in the `perldl` shell if you put this command in your `~/.perldlrc` file. Alternatively you can turn on recording for each plot device independently by setting the

Recording option to true when starting a device:

```
pdl> dev '/xs', {Recording => 1}
```

Note that if you set the variable it must be set **after** you have use'd the PDL::Graphics::PGPLOT because this package sets the variable when it initialises to its default value of zero.

In the following I will focus my attention on using the recording and playback functions in the perldl shell as I envisage that it will be most useful there. There are a couple of potential uses in scripts as well which I will get back to below, but this is not well thought through yet.

Before we continue it should also be added that the recording facility is somewhat experimental. In particular it doesn't deal very well with multi-panel plotting where you jump back and forth between panels. If you want to do that, make sure you specify the Panel option for every call.

It is very easy to use the recording facilities with a few less obvious aspects. An example should go a long way to get you to understand the basics. First we set up a simple plot using the commands we learned above:

```
pdl> use PDL::Graphics::PGPLOT
pdl> $PDL::Graphics::PGPLOT::RECORDING = 1
pdl> $x = sequence(10)
pdl> $y = random(10)
pdl> dev '/xs'
pdl> env(-1, 11, -0.5, 1.5, {Xtitle => 'Number'})
pdl> points $x, $y, {Symbol => 'Plus'}
```

which should give you a scatter plot on screen. Now after constructing this fantastic piece of scientific illumination you decided to make a Postscript version of it, but you are loathe to use the up key to execute the commands again so you decide to use the recording facilities.

```
pdl> $s = retrieve_state()
pdl> dev 'replay_ex.ps/ps'
pdl> replay $s
```

That is all. These commands should now have created a file called replay_ex.ps in the present directory.

The retrieve_state commands retrieves the current state of the plot device and returns a variable to hold this in. This state contains references to the data plotted and plot commands executed and can be replayed, or re-executed, at a later stage using the replay command. You can also turn on and off recording temporarily with the turn_off_recording and turn_on_recording commands.

This suffices for most situations and should work for any complexity of plot constructed. There are however a few rules that needs to be observed and possible pitfalls:

If you turn on recording globally using $PDL::Graphics::PGPLOT::RECORDING, you must set the variable **before** opening a plot device because the value of the variable is only checked then. If you forget, you can of course always turn it on with the turn_on_recording function.

The state is cleared whenever the plot window is erased, or if the user executes the clear_state command. In particular this occurs when you change plotting device (although if you use several windows they will each have their own state; see also the following section), so use the retrieve_state command **before** you change device!

The state contains references to the data plotted. This does not use memory (at least not appreciably!), but it does mean that an extra reference to the data is kept and the memory to the data might not be freed when you expect it to. This can be problematic if you make a lot of image displays. The best ways to avoid this problem in the perldl shell is to call the clear on the state: perldl>

`$s->clear()` or to re-use the variable next time you call `retrieve_state`. Note that this should only be a problem if you explicitly call `retrieve_state`.

Finally since only references to the data are held, make sure you do not modify them before calling `replay` or you might end up with a rather different looking plot!

What we covered now is the basic use of the recording facility, which hopefully will come in handy rather often (which is why I recommend enabling it permanent ly in the `perldl` shell as outlined above). However there are slightly less common uses of the facility that might come in handy:

Redoing a plot with slightly different data

The fact that the recording state contains references to the data enables a somewhat tricky but potentially very useful trick to be executed: Redoing the plot with adjusted data. Sometimes you make a complex plot only to discover that you had made an error with your data and you need to redo it. This is where you can use the recording functions: Retrieve the state, make adjustments to the data making sure not to break the link and run `replay`.

However, although this sounds quite easy it has a few subtleties that can give surprising results at times. It might therefore be a good idea to look at a few, very similar and very basic, examples and compare their effects. So let us first of all open a plot device:

```
pdl> dev '/xs', {Recording => 1}
```

NOTE: What I describe here is not well tested and is probably buggy. This needs to be sorted out before finishing - at least I have had a few weird results when trying this out.

