BPIDL—BASIC PLOTTING IN IDL: PLOTS, MULTIPLE PLOTS, COLORS, MAKING POSTSCRIPT FILES
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This is an introduction to plotting in IDL. We also cover some embellishments: arrays of plots, 4d plots using symbol size and color, selecting groups of plotted points with the cursor. And we discuss how to make good-looking PostScript plots for papers and talks. This document is only an *introduction*: you can do almost anything on plotting with IDL!

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1. PLOTTING BASICS

1.1. The `plot` Command

We can call `plot` with several keywords and optional inputs. The top panel of Figure 1 is the plot generated by the following commands[1]:

```
plot, xdata, ydata, psym=7, $
xrange=[0,10], yrange=[0,22], xstyle=1, ystyle=1, $
xtitle='x-axis label (units)', $
ytitle='y-axis label (units)', $
title='Global Title'
```

Comparing the plot with the command should make it clear which options did what. A few comments:

1. The optional input `psym=7` defined the plotting symbol; there are many others available[2], which you can obtain from IDL's online help (type `?plot` while in IDL). When `psym` is set to a negative number, the points are plotted and, also, connected by lines.

2. `(xy)range`: setting these equal to a two element vector causes the plot ranges to be set to the values in those vectors. For `x`, the (first, second) elements are the (left, right) axis limits and for `y`, the (bottom, top). So when you are plotting things versus right ascension, which astronomers always plot backwards (high numbers on the left instead of the right), you specify this with the `xrange` vector.

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[1]The $ symbol tells IDL that the command is continuing on the next line; we use multiple lines for clarity in this introduction.

[2]Specifically, `[psym=[0,1,2,3,4,5,6,7,8]` are [plus, asterisk, period, diamond, triangle, square, X, user-defined, undefined, histogram mode]. An easy way to define your own symbols is with GSFC's `plotsym`, which gives you [arrows, a star, triangle, upside-down triangle, square, circle]; and lets you fill them in if you want; for its documentation, type `doc, 'plotsym'` .

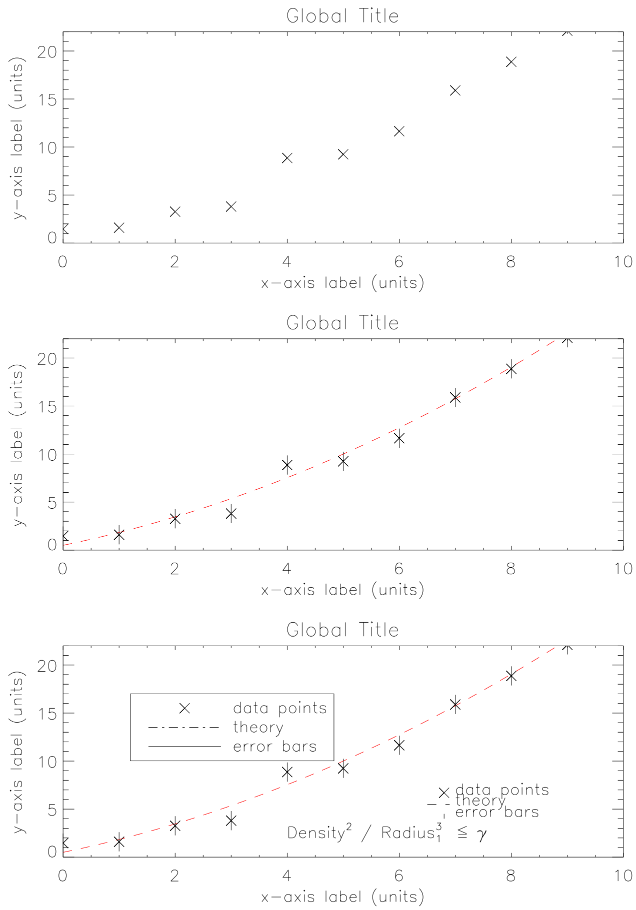


Fig. 1.— An example plot illustrating overplotting, use of color, errorbars, annotating with **`xyouts`** and also with **`legend`**, math and Greek with **`textoidl`**, and making arrays of plots with IDL's native **`!p.multi`** .

3. **`(xy)style`**: Normally, the x and y ranges are rounded to make human-comfortable numbers (like 10 instead of 9.5). Setting these **`styles`** to unity forces the ranges to be exactly what you specify. There are lots of other options for the **`style`** keywords.

