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The Python Graphics Interface, Part IV

Python Gist Graphics Manual

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CHAPTER 1: The Python Graphics Interface

1.1 Overview of the Python Graphics Interface

The Python Graphics Interface (abbreviated PyGraph) provides Python users with capabilities for plotting curves, meshes, surfaces, cell arrays, vector fields, and isosurface and plane cross sections of three dimensional meshes, with many options regarding line widths and styles, markings and labels, shading, contours, filled contours, coloring, etc. Animation, moving light sources, real-time rotation, etc., are also available. PyGraph is intended to supply a choice of easy-to-use interfaces to graphics which are relatively independent of the underlying graphics engine, concealing the technical details from all but the most intrepid users. Obviously different graphics engines offer different features, but the intention is that when a user requests a particular type of plot which is not available on a particular engine, the low level interface will make an intelligent guess and give some approximation of what was asked for.

There are two such graphics packages which are relatively independent of the underlying plotting library. The Object-Oriented Graphics (OOG) Package defines geometric objects (Curves, Surfaces, Meshes, etc.), Graph objects which can be given one or more geometric objects to plot, and Plotter objects, which receive geometric objects to plot from Graph objects, and which interface with the graphics engine(s) to do the actual plotting. A Graph can create its own Plotter, or the more capable user can create one or more, handy when one wishes (for instance) to plot on a remote machine, or to open graphics windows of different types at the same time. The second such package is called EZPLOT; it is built on top of OOG, and provides an interface similar to the command-line interface of the Basis EZN package. Some of our long-time users may be more comfortable with this package, until they have mastered the concepts of object-oriented design.

As mentioned above, a Graph object needs at least one Plotter object to plot itself; only the Plotter objects need know about graphics engines. At present we have two types of Plotter objects, one which knows about Gist and one which knows about Narcisse. Some power users may prefer to use the lower-level library-specific function calls, but most users will use EZPLOT or OOG.

Gist is a scientific graphics library written in C by David H. Munro of Lawrence Livermore National Laboratory. It features support for three common graphics output devices: Xwindows, (color) PostScript, and ANSI/ISO Standard Computer Graphics Metafiles (CGM). The library is small (written directly to Xlib), portable, efficient, and full-featured. It produces x-vs.-y plots with ‘‘good’’ tick marks and tick levels, 2-D quadrilateral mesh plots with contours, vector fields, or pseudocolor maps on such meshes. 3-D plot capabilities include wire mesh plots (transparent or opaque), shaded and colored surface plots, isosurface and plane cross sections of meshes containing data, and real-time anima-

tion (moving light sources and rotations). The Python Gist module `gist.py` and the associated Python extension `gistCmodule` provide a Python interface to this library (referred to as PyGist).

Narcisse is a graphics library developed at out sister laboratory at Limeil in France. It is especially strong in high-quality 3-D surface rendering. Surfaces can be colored in a variety of ways, including colored wire mesh, colored contours, filled contours, and colored surface cells. Some combinations of these are also possible. We have also added the capability of doing isosurfaces and plane sections of meshes, which is not available in the original Narcisse. The Python Narcisse module `narcissemodule` (referred to as PyNarcisse) provides a low-level Python interface to this library. Unlike Gist, Narcisse does not currently write automatically to standard files such as PostScript or CGM, although it writes profusely to its own type of files unless inhibited from doing so, as described below. However, there is a "Print" button in the Narcisse graphics window, which opens a dialog that allows you to write the current plot to a postscript file or to send it to a postscript printer.

1.2 Using the Python Graphics Interface

In order to use PyGraph, you first need to have Python installed on your system. If you do not have Python, you can obtain it free from the Python pages at `http://www.python.org`. You may need the help of your system administrator to install it on your machine. Once you have Python, you have to know at least a smattering of the language. The best way to do this is to download the excellent tutorial from the Python pages, sit down at your computer or terminal, and work your way through it.

Before using the Python Graphics Interface, you should set some environment variables as follows.

- Your `PATH` variable should contain the path to the `python` executable.
- You should set a `PYTHONPATH` variable to point to all directories that contain Python extensions or modules that you will be loading, which may include the OOG modules, `ezplot`, and `narcissemodule` or `gistCmodule`. Check with your System Manager for the exact specifications on your local systems.
- Unless you create your own plotter objects, PyGraph will create a default Gist Plotter which will plot to a Gist window only. If you want your default Plotter to be a Narcisse Plotter, then set the variable `PYGRAPH` to `Nar` or `Narcisse`.

A Gist Plotter object automatically creates its own Gist window and then plots to that window. Narcisse, however, works differently. Narcisse is established as a separately running process, to which the Plotter communicates via sockets. Thus, to run a Narcisse Plotter, you must first open a Narcisse.[1] To do so, you need to go through the following steps:

1. Set your environment variable `PORT_SERVEUR`[2] to 0.

1. I am going to assume that you already have Narcisse installed on your system, and its directory path in your `PATH` variable.
2. We did tell you that Narcisse was French, didn't we?

