gnuplot

or, How To Make Your Data Look Neat and Shiny

Ron Ho
3/14/01
ronho@vlsi.stanford.edu

Introduction

- Plotting data into pretty charts is pretty standard fare
  - Ultimate consumer: journals, conference papers, thesis
  - Immediate consumers: Framemaker, Latex, (troff!?)
- Sources of data often can produce pretty plots themselves
  - Matlab, Mathematica, Mathcad
- But more often, we get raw data outside of nifty software
  - Lab measurements, simulations, C/Perl code
  - … or we're dissatisfied with other tool graphing capabilities
- How does one make data pretty and consumable?

gnuplot

- Tools have come a long way
  - magicplot.pl when I took ee371 and ee315 (a *long* time ago)
    - Took a text file and drew bar graphs in m1/m2/m3
    - Axes in poly, labels using wire lab on bits of diff
- I think the best plotting tool today is gnuplot
  - Very feature-rich
  - I am not an expert it, but I have learned a few tricks
  - I was going to cover matlab, too…
    - But decided I really didn't know matlab very well
    - Besides, this is a long talk already…
- Lots of demonstrations today
  - Which wreak havoc on creating useful slides, but we'll see

Introduction

- UNIX gnuplot 3.7.1 sits in /usr/pubsw/bin (AFS-land)
  - If you don't mount AFS (why not?), you can compile it from
    - ftp://ftp.gnuplot.org/pub/gnuplot
  - Also available for win32 machines in precompiled format

- Offers 2D and 3D plotting with a wide variety of options
  - It has a pretty good online "help" feature: RTFM!

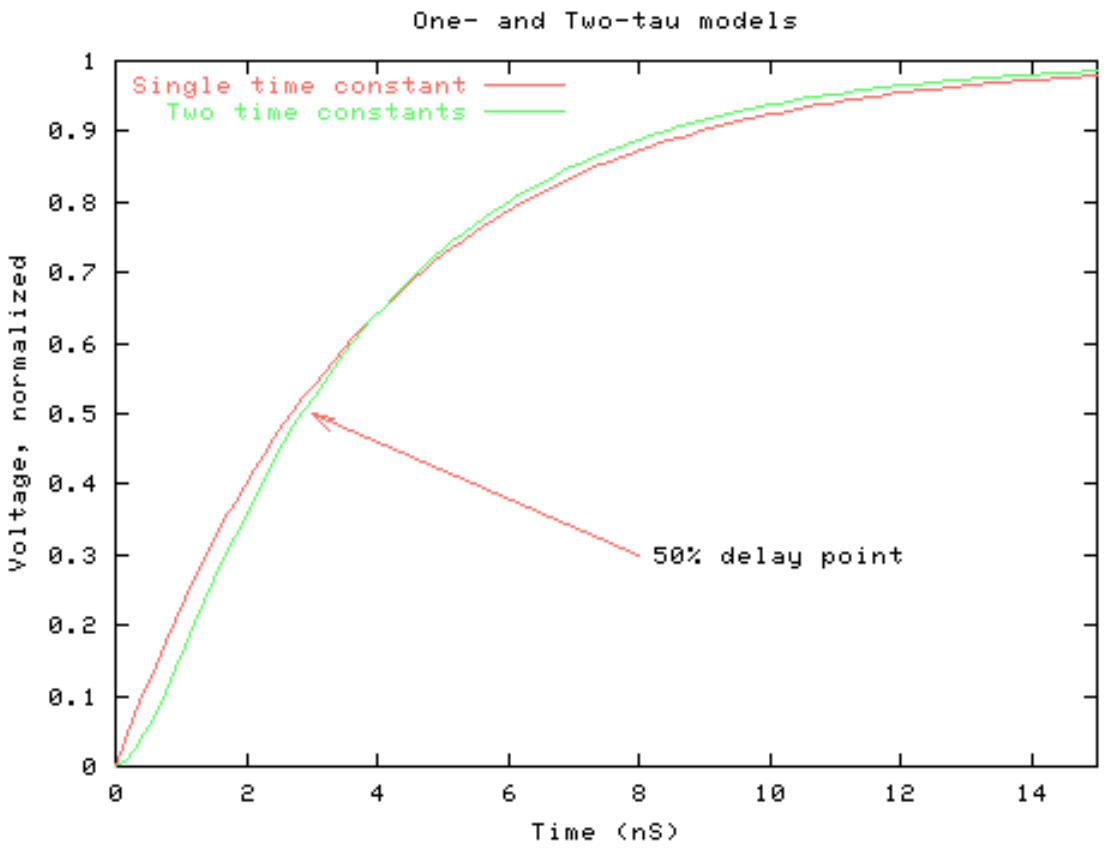
- gnuplot is, interestingly enough, not affiliated with FSF or GNU
  - Hence it's called "gnuplot," not "GNUplot"
    - Historical reason: authors wanted "newplot" but it was taken
  - Not GPL'ed, but plain old copyrighted freeware

1-My First Graph: basics

Script:

- `plot 1-exp(-x/3.8825)`
- `pause –1`
- `set xrange [0:15]; replot`
- `plot 1-exp(-x/3.8825) title "Single time constant"`
- `set xlabel "Time (nS)";` **`replot`**
- `set ylabel "Voltage, normalized"`
- `set key top left`
- `replot 1-(3.44*exp(-x/3.44)-0.44*exp(-x/0.44))/3.0 title "Two time constants"`
- `set title "One- and Two-tau models"`
- `set arrow 1 from 8,0.3 to 3.0,0.5 head`
- `set label 1 "50% delay point" at 8.2,0.3 left`

Each step is followed by a "replot"



Related commands:

- `set key` *x,y*
- `set [no]log (x|y)`
- `set autoscale (x|y)`
- *Note: Screen shots are low-quality to keep the file size down. High-quality .eps plots discussed later.*