1.2. Overplotting

We use the **`oplot`** command to overlay other plots on top of ones we have already made and display the results on the middle panel of Figure 1. Let's plot a fitted dashed line through our data; and just for fun, we color it red:

```
oplot, xtheory, ytheory, linestyle=2, color=!red
```

Here `linestyle=2` produces a dashed line. Our startup file predefines 12 colors (`!red, !blue, etc`; look at the printout when IDL starts up). Let's overplot some errorbars, too:

```
oploterr, xdata, ydata, yerrors
```

There are other ways to plot error bars: `errplot` and `ploterr`. And you can plot errorbars in the x-direction with our `errplot_x`. Finally, the less used but highly functional `plots` command overplots an individual point, or an array of points, all with different colors and/or symbols if you wish (e.g., §1.3).

1.3. Annotating Plots

The `xyouts` command lets you annotate plots. In the example below, `xyouts, 7.0, 6.5, 'data points'` writes the string `data points` beginning at the specified locations of (x,y) = (7.0, 6.5). You can locate the annotation in data coordinates, normalized coordinates (relative to the plot box), or device coordinates (pixels); see the documentation.

You can add legends to your plots using `plots` and `xyouts`. The legends on lower-right in Figure 1 were made with the following commands:

```
plots, 6.8, 6.7, ps=7
xyouts, 7.0, 6.5, 'data points'
plots, [6.5,6.9], [5.5,5.5], lines=2
xyouts, 7.0, 5.4, 'theory'
plots, [6.8,6.8], [4.0,4.5]
xyouts, 7.0, 4.2, 'error bars'
```

That's the hard way! The easy way: use GSFC's `legend` command. To see its documentation, type `doc, 'legend'` in IDL. In Figure 1, for the legend on upper-left of the bottom panel:

```
items= ['data points', 'theory', 'error bars']
psym=[7,0,0]
lines=[0, 3, 0]
legend, items, lines=lines, psym=psym, position=[1.5, 16.0]
```

1.4. You Want Greek Letters or Math? Use `textoidl`

Figure 1, bottom panel also has some math annotation. There are two ways to do Greek letters and sub/superscripting. One is IDL's native embedded formatting, which is infinitely flexible and consequently complicated; the other is the popular non-native procedure `textoidl`, which lets you use TEX notation to generate fancy IDL character strings. That's how we annotated Figure 1 with the string $Density^2/Radius_1^3 \leq \gamma$:

```
xyouts, 4, 2, textoidl('Density^2 / Radius_1^3 \leq \gamma'
```

If this looks like Greek to you, then you don't know TEX. As a scientist, you'll need to learn it!

2. MAKING ARRAYS OF PLOTS

2.1. Arrays of plots using IDL's `!p.multi` System Variable

The `!p.multi` system variable in IDL allows you to place multiple plots into the same window[3]. To accomplish this, set `!p.multi` equal to a three-element vector with the first element zero, the second element equal to the number of plots across the window and the third element equal to the number of plots down the window. Then give your plotting commands. For example, our Figure 1 was made like this:

```
!p.multi=[0,1,3]
plot, xd, yd, psym=7...
;other commands for this plot...

plot, xd, yd, psym=7...
;other commands for this plot...

plot, xd, yd, psym=7...
;other commands for this plot...

!p.multi=0
```

2.2. Arrays of plots using GSFC's `multiplot`

`!p.multi` allows enough space around each plot for its own axis titles, and a plot title. Often, the x-axes and/or the y-axes have identical titles or scales. In such cases, the space around each plot is annoying and wasteful. You can eliminate it by using GSFC's `multiplot.pro`; for its documentation, type `doc, 'multiplot'` if you use our startupfile or, if you don't, type `doc_library, 'multiplot'`. Figure 2, which has the same content as Figure 1, was made like this:

[3] `!p.multi` is an IDL system variable because it is prepended by a ! . System variables are always accessible, whether you are at the main level or in any procedure or function. Some other noteworthy system variables are `!pi, !dtor, !radeg` . And in our startup file we define colors, such as `!red`, as system variables.