2. Start up Narcisse by typing in the command `Narcisse &`. It will take a few moments for the Narcisse GUI to open, then immediately afterwards it will be covered by an annoying window which you can eliminate by clicking its `OK` button.
3. You will note that there is a server port number given on the GUI. Set your `PORT_SERVEUR` variable to this value.
4. Narcisse has an annoying habit of saving everything it does to a multitude of files, and notifying you on the fly of all its computations. If you do a lot of graphics, these files can quickly fill up your quota. In addition, the running commentary on file writing and computation on the GUI is time-consuming and slows Narcisse down to a truly glacial pace. To avoid this, you need to turn off a number of options via the GUI before you begin. They are all under the `STATE` submenu of the `FILE` menu, and should be set as follows: set ‘‘`Socket compute`’’ to “`no`,’’ set ‘‘`File save`’’ to “`nothing`,’’ set ‘‘`Config save`’’ to “`no`,’’ and set “`Ihm compute`’’ to “`no`.’’ (“IHM’’ are the French initials for ‘‘GUI.’’)

1.3 About This Manual

This manual is part of a series of manuals documenting the Python Graphics Interface (PyGraph). They are:

- I. EZPLOT User Manual
- II. Object-Oriented Graphics Manual
- III. Plotter Objects Manual
- IV. Python Gist Graphics Manual
- V. Python Narcisse Graphics Manual

EZPLOT is a command-line oriented interface that is very similar to the EZN graphics package in Basis. The Object-Oriented Graphics Manual provides a higher-level interface to PyGraph. The remaining manuals give low-level plotting details that should be of interest only to computer scientists developing new user-level plot commands, or to power users desiring more precise control over their graphics or wanting to do exotic things such as opening a graphics window on a remote machine.

PyGraph is available on Sun (both SunOS and Solaris), Hewlett-Packard, DEC, SGI workstations, and some other platforms. Currently at LLNL, Narcisse is installed only on the X Division HP and Solaris boxes, however, and Narcisse is not available for distribution outside this laboratory. Our French colleagues are going through the necessary procedures for public release, but these have not yet been crowned with success. Gist, however, is publicly available as part of the Yorick release, and may be obtained by anonymous ftp from `ftp-icf.llnl.gov`; look in the subdirectory `/ftp/pub/Yorick`.

A great many people have helped create PyGraph and its documentation. These include

- Lee Busby of LLNL, who wrote `gistCmodule`, and wrought the necessary changes in the Python kernel to allow it to work correctly;

- Zane Motteler of LLNL, who wrote `narcissemodule`, `ezplot`, the OOG, and some other auxiliary routines, and who wrote much of the documentation, at least the part that was not blatantly stolen from David Munro and Steve Langer (see below);
- Paul Dubois of LLNL, who wrote the `PDB` and `Ranf` modules, and who worked with Konrad Hinsen (Laboratoire de Dynamique Moleculaire, Institut de Biologie Structurale, Grenoble, France) and James Hugunin (Massachusetts Institute of Technology) on `NumPy`, the numeric extension to Python, without which this work could not have been done;
- Fred Fritsch of LLNL, who produced the templates and did some of the writing of this documentation;
- Our French collaborators at the Centre D'Etudes de Limeil-Valenton (CEL-V), Commissariat A L'Energie Atomique, Villeneuve-St-Georges, France, among whom are Didier Courtaud, Jean-Philippe Nomine, Pierre Brochard, Jean-Bernard Weill, and others;
- David Munro of LLNL, the man behind Yorick and Gist, and Steve Langer of LLNL, who collaborated with him on the 3-D interpreted graphics in Yorick. We have also shamelessly stolen from their Gist documentation; however, any inaccuracies which crept in during the transmission remain the authors' responsibility.

The authors of this manual stand as representative of their efforts and those of a much larger number of minor contributors.

Send any comments about these documents to ‘‘`support@icf.llnl.gov`’’ on the Internet or to ‘‘`support`’’ on Lasnet.

CHAPTER 2: Introduction to Python Gist Graphics

Gist is a scientific graphics library written in C by David H. Munro of Lawrence Livermore National Laboratory. It features support for three common graphics output devices: X-Windows, (color) Postscript, and ANSI/ISO Standard Computer Graphics Metafiles (CGM). The library is small (written directly to Xlib), portable, efficient, and full-featured. It produces x-vs-y plots with ''good'' tick marks and tick labels, 2-D quadrilateral mesh plots with contours, filled contours, vector fields, or pseudocolor maps on such meshes. Some 3-D plot capabilities are also available. The Python Gist module `gist.py` and the Python extension `gistCmodule` provide a low-level Python interface to this library as far as 2-D is concerned. In addition, there are several other Python modules which interface with the 2-D graphics to produce 3-D graphics and animation: `movie.py` (supporting animation), `pl3d.py` (basic 3-D plotting algorithms), `plwf.py` (wire frame plotting), and `slice3.py` (providing mesh capability with isosurface and plane slicing). Collectively all of these interface modules are known as PyGist.