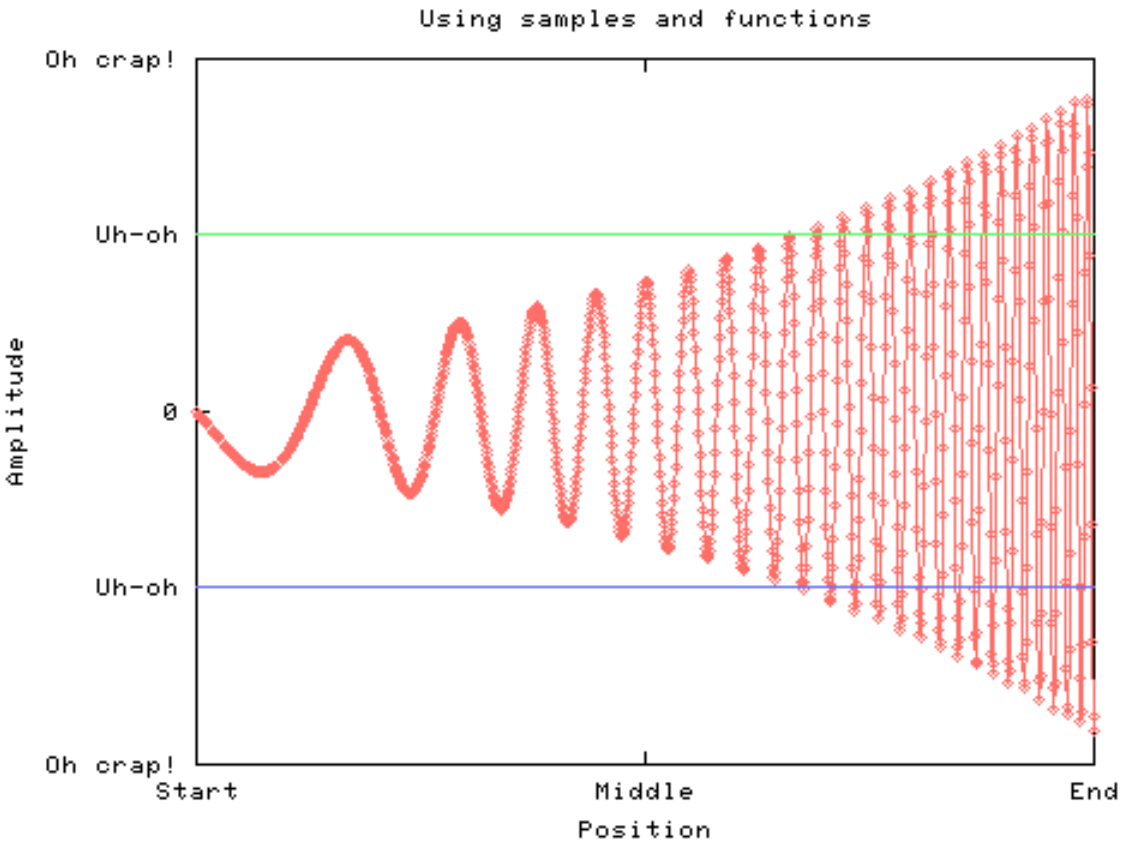
2-Plotting functions and sampling

Script:

- `clear; reset`
- `set xrange [x1:x2]; set yrange [y1:y2]`
- `set xlabel "…"; set ylabel "…"`
- `set title "Using samples and functions"`
- `f(x) = x**5`
- `pi = 3.14159; sf = 4.5`
- `plot (sf**x)*sin(f(x)*pi) notitle with linespoints`
- `set samples 1000` ← *normally, get 100 points*
- `set xtics ("Start" 1, "Middle" 1.6, "End" 2.2)`
- `set ytics ("Oh crap!" -30, "Uh-oh" -15, "0" 0, "Uh-oh" 15, "Oh crap!" 30)`
- `replot 15 notitle; replot -15 notitle`

Related commands:

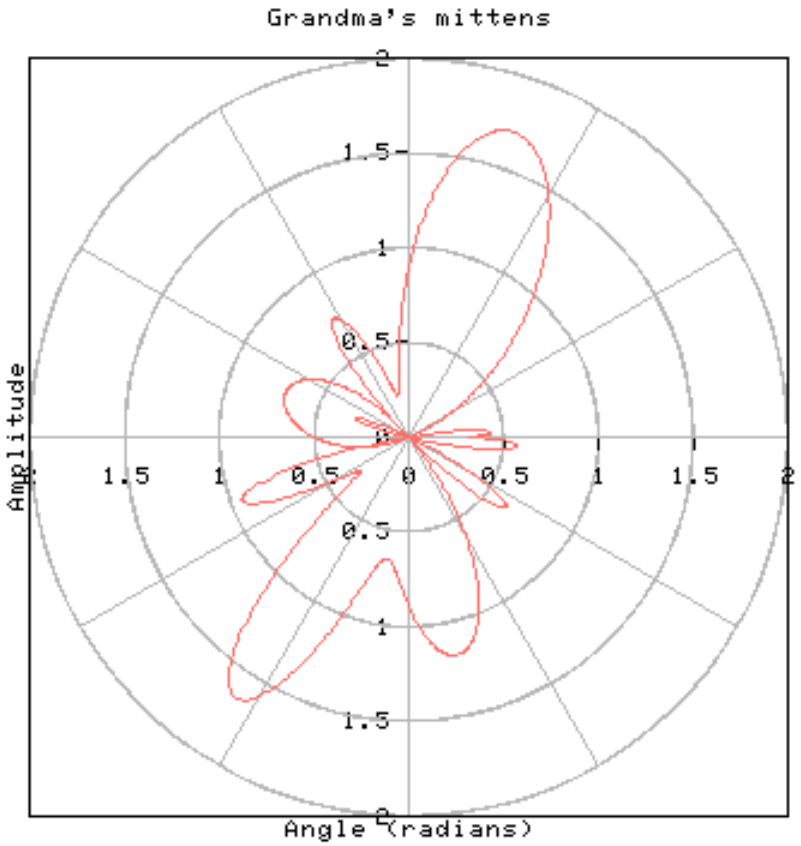
- `show variables`
- `show functions`
- `high=110; f2c(t)=(x-32)*5.0/9.0`
- `set yrange [f2c(20):f2c(high)]`



3-More 2D plots

Script:

- `set samples 1000`
- `set xlabel; set ylabel; set title`
- `set xrange [-pi:pi]` ← *pi predefined!*
- `plot sin(x)*cos(x) + sin(x)*sin(x) - 0.5*cos(2*x*x) notitle`
- `set grid`
- `set polar`
- `set trange[-pi:pi]`
- `plot sin(t)*cos(t) + sin(t)*sin(t) - 0.5*cos(2*t*t) notitle`
- `set grid polar`
- `set xtics axis; set ytics axis`
- `set xrange [-2:2]; set yrange [-2:2]`
- `set size square`
- `set title "Grandma's mittens"`



Related commands:

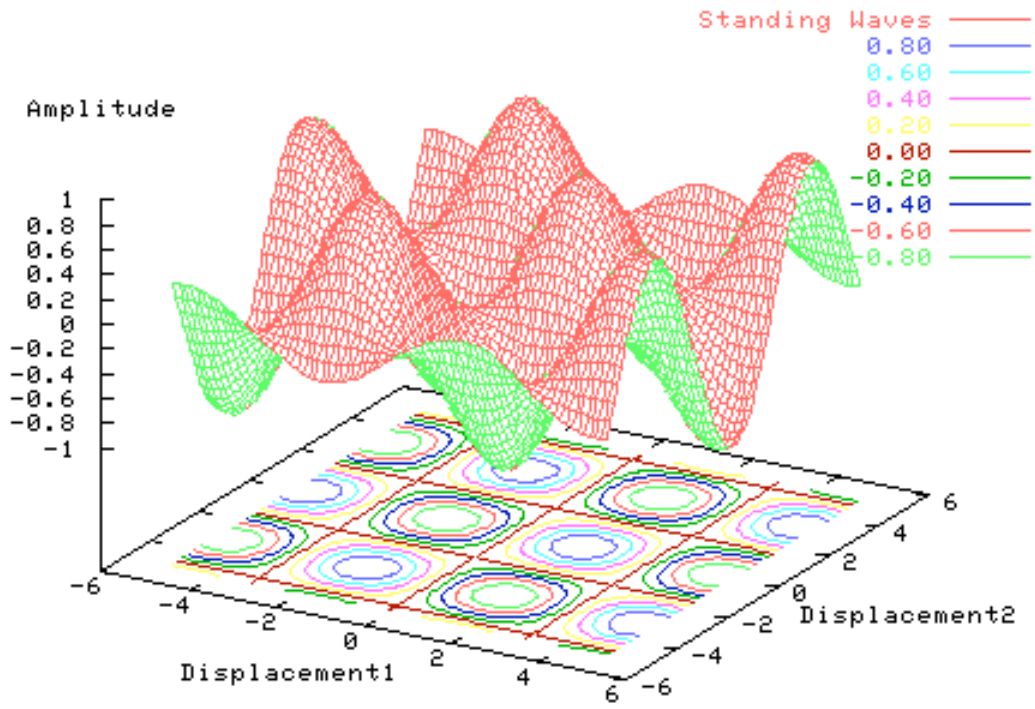
- `set size ratio` *aspectratio*
- `set size` *xscale,yscale*
- `set parametric` <- *polar is a special case*