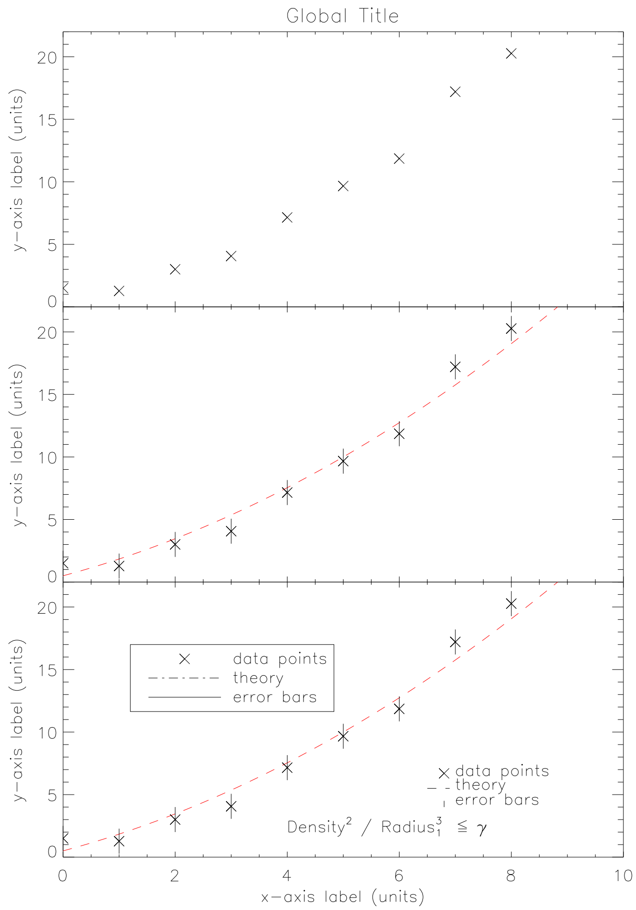


Fig. 2.— The same plots as in Figure 2. The array was made with **multiplot** .

```
multiplot, /init

multiplot,[1,3]
plot, xd, yd, psym=7, xstyle=1, title=title ...
;other commands for this plot...

multiplot
plot, xd, yd, psym=7, xstyle=1 ...
;other commands for this plot...

multiplot
plot, xd, yd, psym=7, xstyle=1, xtitle=xtitle ...
multiplot,/reset
```

```
;other commands for this plot...
```

Note the trick: you can't write a global title (with `title`) except on the top plot of a column, and you can't write an `xtitle` on any plot except the bottom—you don't want the x-axis information in the lower plot area! For the same reason, `multiplot` automatically suppresses the numbers on the x-axis for all plots other than the bottom one.

3. USE DIFFERENT-STYLED POINTS TO REPRESENT A THIRD (OR FOURTH! OR FIFTH!) VARIABLE

Sometimes you want to represent a third variable with the plot-point style. For example, your data points might come from different years. You can use different `psym` values or different symbol sizes to get differently-shaped points.

Alternatively, you can use color, and have a colorbar tell what the colors mean. And you can even represent *four* variables using *both* `psym` and color! And you can represent *five* using symbol size, shape, and color! The easy way is with our home-grown procedure colorpntplt.pro. Figure 3 was made like this:

```
;FIRST, CONSTRUCT A USER-DEFINED SQUARE, FILLED-IN PLOT SYMBOL...
plotsym, 8, 1, /fill

;MAKE AN ARRAY OF SYMBOL SIZES PROPORTIONAL TO SOURCE FLUX DENSITIES...
symsize= (tx.flux < 2) + 0.4

;MAKE THE PLOT...
colorpntplt, ell, bee, tx, xra=[360, 0], yra=[-20,90.], zra=[0,100], $
xtit='Gal Long', ytit='Gal Lat', ztit='Tspin', tit='Symsize is flux', $
psym=8, symsize=symsize, /bg

;SETTING bg ABOVE FILLS THE PLOT ``background'' WITH GRAY, WHICH IS
;       OFTEN GOOD FOR COLORS.
```

Two important points:

1. What color scheme to use for the plotted points? Here, we follow the philosophy that all colors should be perceived as being of equal brightness. This results in a color scheme that uses nonsaturated colors. For details, see §3.2 in the handout "1d2d3d: One, Two, and Three Dimensional Color Images".