This chapter will summarize the plotting features that are available in PyGist, and list (in the final section) the functions that are to be described in future chapters.

2.1 PyGist 2-D Graphics

In two dimensions, PyGist supplies functions to plot curves, meshes (with various combinations of contours, filled mesh cells, and vector fields on the mesh, with color-filled contours in the future), sets of filled polygons, cell arrays, sets of disjoint lines, text strings, and a title. These are all provided by the Python module `gist.py`.

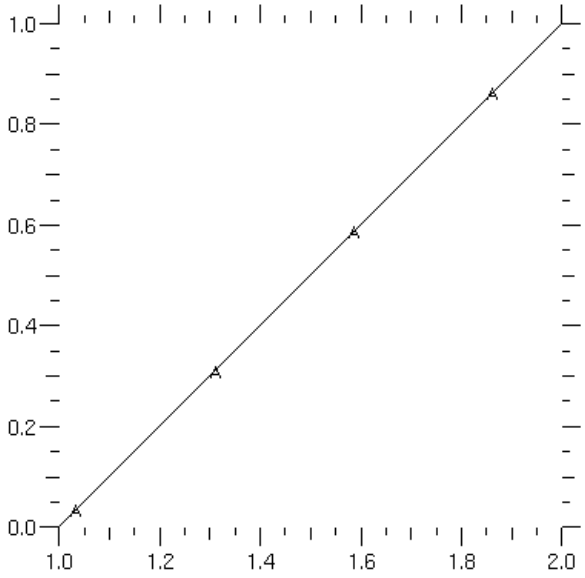
We will show a couple of simple examples below to give the reader a flavor of the interface.

Example 1

In the first example we simply plot a straight line from `(1, 0)` to `(2, 1)`. Note that only two coordinates are specified for `y`; `x` is not specified. In such a case, the values of `x` default to the integers from `1` to `len (y)`.

```
from gist import *   # Put plot functions in name space.
pldefault (marks = 1, width = 0, type = 1, style = "work.gs",
   dpi = 100)        # Set some defaults.
winkill (0)          # Kill any existing window.
window (0, wait = 1, dpi = 75)
```

```
plg ( [0, 1])        # The first positional argument is y.
```

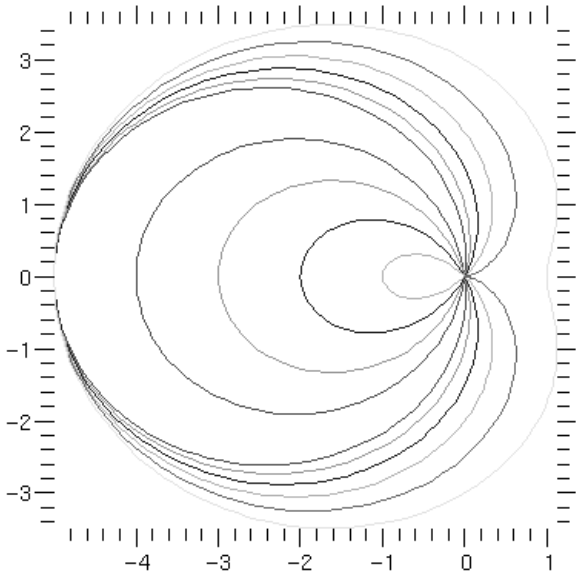


As can be deduced from this example, most PyGist function calls can be augmented with a number of optional keyword arguments. These can (usually) be supplied in any order, and each is of the form `keyword=`*`value`*. Throughout this manual, a list of the available keywords for a function is given with the description of the function.

Example 2

The next example computes and plots a set of nested cardioids in the primary and secondary colors.

```
fma()
x = 2 * pi * arange (200, typecode = Float) / 199.0
for i in range (1, 7):
   r = 0.5 * i - (5 - 0.5 * i) * cos (x)
   s = 'curve ' + `i` #Backticks produce something printable.
   plg (r * sin (x), r * cos (x), marks = 0, color = - 4 - i,
      legend = s)     # Curves unmarked, in colors.
# (See next page.)
```



2.2 PyGist 3-D Graphics

2.2.1 General overview of module `pl3d`

The Python module `pl3d.py` contains the basic 3-D plotting algorithms and is the workhorse of the PyGist 3-D graphics. The philosophy behind 3-D plotting is to instruct the 3-D plotting functions to accumulate information about the plot until such time as the information is complete, and then ask that the picture be drawn. The information about the plot is stored in a Python list containing the following information:

- The orientation of the axes, the location of the origin, and the distance of the viewpoint;
- A set of pairs of plot functions to call and their argument lists; and
- A collection of one or more quintuples specifying the lighting (it is possible to specify multiple light sources).