We are going to use our example of plotting a parabola, and replaying it with various parameter sets. Let us therefore define a couple of variables and plot this, first letting PDL decide on the plot limits:

```
pdl> $x = sequence(10); $y = $x*$x
pdl> line $x, $y;
pdl> $s = retrieve_state()
```

The whole point of this problem is to change the variables, so let us add 3 to the X-values and replay the command:

```
pdl> $x += 3
pdl> replay $s
```

This should give you a part of a parabola from `x=3` to `x=12`, but now defined by the equation `y=pow((x-3),2)` . Also the limits of the plot window should have adjusted themselves to the new *x* values. Note that the *y* values are unchanged.

In the previous example the limits in the plot window adjusted to the new values for *x* and *y* because the `line` command sets the plot limits if the plot is not held (such as with an explicit call to `env`). But what happens if we redo the example with our own chosen limits?

```
pdl> $x = sequence(10); $y = $x*$x
pdl> env (0, 9, 0, 81)
pdl> line $x, $y;
pdl> $s = retrievestate()
pdl> $x += 3; replay $s
```

The result now should be as shown in Figure XXXXXXXX which has the same plot limits as before, but a shifted parabola. This is because the state now remembers the explicit `env` statement that you had made and uses that to set the limits.

Finally you must remember that the reference is not to a variable name, but to a piddle which exists separately from the variable. Thus you cannot change your data at a whim, so the following change will change the data back to where we started

```
pdl> $x -= 3; replay $s
```

But the following will **not** plot a parabola starting at *x=5*:

```
pdl> $x = sequence(10)+5.0; replay $s
```

The reason for this is that the reference kept in the state object is to the actual **data** in the previous *$x* -object and not to the variable name.

However sometimes you want to give a entirely new dataset to the plot. Say you wanted to plot a sine curve instead of a parabola. Is there any way to do that? The answer is yes, but it looks rather ugly, so you might want to consider whether this is something you want to do

```
pdl> $x = sequence(10); $y = $x*$x
pdl> line $x, $y; $s=retrievestate()
# Now let us transfer this to a sine plot
pdl> $y -= $y; $y += sin($x)
pdl> replay $s
```

And voila! a sine curve does step forth. Not exactly elegant, but this trick allows you to replace any variable used in a complex plot with a totally different content.

Using recording in scripts

In general the recording facility is of rather limited use in scripts because you can just as easily encapsulate your plot commands in a subroutine and just call the subroutine when need be. At present the only saving is probably in typing, but if the facility is extended to saving and restoring plot commands the situation would change.

The object oriented approach

Assume that you are developing a simulation. When you are testing the code (all written in PDL of course) you have to keep track of how some data changes at every time-step, but at the same time you want to look at time-averages. If you were to use what we discussed above you would probably want to display the time-steps in one panel and the time-averages in another panel in a plot window. The problem with this is of course that one panel is updated a lot more often than the other so you have to waste a lot of time re-plotting the time-average.

Clearly there are two possible ways to improve this: a) have a method which allows you to plot to a given panel when you want and b) have to plot windows. It is possible to use the first approach by giving the `Panel` option to the plot commands:

```
dev('/xs');
for (my $i=0; $i<$n; $i++) {
   $integrand = func($x, $i);
   points $x, $integrand, {Panel => 2};
   $sum += $integrand;
}
points $x, $sum/$n, {Panel => 1};
```

So that this hypothetical code-bit would keep plotting in panel 2, updating the plot there until the loop is over at which point panel 1 is updated.