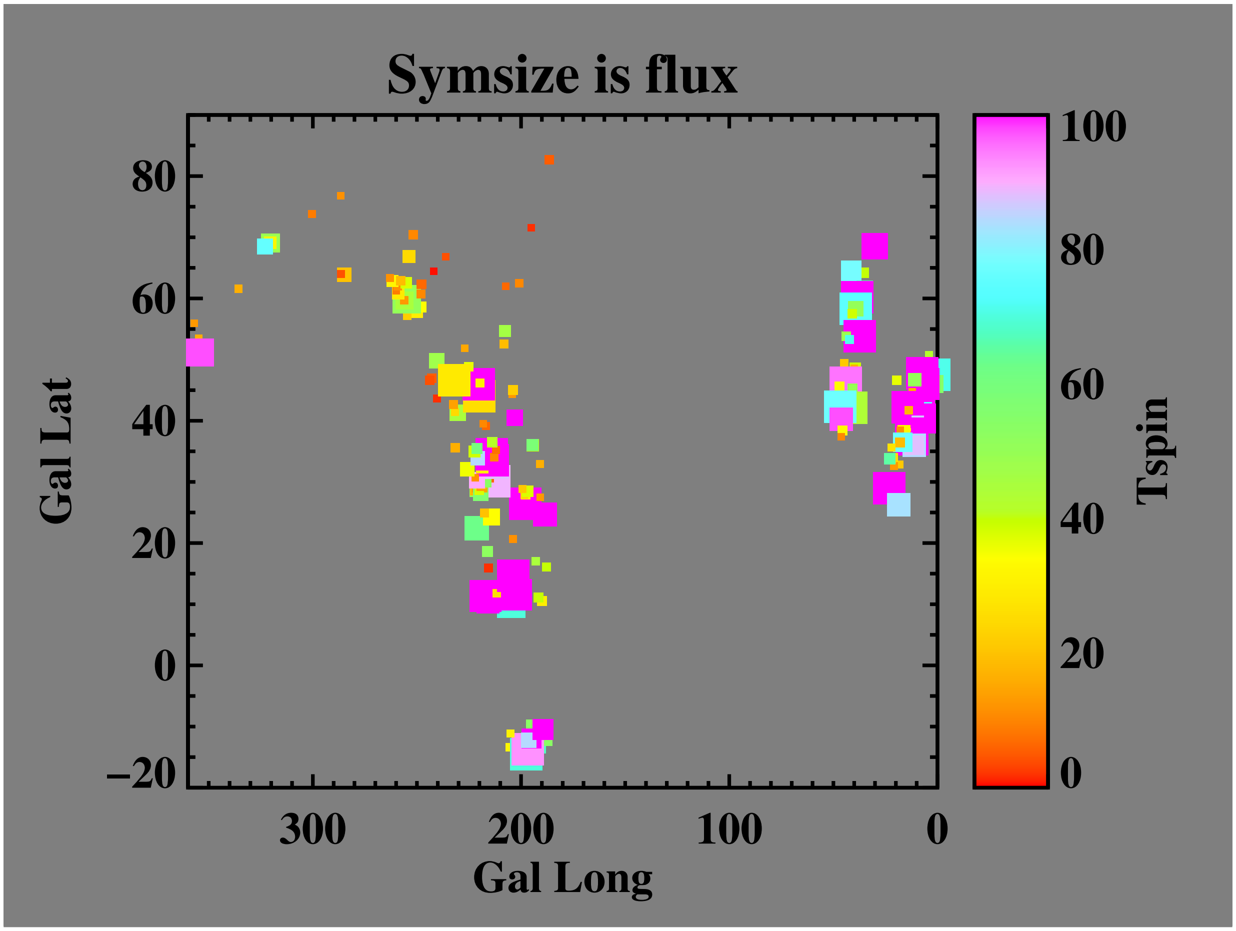


Fig. 3.— A 4-d plot (in which each point represents four different quantities). To make any sense at all, this plot *must* be viewed in color!

2. What background color for the plot? Note we use gray. This has the great advantage of having good contrast with all relevant colors—even both black and white!

4. SELECTING GROUPS OF POINTS IN A PLOT

Often, after you plot some points, you wonder about a few that occupy a region of the plot space. We have two procedures than enable you to select groups of points. One, `pointsinside.pro`, uses the cursor; the other, `graphselect.pro`, selects the points within a curve you plot using the `oplot` command. Try them!

5. FOR DOCUMENTS AND TALKS, USE POSTSCRIPT

IDL makes exportable images in many formats, but the one you'll use for most purposes is PostScript. It's best because, uniquely, its images are pixelized, but its characters are vectorized. This means that characters are drawn using lines whose placement is limited only by the resolution of the plotting device, not the resolution imposed by finite-sized pixels. To do PostScript the easy way, see §6 below.