The first and third items above default to reasonable values if the user does not call functions (e. g., `rot3`, `mov3`, `aim3`, `set3_light`., etc.) to set them. The list described in the second bullet is built by a set of one or more calls to the various plotting functions, which create the list of arguments for each call and then add the function name and argument list pair to the plot list for future execution. When the list is complete, a call to `draw3` causes the list to be traversed, and at this point each plotting function on the list executes with the argument list that was built when it was first called.

2.2.2 Overview of module `plwf`

The main function of interest in `plwf.py` is the function `plwf` (‘‘plot wire frame’’), which enables the user to plot an arbitrary wire frame on a quadrilateral grid. The grid may be see-through or not (cells filled with the background color). In the latter case, the drawing order of the zones is deter-

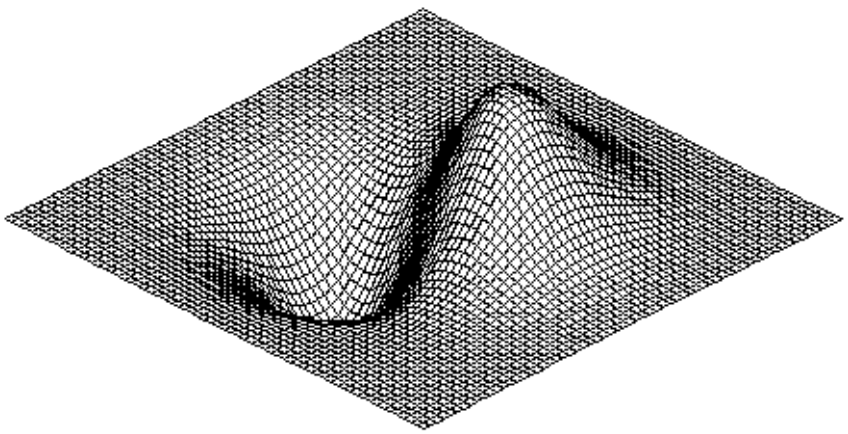
mined by a simple ‘‘painter’s algorithm’’, which works fairly well if the mesh is reasonably nearly rectilinear, but can fail even then if the viewpoint is chosen to produce extreme fisheye perspective effects. One must look at the resulting plot carefully to be sure the algorithm has correctly rendered the model in each case.

A 3-D wire mesh can also be plotted using shading and lighting effects as determined by values set in the `pl3d` module; or the zones can be colored (using the current palette) by their average height or by the values of some function, which may be zone-centered or node-centered.

Examples

The following is a fairly simple example of a wire mesh plot.

```
from pl3d import *
set_draw3_ (0)
x = span (-1, 1, 64, 64)
y = transpose (x)
z = (x + y) * exp (-6.*(x*x+y*y))
orient3 ( )
light3 ( )
from plwf import *
plwf (z, y, x)
[xmin, xmax, ymin, ymax] = draw3(1)
limits (xmin, xmax, ymin, ymax)
```



Calling `set_draw3_` with argument zero tells the 3d plotting routines not to draw the graph until asked (by a call to `draw3`). `orient3` and `light3` set the orientation and lighting parameters to default values when called with no arguments. (`light3` is irrelevant for this durface, since it is not shaded.) The `plwf` call puts this surface on the drawing list (`plwf` = ‘‘plot wire frame.’’) The

draw3 call then causes the drawing list to be plotted. draw3 returns the maxima and minima of the x and y variables, which must then be sent to the limits function to prevent the plot appearing distorted. (Ah, the perils of using low level graphics.)

2.2.3 Overview of module slice3

Module slice3.py contains two plotting functions of interest. First, pl3surf can be used for graphing surfaces on an arbitrary two-dimensional mesh with filled cells and no mesh lines. (Currently plwf can be used to do the same thing in the case of a mesh all of whose cells are quadrilateral, and has more flexibility, in that it allows mesh lines to be drawn and/or allows for the mesh to be see-through.) Secondly, pl3tree is a plotting function that can be called multiple times in order to have several surfaces drawn on the same graph. pl3tree (as its name suggests) creates a tree of values sorted as to when they will be plotted on the screen; if the algorithm works correctly, then more distant cells are plotted first, then covered by closer cells which are plotted later, giving the surface the correct appearance.

Surfaces to be plotted by pl3surf or pl3tree can be generated by taking plane sections of an arbitrary mesh or by creating isosurfaces for some function or functions defined on the mesh. These planes and isosurfaces can themselves be sliced and portions discarded, to enhance visibility of the interior. The functions mesh3 and slice3mesh take raw input data and put it into the form accepted by slice3, which can form plane sections or isosurfaces through the mesh. Functions slice2 (which returns the portion of a surface in front of the slicing plane) and slice2x (which returns the two parts of a surface sliced by a plane) complete the triumvirate of slicing functions.

The algorithms in slice3 are independent of the underlying graphics. Thus slice3 may equally well be used with Narcisse graphics.