4-Basic 3D plots

Script:

Just to illustrate "set parametric"; could also use `splot sin(x)*cos(y)` *w/o parametric*

- `set xlabel; set ylabel`
- `set zlabel "Amplitude"`
- `set parametric`
- `splot u,v,sin(u)*cos(v) title "Standing Waves"`
- `set isosamples 75,75` ← *10 is normal*
- `set contour base`
- `set cntrparam level incremental -1, 0.2, 10` ← *start,incr,num*
- `set clabel '%4.2f'` ← *C's scanf*
- `set contour surface`
- `set contour base; set nosurface`
- `set surface;`
- `set view 20,60`
- `set view 60,30` ← *xrot, zrot*
- `set hidden3d`



Related commands:

- `set contour [base|surface|both]`
- `set [no]surface`

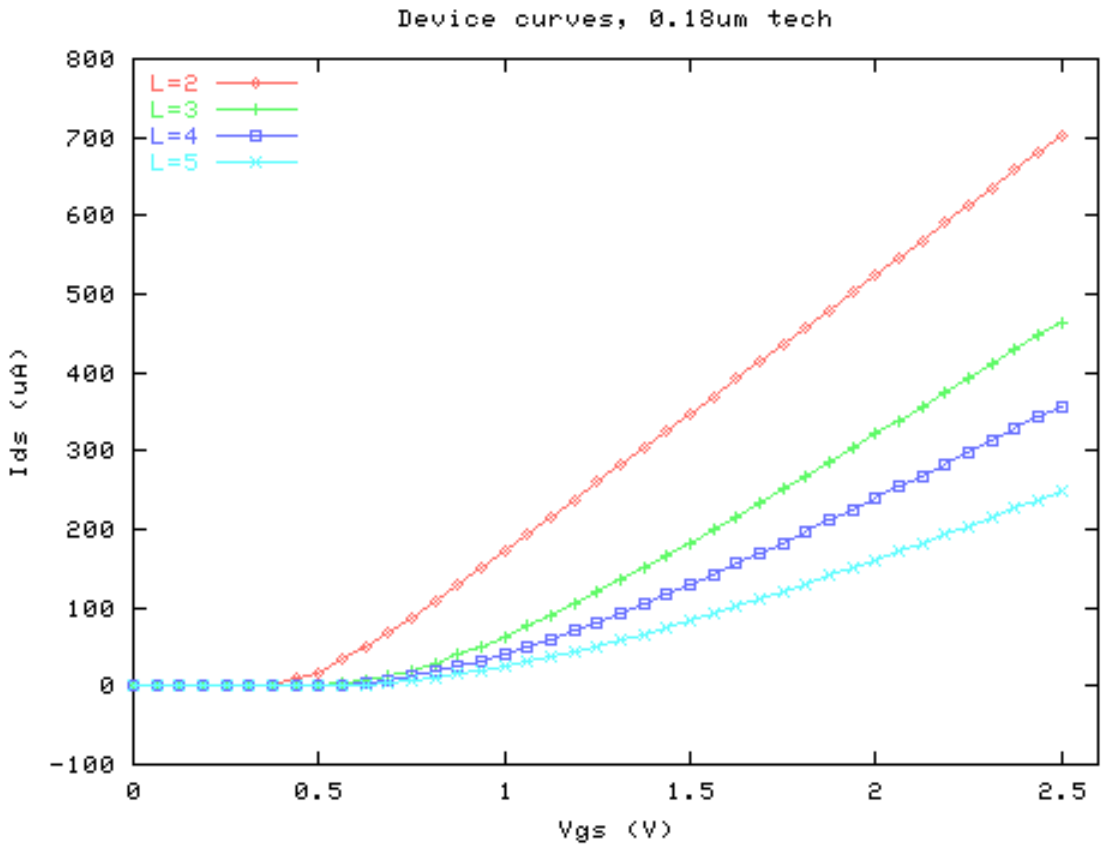
5-Plotting from data files

Script:

- `set xlabel; set ylabel; set title`
- `set key top left`
- `plot "plot5.dat" title "IV curves"`
- `plot "plot5.dat" using ($1*2.5/2e-9):($2*-1e6) title "IV curves"`
- `set xlabel "Vgs (V)"; set ylabel "…"`
- `set xrange [0:2.6]`
- `plot "plot5.dat" index 2 using ($1*2.5/2e-9):($2*-1e6) title "L=4"`
- `replot "plot5.dat" index 3 using ($1*2.5/2e-9):($2*-1e6) title "L=5" with lines`
- `set data style linespoints`
- `plot "plot5.dat2" u ($1*2.5/2e9):($3*-1e6) title "L=3"`
- `plot "plot5.dat3" u ($1*2.5/2e9):($2*-1e6) '%lf,%lf,%lf,%lf,%lf' title "L=2"`

Notes:

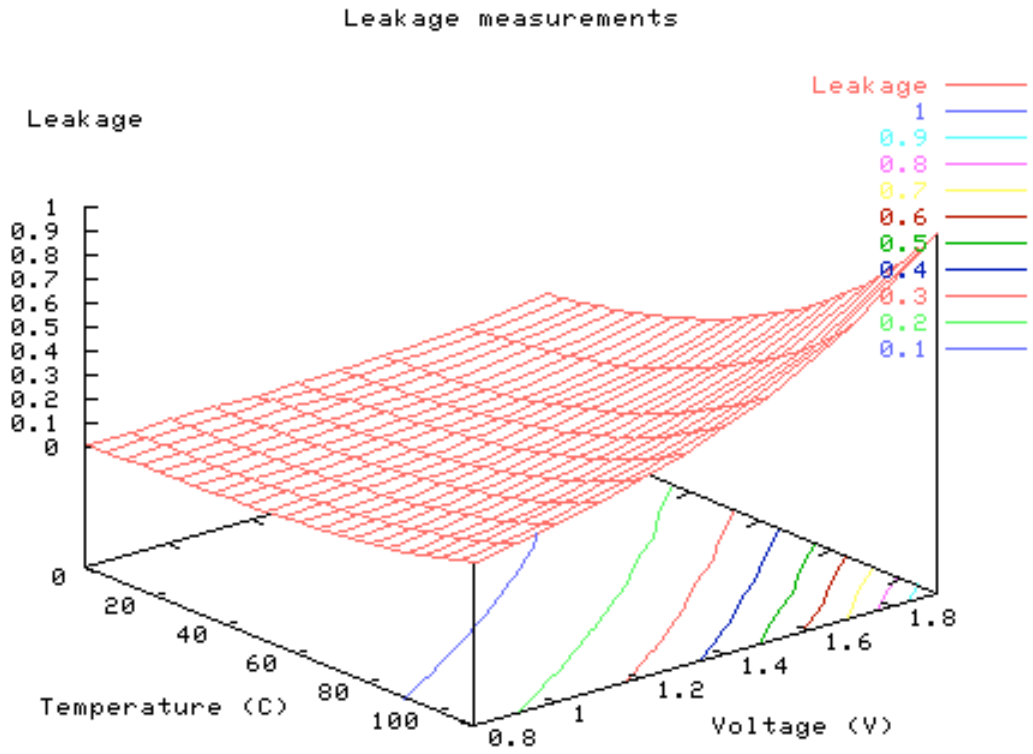
- `plot <FILE> index n …`
  requires \n\n between datasets