5.1. Don't Ignore the Aesthetics!

Your documents and talks are your link to the world and it is important to make this link as clear and attractive as possible. Think of all the PowerPoint illegible graphs and text you've had to sit through in a dark room with a boring speaker who rushes from one slide tto the next without explaining what the axes are on his illegible graphs!

There's an art—based human physiology, document printing technology, and PowerPoint technology—to making plots and images that are easily read and absorbed into the human psyche. To this end, *fonts, characcter size, symbol size,* and *line thickness* are **very important!** IDL's default font is meant for computer screens: it's fast and legible when you're up close. Ditto for it's default line thickness and, usually, character sizes. But they're not so great for the finished product.

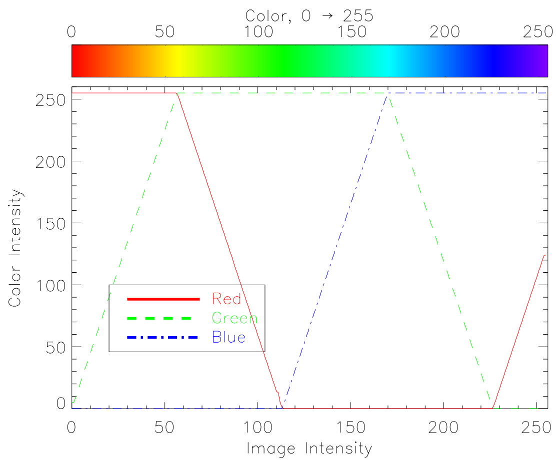
For example, compare the two plots below. Which is more legible—especially when projected on a screen during a talk? It's easy to do this right. We've written a crude wrapper called `ps_ch.pro` to set quantities to values that are suitable for most purposes; it replaaces `psopen` and `psclose`. Here's how it's used:

```
ps_ch, 'psfilename.ps', /defaults, /color, xsize=8, ysize=8, /inch

[put your plot and imaging commmands
  here]

ps_ch, /close
```

You might not like it's defaults; you can change them, or write your own following the style in this procedure.



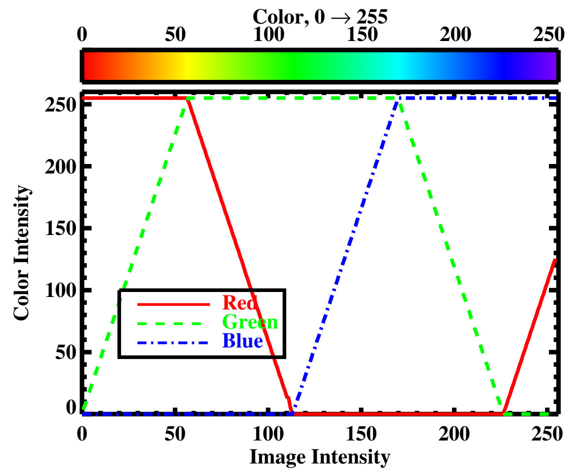


Fig. 4.— Plots from PostScript files. The left-hand one uses default fonts and thicknesses; the right-hand one uses non-default ones.

5.2. Some cautionary words about color.

Unnecessary use of color is a no-no because lots of people are colorblind—about 15% of males. The most common form of colorblindness is the inability to distinguish red from green. Physiologically, a non-colorblind eye has three types of receptors—red, green, and blue—and these seem like the natural colors to use. However, instead of red and green, use magenta (red + blue) and cyan (blue + green); red/green colorblind people find these easier to distinguish. Even better: don't use color at all! Instead, distinguish different types of points and lines using `psym` and `linestyle`. Or, if you must use color, *also* use `psym` and `linestyle`!

I recommend the following websites:

1. `http://www.nature.com/nature/journal/v445/n7128/full/445593c.html` (Comments by an annoyed colorblind proposal reviewer)

2. `http://colororacle.cartography.ch/` (Download software to see how a colorblind person sees your stuff)

3. `http://colorfilter.wickline.org/` (Measure the readability of your stuff)

Generally, you need to use contrasting colors that are easily distinguishable. The highest contrast comes with a primary color and its complement—e.g., [white (red+green+blue) *vs.* black (white–(red+green+blue))]; [magenta (red+blue) *vs.* green (white–(red+blue)); [cyan (green+blue) *vs.* red (white–(green+blue))]; [yellow (red+green) *vs.* blue (white–(red+green))]. You can get away with somewhat less contrasty combinations.