2.3 movie.py: PyGist 3-D Animation

The module movie.py supports 3-D real time animation. Function movie accepts as argument the name of a drawing function which has as its single argument a frame number; movie then calls this drawing function within a loop, halting when the function returns zero. The idea is that the drawing function increments from the previous frame and draws the new frame, returning zero when some predefined event takes place, e. g., some set number of frames has been drawn, or a certain amount of time has elapsed. The function spin3 in module pl3d calls movie; the drawing function _spin3 draws the successive frames of a rotating 3-D plot. The demonstration module demo5.py contains an example of a shaded surface with a moving light source; the drawing function, demo5_light, moves the light and draws the next frame.

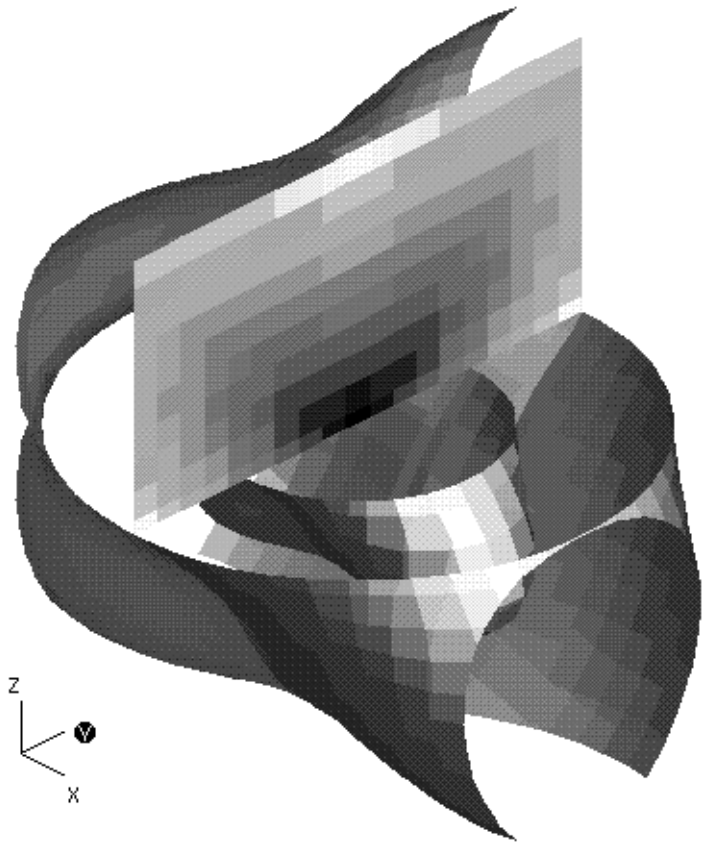
Examples

The following example is explained by comments in the code. It is taken from demo5.py. (To repeat, demo5_light is a function which appears in demo5.py.)

```
# First we define the mesh and functions on it.
# (Note: nx == ny == nz == 20)
```

```
xyz = zeros ( (3, nx, ny, nz), Float)
xyz [0] = multiply.outer ( span (-1, 1, nx),
   ones ( (ny, nz), Float))
xyz [1] = multiply.outer ( ones (nx, Float),
   multiply.outer ( span (-1, 1, ny), ones (nz, Float)))
xyz [2] = multiply.outer ( ones ( (nx, ny), Float),
   span (-1, 1, nz))
r = sqrt (xyz [0] ** 2 + xyz [1] **2 + xyz [2] **2)
theta = arccos (xyz [2] / r)
phi = arctan2 (xyz [1] , xyz [0] + logical_not (r))
y32 = sin (theta) ** 2 * cos (theta) * cos (2 * phi)
# mesh3 creates an object which slice3 can slice. The
# isosurfaces will be with respect to constant values
# of the function r * (1. + y32)].
m3 = mesh3 (xyz, funcs = [r * (1. + y32)])
[nv, xyzv, dum] = slice3 (m3, 1, None, None, value = .50)
    # (inner isosurface)
[nw, xyzw, dum] = slice3 (m3, 1, None, None, value = 1.)
    # (outer isosurface)
pxy = plane3 ( array ([0, 0, 1], Float ), zeros (3, Float))
pyz = plane3 ( array ([1, 0, 0], Float ), zeros (3, Float))
[np, xyzp, vp] = slice3 (m3, pyz, None, None, 1)
    # (pseudo-colored plane slice)
[np, xyzp, vp] = slice2 (pxy, np, xyzp, vp)
    # (cut slice in half, discard "back" part)
[nv, xyzv, d1, nvb, xyzvb, d2] = \
    slice2x (pxy, nv, xyzv, None) # halve inner isosurface
[nv, xyzv, d1] = \
    slice2 (- pyz, nv, xyzv, None)
          # (...halve one of those halves)
[nw, xyzw, d1, nwb, xyzwb, d2] = \
    slice2x ( pxy , nw, xyzw, None)
          # (split outer isosurface in halves)
[nw, xyzw, d1] = \
    slice2 (- pyz, nw, xyzw, None) # discard half of one half
fma () # frame advance
# split_palette causes isosurfaces to be shaded in grey
# scale, plane sections to be colored by function values
split_palette ("earth.gp")
gnomon (1) # show small set of axes
clear3 ()      # clears drawing list
set_draw3_ (0) # Make sure we don't draw till ready
# Create a tree of objects and put on drawing list
pl3tree (np, xyzp, vp, pyz)
pl3tree (nvb, xyzvb)
```

```
pl3tree (nwb, xyzwb)
pl3tree (nv, xyzv)
pl3tree (nw, xyzw)
orient3 ()
# set lighting parameters for isosurfaces
light3 (diffuse = .2, specular = 1)
limits (square=1)
demo5_light (1) # Causes drawing to appear
```