6-Plotting from data files

Script:

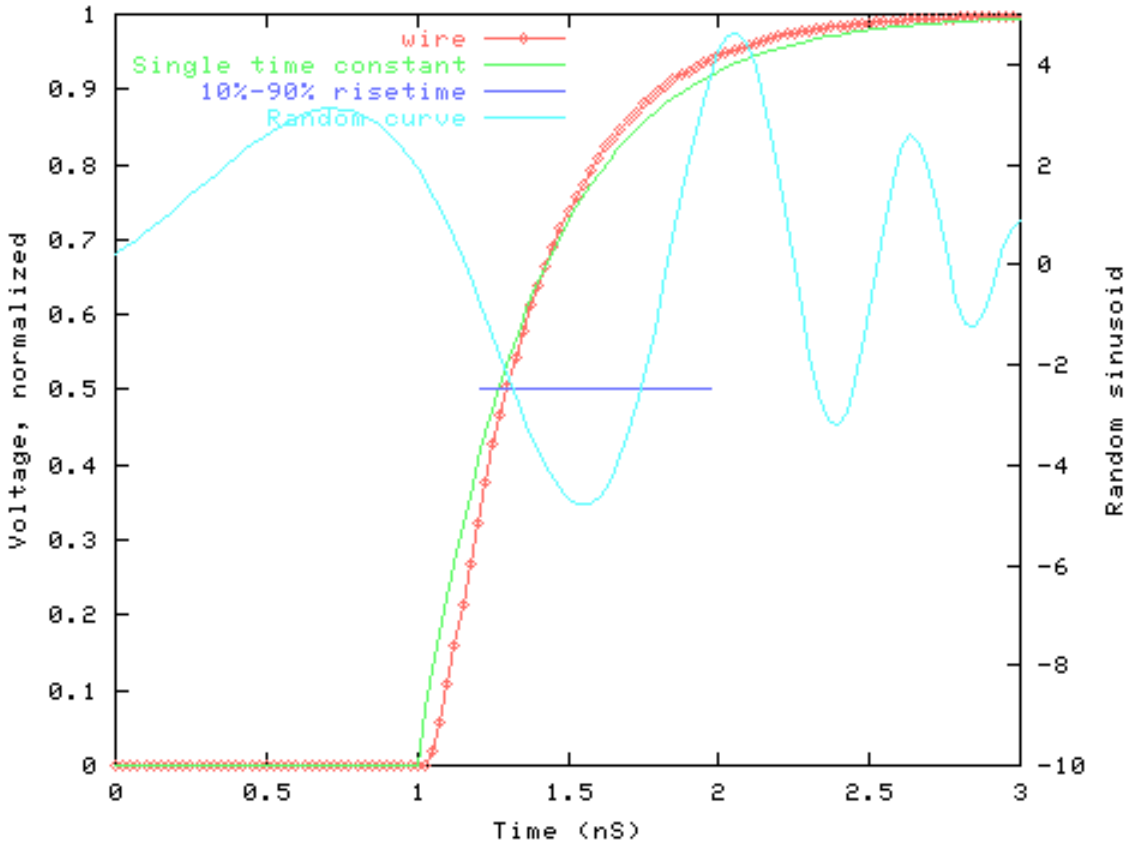
- `set xlabel; set ylabel; set title`
- `set xrange [0:110]`
- `plot "plot6.dat" u 1:3 t "Leakage" w p`
  only need "$" for expressions
- `plot "plot6.dat" u 1:3 t "Leakage" w l`
- `plot "plot6.dat2" u 1:3 t "Leakage" w l`
  \n in data prevents line-connecting
- `set xrange [0.8:1.9]`
- `set xlabel "Voltage (V)"`
- `plot "plot6.dat2" u 2:3 t "Leakage" w l`
- `set xrange [0:110]; set yrange [0.8:1.9`
- `set xlabel "Temperature (C)" ,-1`
- `set ylabel "Voltage (V)" ,-1`
  xoff=0,yoff=-1 in x's
- `set zlabel "Leakage"`
- `splot "plot6.dat2" u 1:2:3 t "Leak" w l`
  splot using x:y:z
- `set view ,50`
- `set contour base`
- `set hidden3d`
  only works for lines or linespoints



7-Axes. Ternary operations.

Script:

- `set xrange; set xlabel; set ylabel`
- `set key top left`
- `plot "plot7.dat" u ($1*1e9):($2/1.8) t "wire" w lp`
- `replot 1-exp(-(x-1)/.38825) t "Single time constant"`
- `plot "plot7.dat" u ($1*1e9):($2/1.8) t "wire" w lp`
- `replot (x<1) ? 0 : 1-exp(-(x-1)/.38825) t "Single time constant"`
- `replot x>1.2 && x<2 ? 0.5:1/0 t "10%-90% risetime"`
- `replot 5*sin(exp(x))*sin(x)+0.2 axes x1y2 t "Random curve"`
- `set y2tics`
- `set ytics nomirror`
- `set y2label "Random sinusoid"`
- `set y2range [-10:5]`



Related commands:

- `plot 'file' u 1:($4<0?1/0:($2+$3)/2)`
  plots average of $2,$3 only if $4>=0

8-Nifty side-note

Ternary operator surprisingly powerful!