This can be practical, but it is rather limited given the requirement of giving the panel number every time. Instead an alternative approach would be to create several plot windows, and for this you really ought to use an object oriented approach. In this approach every plot device is a separate object and you call every plot command via this object. So the previous example would be

```
my $opt = {Device => '/xs', WindowWidth => 7, Aspect => 1};
my $integrandwindow = PDL::Graphics::PGPLOT::Window->new($opt);
my $integralwindow = PDL::Graphics::PGPLOT::Window->new($opt);
for (my $i=0; $i<$n; $i++) {
   $integrand = func($x, $i);
   $integrandwindow->points($x, $integrand);
   $sum += $integrand;
}
$integralwindow->points($x, $sum/$n);
```

Why use the OO interface

So, you may say, what is the point with the OO interface except appeasing the OO fanatics around? It seems to require more typing and I can see no significant advantage.

In many situations these are valid arguments, if you are just plotting data on the command line in `perldl` , for instance, or do not need multiple plot windows. And at some level the OO interface is primarily a convenience for the programme r, and it is in fact how the PDL::Graphics::PGPLOT package is implemented. That said though there are some (possibly strong) arguments for using the OO interface:

- You do not pollute your namespace, which means that you are free to define routines that are called `line` , `points` and so on. This is the main reason why I use this interface personally when doing simple plots in programs.
- It is a **lot** easier to deal with multiple plot windows when using the OO interface, in fact I would personally discourage people from having multiple plot windows without using the OO interface.

Eventually an argument in favour of the OO interface will hopefully be that it would enable an easier mix of different plotting packages so that they can all be accessed in a similar way, but we are not there yet.

Usage of the OO interface

To use the OO interface one needs to create a new plot object and then call the plot routines through this object. If you want several windows, you just create more objects and switching between these should be straightforward as you should be able to see in the following examples.

Note that since the OO interface is less suited to use on the command line, I have opted to show the examples as small code-bits but they should all be possible to execute from the `perldl` command line. In addition this section will merely give several examples of use of the OO interface and not discuss (again) the different commands since they are the same as we went through above, it is just a different way of calling them.

Opening a plot object and plotting a simple plot

To create a plot object we first need to `use` the PDL::Graphics2D package - this is merely a shortcut for the true PDL::Graphics::PGPLOT::Window package, but why type more when it doesn't gain you anything? Then we create the object using the standard Perl notation `PDL::Graphics2D-`new()> :

```
use PDL;
# Note that we could also access this as
# PDL::Graphics::PGPLOT::Window, but since this is
# shorter I advocate its use.

use PDL::Graphics2D;
# Now create a plot window
my $winopt = {Device => '/xs', WindowWidth => 7, Aspect => 1};
my $w = PDL::Graphics2D->new($winopt);
```

```
# Create a simple plot
$x = sequence(10);
$w->points($x, $x*$x, {Symbol => 'Triangle'};
```

Note how we use the window object (`$w`) when calling the `points` routine - since we didn't `use` the PDL::Graphics::PGPLOT package there isn't any function called `points` in our namespace and we use the window object to get hold of it. The structure is of course very similar to what we did in *Drawing lines and plotting points* above and there really is little practical difference between the two interfaces when plotting to only one window.

Therefore let us up the stakes somewhat and try a more practical example. In many situations you might have one plot where each point in the plot has many values associated to it (i.e. your plot is a slice in a multidimensional space). When you examine such data you often would like to click on a point on your plot and bring up associated data for that point in a different display - this is an obvious situation for the OO interface.

The logic for this project is easy: We first create two windows

```
use PDL;
use PDL::Graphics2D;
# Create two identical windows
my $winopt = {Device => '/xs', WindowWidth => 7, Aspect => 1};
my $data = PDL::Graphics2D->new($winopt);
my $associated = PDL::Graphics2D->new($winopt);
```

Note that it is a good idea to name your variables containing the window objects with sensible names for later use.