`demo5.py` also contains code which rotates the above object in real-time animation. It is not possible to illustrate that here.

2.4 Function Summary

Here is a summary of the functions which are described in the remainder of this manual.

- Control functions (CHAPTER 3: “Control Functions”)

```
window ( [n] [, <keylist>]) # open or select device n
     keywords: display, dpi, dump, hcp, legends, private,
          style, wait
winkill ( [n])              # delete device n
n = current_window ()       # determine active device
fma ()                      # frame advance
```

- Plot limits and scaling (CHAPTER 4: “Plot Limits and Scaling”)

```
old_limits = limits ()
old_limits = limits (xmin [, xmax[, ymin[, ymax]]]
     [, <keylist>] )
     keywords: square, nice, restrict
limits (old_limits )
ylimits (ymin[, ymax] )
logxy (xflag[, yflag] )
gridxy (flag )
gridxy (xflag, yflag )
zoom_factor (factor )
unzoom ()
```

- Two-dimensional plotting functions (CHAPTER 5: “Two-Dimensional Plotting Functions”)

```
plg (y [, x][, <keylist>] ) # plot a graph
     keywords: legend, hide, type, width, color, closed,
          smooth, marks, marker, mspace, mphase, rays
plmesh ([y, x][, ireg][, triangle=tri_array] )
                            # set default mesh
plmesh ()                   # delete default mesh
plm ([y, x][, ireg][, <keylist>] )
                            # plot mesh
     keywords: boundary, inhibit, legend, hide, type, width,
          color, region
plc (z[, y, x][, ireg][, <keylist>] )
                            # plot contours
     keywords: levs, triangle, legend, hide, type, width,
          color, smooth, marks, marker, mspace, mphase,
          region
plfc (z[, y, x][, ireg][, <keylist>] )
                             # plot filled contours
     keywords: contours, colors, region, triangle, scale
```

```
plv (vy, vx[, y, x][, ireg][, <keylist>] )
                              # plot vector field
     keywords: scale, hollow, aspect, legend, hide, type,
          width, color, smooth, marks, marker, mspace,
          mphase, triangle, region
plf (z[, y, x][, ireg][, <keylist>] )
                               # Plot a filled mesh
     keywords: edges, ecolor, ewidth, legend, hide, region,
          top, cmin, cmax
plfp (z, y, x, n[, <keylist>] )
                               # Plot filled polygons
     keywords: legend, hide, top, cmin, cmax
pli (z[[, x0, y0], x1, y1][, <keylist>] )
                               # Plot a cell array
     keywords: legend, hide, top, cmin, cmax
pldj (x0, y0, x1, y1[, <keylist>] )
                               # Plot disjoint lines
     keywords: legend, hide, type, width, color
plt (text, x, y[, <keylist>] )
     keywords: tosys, font, height, opaque, path, justify,
          legend, hide, color
pltitle (title )               # Plot a title
```

- Inquiry and Miscellaneous functions (CHAPTER 6: “Inquiry and Miscellaneous Functions”)

```
plq ()                         # Query plot element status
legend_list = plq ()
     **** RETURN VALUE NOT YET IMPLEMENTED ****
plq (n_element[, n_contour] )
properties = plq (n_element[, n_contour])
pledit ([n_element[, n_contour],] <keylist> )
      # Change Plotting Properties of Current Element
```

The keywords can be any of the keywords that apply to the current element.

```
pldefault (key1=value1, key2=value2, ... )
      # Set default values
```

The keywords can be most of the keywords that can be passed to the plotting commands.

```
bytscl (z[, top=max_byte][, cmin=lower_cutoff]
     [, cmax=upper_cutoff])
      # Convert data to color array
histeq_scale (z[, top=top_value][, cmin=cmin][,
     cmax=cmax]) **** NOT YET IMPLEMENTED ****
      # Histogram Equalized Scaling
mesh_loc (y0, x0[, y, x[, ireg]] )
      # Get zone index of (x0, y0)
result = mouse (system, style, prompt)
```

```
      # Handle Mouse Click
moush ([y, x[, ireg]] )
      # Return zone index of point clicked in mesh
pause (milliseconds) # self-explanatory
```