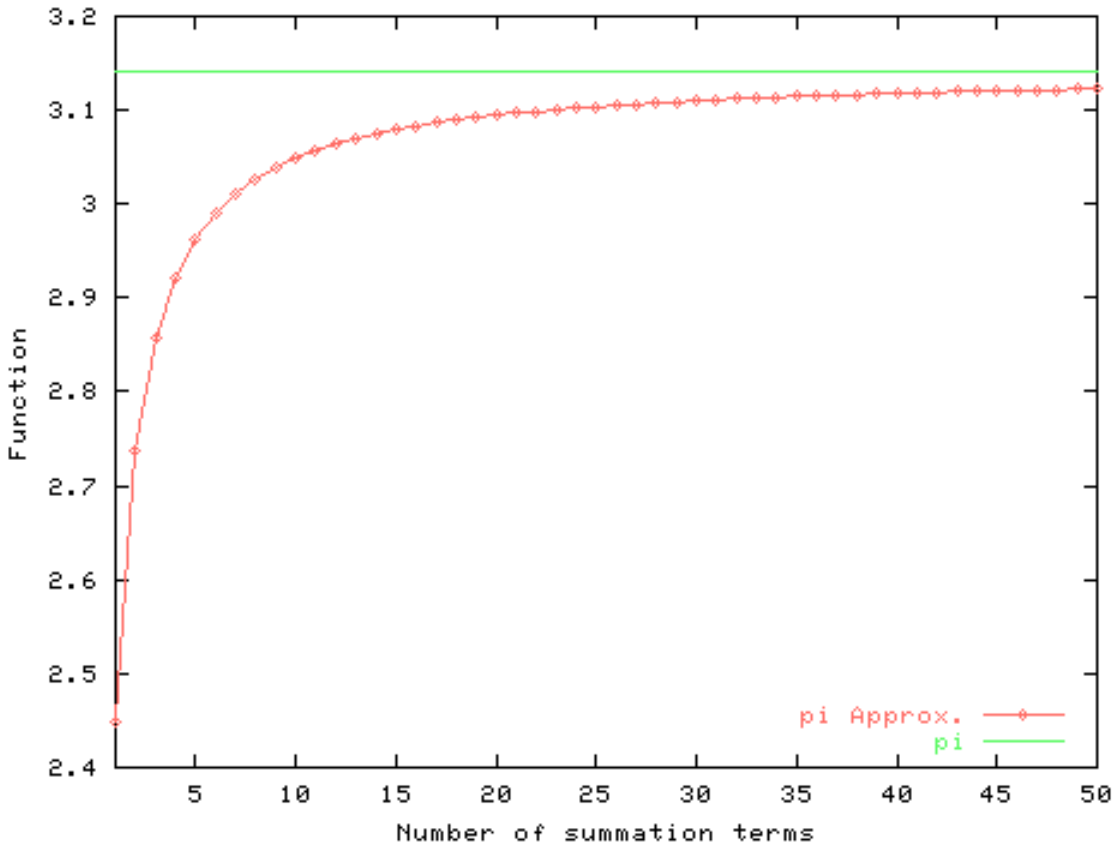
How quickly does $\sqrt{6\sum_{i=1}^{\infty}\frac{1}{i^2}}$ **converge to pi?**

Script:

- `set xlabel "Number of summation terms"`
- `set ylabel "Function"`
- `set xrange [1:50]`
- `set samples 50` ← *critical: integers only!*
- `set key bottom right`
- `f_part(x) = 1/(x*x)`
- `f_sum(x) = f_part(x) + ((x>1) ? f_sum(x-1) : 0)`
- `f(x) = sqrt(6*f_sum(x))`
- `plot f(x) title "pi Approx." w lp`
- `replot pi`

Answer: Not very quickly!

Note: *Stack space is limited; plotting from [0:100] runs out of stack space ☹ (do it using two functions)*



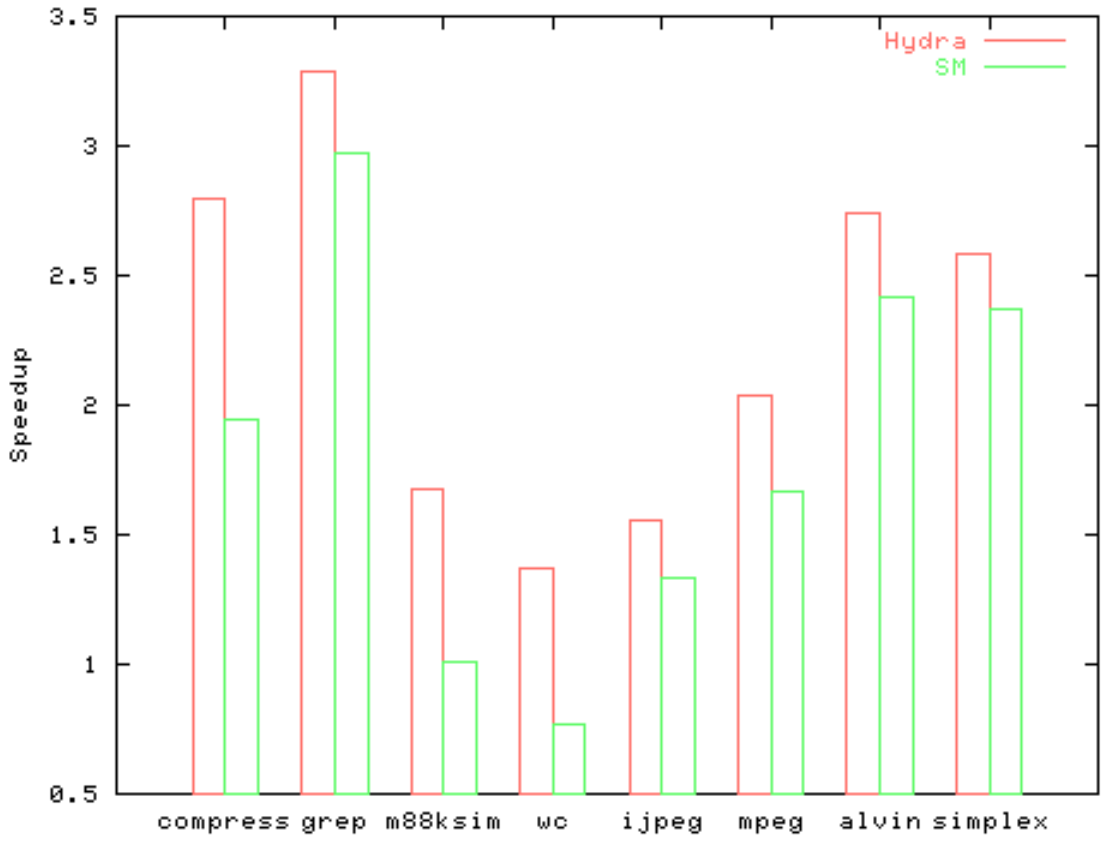
9-Bar graphs

Script:

- `set xtics ("compress" 1, "grep" 2, "m88ksim" 3, "wc" 4, "ijpeg" 5, "mpeg" 6, "alvin" 7, "simplex" 8)`
- `set ylabel "Speedup"`
- `set xrange [0:9]`
- `plot "plot8.dat" u 1:2 t "Hydra" w lp`
- `replot "plot8.dat" u 1:3 t "SM" w lp`
- `plot "plot8.dat" u 1:2 t "Hydra" w boxes`
- `replot "plot8.dat" u 1:3 t "SM" w boxes`
- `set boxwidth 0.3`
- `plot "plot8.dat" u ($1-0.15):2 t "Hydra" w boxes`
- `replot "plot8.dat" u ($1+0.15):3 t "SM" w boxes`

Notes:

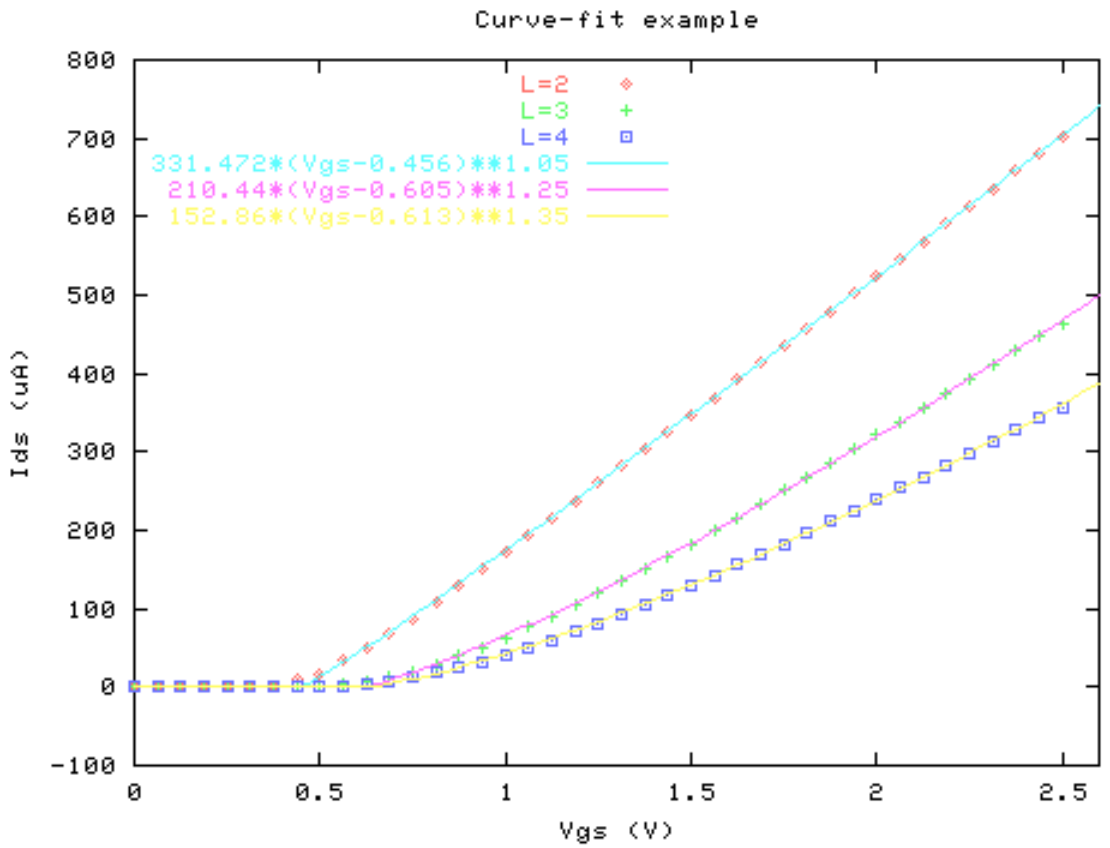
No way to fill in the boxes using stock gnuplot (although some post-processing hacks exist, including simply using Frame)



10-Curve-fitting

Script:

- `set xlabel; set ylabel; set title`
- `set xrange [0:2.6]; set key`
- `plot "plot5.dat2" u ($1*2.5/2e-9):($2*-1e6) t "L=2" w p`
- `replot "plot5.dat2" u ($1*2.5/2e-9):($3*-1e6) t "L=3" w p`
- `f1(x) = x>b1 ? a1*((x-b1)**c1) : 0`
- `fit f1(x) "plot5.dat2" u ($1*2.5/2e-9):($2*-1e6) via a1,b1,c1`
- `replot f1(x) title "331.472*(Vgs-0.456)**1.05" w l`
- `f2(x) = x>b2 ? a2*((x-b2)**c2) : 0`
- `fit f2(x) "plot5.dat2" u ($1*2.5/2e-9):($3*-1e6) via a2,b2,c2`
- `replot f2(x) title "210.44*(Vgs-0.605)**1.25" w l`



Notes:

Max 3000 data points for curvefitting

fit.log holds the iterative information

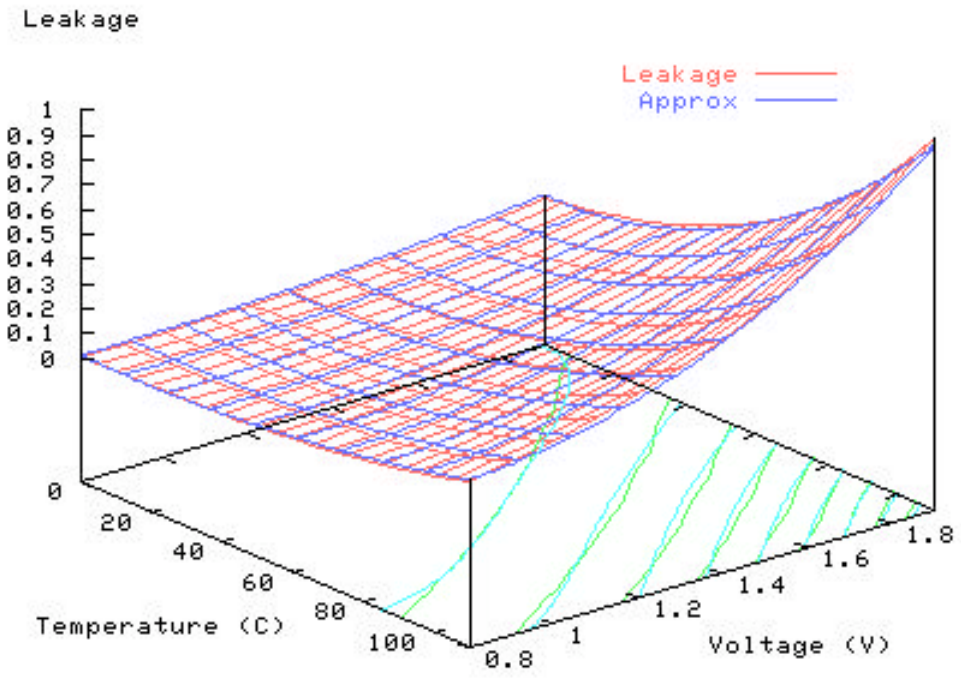
Must manually type in the fitted values for titles/labels. Most often requested feature for v3.8!