But *stay away* from the *least* contrasting color combinations. Remember that the eye is not very sensitive to blue light. So blue on black is almost unreadable. Ditto for the complementary pair, yellow on white. Too many PowerPoint slides show a bunch of curves in different colors and the most important is yellow. Plotted on a white background, it is almost invisible. How many speakers have said "Sorry that the most important curve is so hard to see on this slide…"—as if they couldn't do anything about it! When the speaker made the original plot, it was probably on the black background of the computer screen, where yellow looks terrific!

6. TWO EASY WAYS TO MAKE PostScript

IDL has native routines, but we recommend our wrappers[4]. Here's what you do:

6.0.1. The easier way

If you're not that much of a perfectionist and want something adequate, easy, and quick (that's me!), then…

1. Open the PostScript device, making sure to specify the x- and y-sizes; this determines the aspect ratio of your PostScript window.

   ```
   ps_ch, 'xray.ps', /defaults, /color, xsize=8, ysize=8, /inch
   ```

2. At this point, redefine the defaults set by `ps_ch` if you so desire.
3. Display the image, using the same commands you used for your X window (your computer screen).
4. Now close the PostScript device with `ps_ch, /close` . This also resets all of the defaults.

6.0.2. The slightly less easy way

1. Open the PostScript device, making sure to specify the x- and y-sizes; this determines the aspect ratio of your PostScript window.

   ```
   psopen, 'xray.ps', /times, /bold, /isolatin1, /color, xsize=8, ysize=8, /inch
   setcolors, /sys
   ```

   This defines the output for your plot to be the PS file `xray.ps`, uses the Times/Bold font, allows color in the image (you don't need `/color` or the `setcolors` command for a black-and-white plot), and sets the x and y sizes to 8 and 8 inches.

[4]For more information about PostScript, see our tutorial "PSIDL—Postscript Files in IDL…".

2. Set character sizes, line thicknesses, and font appropriately. You can do this by specifying them within the plot and other commands; alternatively, you use our preferred method, which is to set system variables before plotting and then reset them afterwards.

   If you're a perfectionist, you'll use larger sizes and thicker lines for PowerPoint than you will for a paper document. If you're lazy, you can use our wrapper for `psopen`, called `ps_ch` (see below); if you're not lazy, you can use `ps_ch` as a model for how you set the system variables.

3. Display the image, using the same commands you used for your X window (your computer screen).

4. Now close the PostScript device and return to X windows and its colortable:

```
psclose
setcolors, /sys
```

7. QUICK AND DIRTY: WRITING SCREEN PIXELS TO POSTSCRIPT

Above we described how to make elegant, beautiful PostScript images. It requires rerunning the plot/imaging commands. Here we describe the quick and dirty way, which does *not* require rerunning: you first generate the X window version; then you read the image pixels directly from the screen and turn them into a PostScript file. Using our procedures, this is quick and totally painless. However, the output looks ratty for text and graphs, which consist of lines; pixelized lines don't look very good. But you may be willing to put up with this sometimes—if you're in a hurry, or making a hardcopy for your lab notebook, for example. If you want to use this quick and dirty technique but want better-looking results, use a larger window; the pixelization on the hardcopy will be less noticeable.

This consists of two subsections, one for plots and one for images. For plots, we assume grayscale with either two levels (1 bit—black and white) or 256 levels (8 bits—grayscale; some plots have shading). If your color table has fewer than 256 levels, we interpolate it to 256; this is great for grayscale, but if you are using a non-gray color table it will probably give you weird results.

Both procedures retain the aspect ratio on the window, even if you try to change it with the keywords. If you want a different aspect ratio, then generate a new window with the desired aspect ratio (using IDL's `window, xsize=256, ysize=512`, for example) or rewrite the procedure for yourself.

7.1. Copying plots with `hardplot`

We assume you've already generated your plot, which is displayed in an IDL window. If necessary, select this window using IDL's `wset` command. Then type

```
hardplot
```

It will ask for the name of the output filename. `hardplot` is a home-grown procedure that has keywords that allow you to do various things. The default values are set for reproducing ordinary black/white plots, *inverting the white-on-black that you see on your screen to the black-on-white that you should use for a printed output.*

7.2. Copying images with `hardimage`

`hardimage` reproduces the X window display faithfully to the PostScript file. It's almost identical to `hardplot` running with `nbits=8` and the `noreverse` option, but it also copies the colors if the image is not grayscale.