- Three-dimensional plotting functions (CHAPTER 7: “Three-Dimensional Plotting Functions”)

```
orient3 (phi = angle1, theta = angle2)
rot3 (xa = anglex, ya = angley, za = anglez)
mov3 (xa = val1, ya = val2, za = val3)
aim3 (xa = val1, ya = val2, za = val3)
light3 (ambient=a_level, diffuse=d_level,
     specular=s_level, spower=n, sdir=xyz)
clear3 ( )
window3 ( [n] [, dump = val] [, hcp = filename])
gnomon ( [onoff] [, chr = <labels>] )
set_default_gnomon ( [onoff])
[lims = ] draw3 ( [called_as_idler = <val>])
limits (lims [0], lims [1], lims [2], lims [3])
set_draw3 (n)
n = get_draw3 ( )
clear_idler ( )
set_idler (func_name)
set_default_idler ( )
call_idler ( )
plane3 (<normal>, <point>)
mesh3 (x, y, z)
mesh3 (x, y, z, funcs = [f1, f2, ...], [verts = <spec>])
mesh3 (xyz, funcs = [f1, f2, ...])
mesh3 (nxnynz, dxdydz, x0y0z0, funcs = [f1, f2, ...])
slice3mesh (z [, color])
slice3mesh (nxny, dxdy, x0y0, z [, color])
slice3mesh (x, y, z [, color])
slice3 (m3, fslice, nv, xyzv [, fcolor [, flg1]]
     [, value = <val>] [, node = flg2])
[nverts, xyzverts, values] = slice2 (plane, nv, xyzv, vals)
[nverts, xyzverts, values, nvertb, xyzvertb, valueb] =
     slice2x (plane, nv, xyzv, vals)
plwf (z [, y, x] [, <keylist>] )
     keywords: fill, shade, edges, ecolor, ewidth, cull,
          scale, cmax
pl3surf (nverts, xyzverts [, values] [, <keylist>])
     keywords: cmin, cmax
```

```
pl3tree (nverts, xyzverts [, values] [, <keylist>])
```
keywords: `plane, cmin, cmax, split`

- Animation functions (7.7 “Animation: movie and spin3”)

```
movie (draw_frame [, time_limit = 120.]
       [, min_interframe = 0.0]
       [, bracket_time = array ([2., 2.], Float )]
       [, lims = None]
       [, timing = 0])
spin3 (nframes = 30,
   axis = array ([-1, 1, 0],  Float),
   tlimit = 60.,
   dtmin = 0.0,
   bracket_time = array ([2., 2.],  Float),
   lims = None,
   timing = 0,
   angle = 2. * pi)
```

- Syntactic Sugar (7.8 “Syntactic Sugar: Some Helpful Functions”)

```
split_palette ( [palette_name])
view = save3 ()
restore3 (view)
```

CHAPTER 3: Control Functions

This chapter contains all the information you need to control PyGist devices. *Device* refers to an X window or a hard copy file. In addition, we describe functions which control some aspects of the appearance of the graph.

3.1 Device Control

3.1.1 Window Control

Calling Sequences

```
window ( [n] [, <keylist>])
winkill ( [n])
n = current_window ()
fma()
```

Description

The `window` function selects device `n` as the current graphics device. *n* may range from 0 to 7, inclusive. Each graphics device corresponds to an X window, a hardcopy file, or both, depending on the values of the keyword arguments described below. If *n* is omitted, it defaults to the current active device, if any. `window` returns the number of the currently active device. `winkill` deletes the current graphics device, or device *n* if *n* is specified. `current_window` returns the number of the current active device, or `-1` if there is none. `fma` frame advances the current graphics device. The current picture remains displayed in the associated X window (if any) until the next element is actually plotted. An `fma` must be given after the last plot to a hardcopy file for that plot to appear when the file is printed.

The keywords accepted by the `window` function are

`display, dpi, dump, hcp, legends, private, style, wait`

and are described in the next subsection.

Keyword Arguments

The following keyword arguments can be specified with this function.

`display`

A string of the form `"host:server.screen"` which tells where the X window will

appear (for example, `"icf.llnl.gov:0.0"`). If not specified, uses your default display (which it gets from your `DISPLAY` environment variable). Use `display = ""` (the null string) to create a graphics device which has no associated X window. (You should do this if you want to make plots in a non-interactive batch mode.)

`dpi`

The allowed values for `dpi` are `75` and `100`. The X window will appear on your default display at 75 dpi, unless you specify the `display` and/or `dpi` keywords. A `dpi = 100` X window is larger than a `dpi = 75` X window; both represent the same thing on paper.

`dump`

The `dump` keyword, if present, controls whether all colors are converted to a gray scale (`dump = 0`, the default), or the current palette is dumped at the beginning of each page of hardcopy output. Set `dump` to `1` if you are doing color plots. The `dump` keyword applies only to the specific hardcopy file defined using the `hcp` keyword (see below) -- use the `dump` keyword in the `hcp_file` command to get the same effect in the default hardcopy file.