11-Curve-fitting, another example

Script:

```
➢(x|y}range; (x|y|z)label
➢set data style lines
➢set view ,50; set key 60,1.9,1
➢splot "plot6.dat2" u 1:2:3 t "Leakage"
➢f(x,y) = a+b*x+c*y
➢fit f(x,y) "plot6.dat2" u 1:2:3:(1) via
a,b,c
➢replot f(x,y)
➢splot "plot6.dat2" u 1:2:($3-f($1,$2)) not
➢f(x,y) = a+b*x+c*y*y+d*y+e*x*y*y+f*x*y
➢fit f(x,y) "plot6.dat2" u 1:2:3:(1) via
a,b,c,d,e,f; replot f(x,y)
➢splot "plot6.dat2" u 1:2:($3-f($1,$2)) not
➢f(x,y) = a + b*x*x + c*x + d*y*y + e*y +
f*x*x*y*y + g*x*x*y + h*x*y*y + i*x*y
➢fit f(x,y) "plot6.dat2" u 1:2:3:(1) via
a,b,c,d,e,f,g,h,i; replot f(x,y)
➢splot "plot6.dat2" u 1:2:($3-f($1,$2)) not
➢set contour base; set noclabel
➢splot "plot6.dat2" u 1:2:3 t "Leakage"
➢replot f(x,y) t "Approx"
```

x:y:z:(1) indicates evenly-weighted data. "help fit" for more details



Output

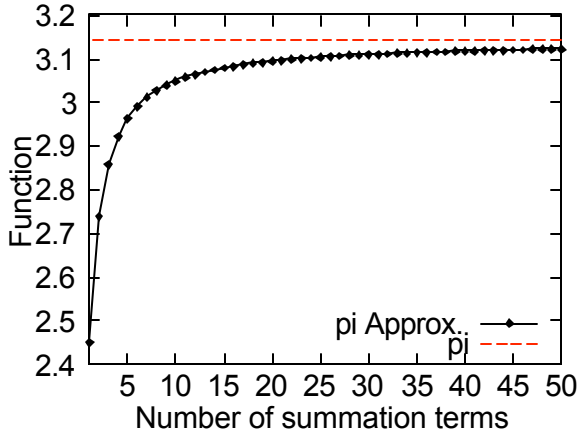
- Basic framework is

```
set terminal <TERMTYPE> <OPTIONS>     ← see "help set term"
set out "<FILENAME>"                  ← specifies output file
replot                                ← writes it to disk
set out                               ← closes the filehandle
set terminal windows|x11              ← restores the terminal
replot                                ← redraws the plot
```

- Most plots are automatically sized to fill a sheet of paper
  - Exceptions: encapsulated ps (more on this later), multiplot
  - So generally I preface this with
    - *set size 0.75,0.75* (or so, give or take)
  - Restore with
    - *set size 1,1*

Output (for windows)

- Windows wants a file that works with *Insert→Picture→From File*
  - For this talk, I used .png, the (free) alternative to .gif
    - *set term png small color*
  - For windows files that can be modified within PPT/Frame
    - *set term cgm color*
    - Then double-clicking converts it to a windows object
    - Functionally the same as right-click-copying from the display



Output (for real computers)

- Postscript terminal takes many options

```
                    [landscape]
set term post       [portrait]   [enhanced]   [color]  [solid]              [font] [size]
                                              [mono]   [dashed]
                    [eps]
```

- *set term post eps enhanced color* is pretty standard fare
  - eps generates plots that are 5"x3.5"
    - set size 0.65,0.65 creates 1-LaTeX-column-sized plots
  - "Helvetica" 14 set by default; "Times-Roman" 14 decent, too
  - enhanced allows fancy texting in LaTeX-jargon (more later)

- Other possibilities include ("help set term latex")
  - fig: munging in xfig, then using transfig→ps or mifXfig→mif
  - latex, pslatex, pstex: direct incorporation into .tex files

From ps_guide.ps (comes with the gnuplot distro)

The handouts have the real pages

Syntax for **postscript enhanced** option

enhpost is the product of David Denholm and Matt Heffron.

This guide is the product of Dick Crawford.

	text	result
Superscripts are denoted by ^:	'10^{-2}'	10^{-2}
Subscripts are denoted by _:	'A_{j,k}'	$A_{j,k}$
Braces are not needed for single characters:	'e^x'	e^{x}
Use @ to align sub- and superscripts:	'x@^2_k'	x_k^2
Put the shorter of the two first:	'x@_0^{-3/2}y'	$x_0^{-3/2}y$
...rather than:	'x@^{-3/2}_0y'	$x_0^{-3/2}y$
Font changes are enclosed in braces:	'{/Helvetica m}'	m
...size, too:	'{/=8 m}'	m
...or both:	'{/Helvetica=18 m}'	m
Characters can be specified by code:	'{\120}'	P
...which is how to get nonkeyboard characters:	'{\267}'	•
Use keyboard characters or codes for other fonts:	'{/Symbol p\271 22/7}'	π≠ 22/7
Everything outside braces is in the default font:	'P = {/Symbol r}kT'	P = ρkT
Space of a given size can be inserted with &:	'<junk>'	<junk>
	'<&{junk}>'	< >
Special characters (^,_,{,},@,&,\) can be escaped by \:	'f\{x,y\}'	f{x,y}
...or \\ if within a double-quoted string:	"f\\{x,y\\}"	f{x,y}

Everything can be done recursively:

the text '{/Symbol=18 \362@_{/=9.6 0}^{/=12 \245}}
{/Helvetica e^{-{/Symbol m}^2/2} d}{/Symbol m = (p/2)^{1/2}}'

produces the result: $\int_0^{\infty} e^{-\mu^2/2}\, d\mu = (\pi/2)^{1/2}$

Note how font sizes and definitions are preserved across pairs of braces.

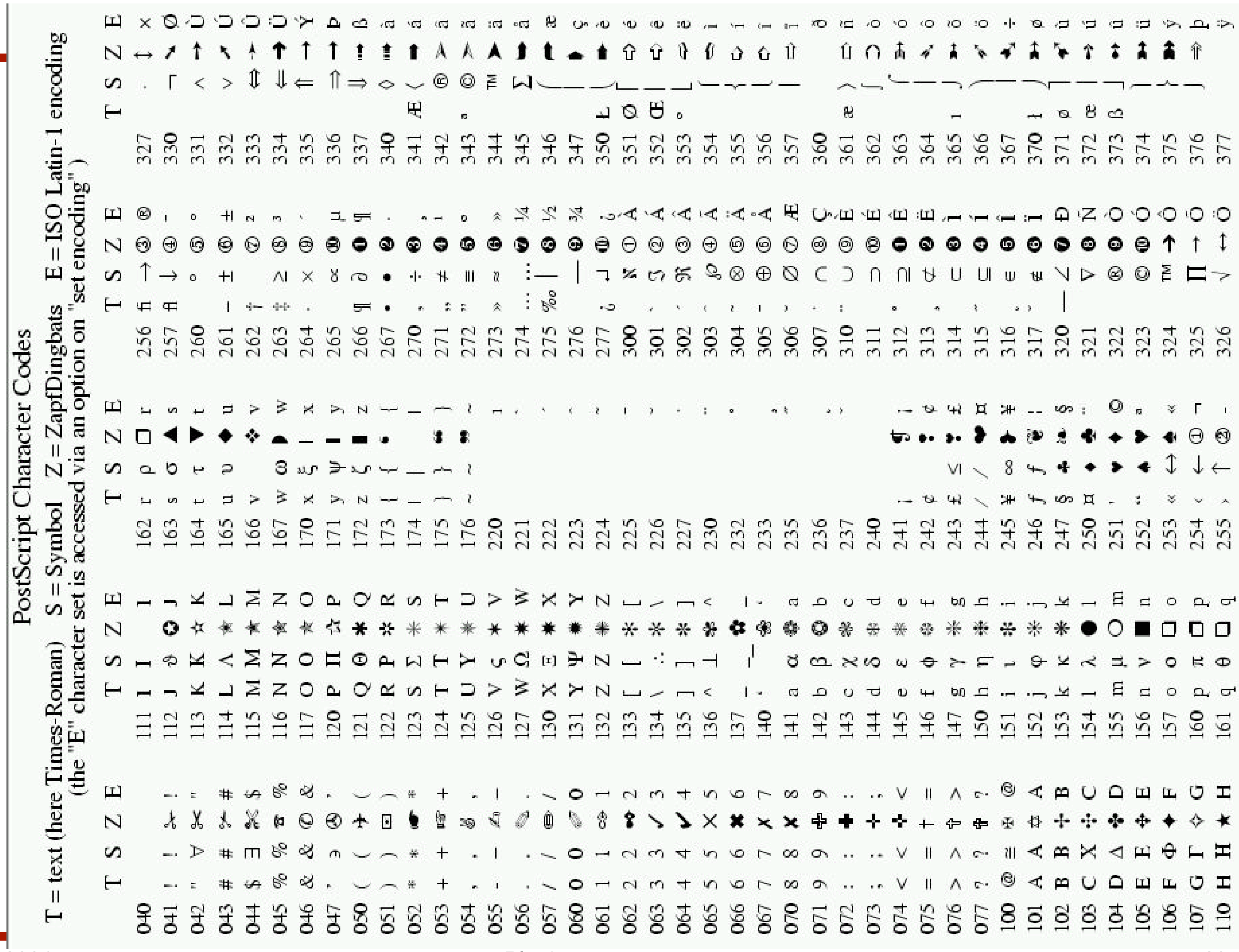
The default font for this page is /Times-Roman=12. These and other options may be changed on the command **set terminal postscript**. See the manual or **help postscript** for details.