The next step is to plot data (well, in this example I will merely create them):

```
my $x = sequence(10);
my $y = $x**2;
# Plot points using standard symbol
$data->points($x, $y);
```

which should draw a nice parabola on your screen. Now the user (that is you, reader) has to click on (or near) a point to select it - we will then use the X-value of that point to set the period of sine curve:

```
print "Dear user, please click on (or close to) a point\n";
my ($xin, $yin) = $data->cursor();
# closest will now contain the index of the point closest to
# where the user clicked.
my $closest = minimum_ind(abs($x-$xin) + abs($y-$yin));
my $y_associated = sin($x->at($closest)*$x);
$associated->line($x, $y_associated);
```

That should now give you a sine wave in the second window with a frequency dependent on where along the X-axis you clicked. Of course it would be a lot easier to use `$xin`, but that wasn't what we tried to do after all.

This is of course a very simplified example, but it does provide a framework for a more comprehensive data explorer. From astronomy a typical example would be to plot scatter-plots for two variables and bringing up images of the objects by clicking at their data in the plot window. In other situations the data might be financial data for a set of companies and clicking on the points would bring up a comprehensive summary of that company. You are limited by your imagination!

The bottom line is that whatever your requirements are, the OO approach is probably better when you need more than one plot window, but when you only use one window, and particularly on the `perldl` command line.

Using PGPLOT commands directly

The Perl module PGPLOT contains interfaces to all PGPLOT functions. The majority of these functions have alternative interfaces in the PDL package, but there might be situations when you need to use these functions directly. And in addition if you are used to using PGPLOT from before you might prefer the interface, although it is rather inconvenient when dealing with PDL.

Full documentation for the PGPLOT functions can be found at Tim Pearson's WWW page: `http://astro.caltech.edu/~tjp/pgplot/` . This is not the place to discuss the details of PGPLOT, but it is interesting to learn how to access these routines from PDL with piddles as arguments.

Typical PGPLOT drawing functions take as arguments the number of points and references to perl arrays to give x and y coordinates, thus:

```
@x = (1,2,3);
@y = (3,-1,7);
pgpoint(3, \@x, \@y, 4);
```

will plot three points with the x and y values indicates and using plotting symbol 4 (circle).

The complication for PDL users is that piddles are not perl arrays and hence have to be converted to array references before they can be passed to a PGPLOT function. This is achieved with the `get_dataref` command which returns a reference to the data in a piddle. Thus the example above would be written:

```
$x = pdl(1,2,3);
$y = pdl(3,-1,7);
pgpoint($x->nelem, $x->getdataref, $y->getdataref, 4);
```

in PDL.

In general you should use the provided wrapper routines for readability, but feel free to combine the two if you prefer. You should be able to pick'n'mix functions from the PDL interface and from PGPLOT directly, although a few subtle bugs might creep in (in particular the handling of several plot windows).

There are several situations where direct access to PGPLOT might be necessary. Although hopefully they are not very common, it can be useful to look at a few to see what the PDL::Graphics::PGPLOT module doesn't do. Since it is possible to mix PGPLOT commands with the PDL::Graphics::PGPLOT commands this is not a major problem though, although it might require you to learn some PGPLOT. So to turn to some examples, I have decided to list a few simple problems:

- Drawing several plot boxes on top of each other to get differently shaded grids. This is done in one of the demonstration programs that come with PGPLOT and can't be easily done in PDL::Graphics::PGPLOT without some playing around with the `PlotPosition` option. It is a lot easier to call `pgbox` directly.
- Complex contour plots - in particular non-rectangular. At present there is no support for non-rectangular contour plots in PDL::Graphics::PGPLOT, and neither is any support planned for the near future. You are advised to read the PGPLOT documentation for `pgconx` and have a look at demo #3 in the PGPLOT distribution for an example.

The bottom line is that as your plots get more and more complex you might end up in a situation where you need the finer control offered by the `PGPLOT` package, but for day-to-day use it is hoped that PDL::Graphics::PGPLOT will address most people's needs. And if doesn't then let us know!

Credits

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