Output with enhanced ps

Output with enhanced ps (con't)

From ps_guide.ps (comes with the gnuplot distro)

The handouts have the real pages

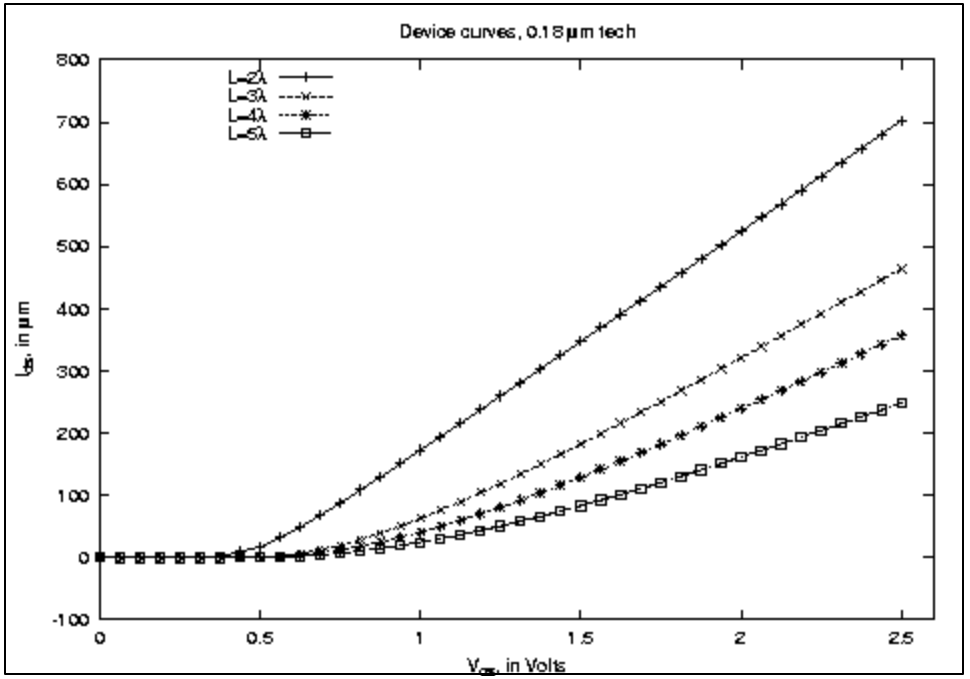


Output with enhanced ps (con't)

- Example of a plot, with labels redone to utilize symbols
  - .eps with windows preview is large (50KB)

Changes:

```
➢set xlabel "V_{gs}, in Volts"
➢set ylabel "I_{ds}, in {/Symbol m}m"
➢set title "Device curves, 0.18 {/Symbol m}m
tech"
➢plot "plot5.dat3" u ($1*2.5/2e-9):($2*-1e6)
'%lf,%lf,%lf,%lf,%lf' t "L=2{/Symbol l}"
➢replot "plot5.dat3" u ($1*2.5/2e-9):($3*-
1e6) '%lf,%lf,%lf,%lf,%lf' t "L=3{/Symbol l}"
➢replot "plot5.dat3" u ($1*2.5/2e-9):($4*-
1e6) '%lf,%lf,%lf,%lf,%lf' t "L=4{/Symbol l}"
➢replot "plot5.dat3" u ($1*2.5/2e-9):($5*-
1e6) '%lf,%lf,%lf,%lf,%lf' t "L=5{/Symbol l}"
➢set term post eps enhan color
➢set out "plot5.eps"; replot
➢set out; set term windows; replot
```



This is a crappy windows preview of an EPS; the printout looks much better

Interfacing with files

- Creating and loading command files
  - They are plain-text, so can create/edit with vi[m]/[x]emacs
  - Within gnuplot, create/use them with *save "file"*/*load "file"*
  - From shell, can call gnuplot with *gnuplot file*

- So far we've only plotted datafiles, but can also plot raw output
  - Within gnuplot, use, e.g.,
    - *plot "< simulator.pl" u 1:($2*1e9) t "ExecTime" w lp*
    - Although this usually optimizes the wrong resources…
  - This also allows constructs like
    - *plot "< awk '{print $1,sqrt($2*$3)}' foo.dat" u 1:2 t "Data" w lp*
    - Although *using $1:sqrt($2*$3)* does the same thing…
      - Plus, calling awk requires *popen()* support, which is missing under W2K…

Other odds and ends

- Using time on the xaxis (or yaxis, or zaxis):
  - *set xdata time; set timefmt "%Y/%m/%d.%H:%M:%S"*
    - … tells gnuplot what format your data x-col is in (*man date*)
- Too much data in your files to plot?
  - *plot "datafile" every 2*
    - … plots every other point. See "help every" for more details
- Want to plot a vertical line? (which isn't a function…)
  - *set arrow n from x1,y1 to x2,y2 nohead*
- gnuplot assumes integers unless you say so
  - 1/3 evaluates to 0; 1. /3. or 1.0/3.0 evaluates to 0.33…
    - … this burns me every other week

Conclusion

- I hope you learned something new about gnuplot
- Lots of sources for help
  - Introduction and FAQs on the web (do a search)
  - comp.graphics.apps.gnuplot and deja/google archives
  - Ask me (but if it's not covered here, I probably don't know…)
- By the way, www.cygwin.com has the tcsh environment for w32
  - It starts to make w32 a usable working environment