`hcp`

The value of this keyword is a quoted string giving a file name. By default, a graphics window does NOT have a hardcopy file of its own -- any requests for hardcopy are directed to the default hardcopy file, so hardcopy output from any window goes to a single file. By specifying the `hcp` keyword, however, a hardcopy file unique to this window will be created. If the `hcp` filename ends in ‘`.ps`’, then the hardcopy file will be a PostScript file; otherwise, hardcopy files are in binary CGM format. Use `hcp = ""` (the null string) to revert to the default hardcopy file (closing the window specific file, if any).

In the next section of this manual we shall consider the hardcopy and file functions. Note that the PyGist default is to write to a hardcopy file only on demand. (See function `hcp`, page 20.)

`legends`

The `legends` keyword, if present, controls whether the curve legends are (`legends = 1`, the default) or are not (`legends = 0`) dumped to the hardcopy file. The `legends` keyword applies to all pictures dumped to hardcopy from this graphics window. Legends are never plotted to the X window.

`private`

By default, an X window will attempt to use shared colors, which permits several PyGist graphics windows (including windows from multiple instances of Python) to use a common palette. You can force an X window to post its own colormap (set its colormap attribute) with the `private = 1` keyword. You will most likely have to fiddle with your window manager to understand how it handles colormap focus if you do this. Use `private = 0` to return to shared colors.

`style`

The `style` keyword, if present, specifies (as a quoted string) the name of a Gist stylesheet file; the default is `"work.gs"`. The style sheet determines the number and location of coor-

dinate systems, tick and label styles, and the like. Here are brief descriptions of the available stylesheets:

`axes.gs`: axes with labeled tick marks along bottom and left of graph.

`boxed.gs`: lines all the way around the plot with tick marks, labeled along bottom and left.

`boxed2.gs`: same as boxed.gs but no tick marks on the top and right sides.

`l_nobox.gs`: no box, axes, or ticks; graph extends all the way to edge of window.

`nobox.gs`: indistinguishable from `l_nobox.gs`.

`vg.gs`: large tick marks all the way around the graph, but no lines, with large infrequent labels on the bottom and left.

`vgbox.gs`: same as `vg.gs` except with lines all the way around as well

`work.gs`: small tick marks with small, frequent labels on bottom and left, no lines.

`work2.gs`: similar to `work.gs`, but no ticks along top and right.

`wait`

By default, Python will not wait for the X window to become visible. Code which creates a new window, then plots a series of frames to that window should use `wait = 1` to assure that all frames are actually plotted.

Examples

The first example ensures that an old window 0 is not hanging around, and then creates a new 100 dpi window.

```
winkill(0)
window (0, wait = 1, dpi = 100)
```

The second example changes the style sheet of window 2.

```
window (2, style = "vgbox.gs")
```

3.1.2 Hard Copy and File Control

Calling Sequences

```
eps (name)
hcp ()
hcp_file ( [filename] [, dump = 0/1])
filename = hcp_finish ( [n])
hcp_out ( [n] [, keep = 0/1])
hcpon ()
hcpoff ()
```

Descriptions

`eps (`*`name`*`)`

Write the picture in the current graphics window to the Encapsulated PostScript file *`name`* + `".epsi"` (i.e., the suffix `.epsi` is added to `name`). The `eps` function requires the `ps2epsi` utility which comes with the project GNU Ghostscript program. Any hardcopy file associated with the current window is first closed, but the default hardcopy file is unaffected. As a side effect, legends are turned off and color table dumping is turned on for the current window. The environment variable `PS2EPSI_FORMAT` contains the format for the command to start the `ps2epsi` program.

`hcp ()`

The `hcp` function sends the picture displayed in the current graphics window to the hardcopy file. (The name of the default hardcopy file can be specified using `hcp_file`; each individual graphics window may have its own hardcopy file as specified by the `window` function.)

`hcp_file ( [`*`filename`*`] [, dump = 0/1])`

Sets the default hardcopy file to *`filename`*. If *`filename`* ends with ‘`.ps`’, the file will be a PostScript file, otherwise it will be a binary CGM file. By default, the hardcopy file name will be ‘`Aa00.cgm`’, or ‘`Ab00.cgm`’ if that exists, or ‘`Ac00.cgm`’ if both exist, and so on. The default hardcopy file gets hardcopy from all graphics windows which do not have their own specific hardcopy file (see the `window` function). If the `dump` keyword is present and non-zero, then the current palette will be dumped at the beginning of each frame of the default hardcopy file. This is what you want to do when you want color plots. With `dump = 0`, the default behavior of converting all colors to a gray scale is restored.

`filename` `= hcp_finish ( [`*`n`*`])`

Close the current hardcopy file and return the filename. If *`n`* is specified, close the `hcp` file associated with window *`n`* and return its name; use `hcp_finish (-1)` to close the default hardcopy file.

`hcp_out ( [`*`n`*`] [, keep = 0/1])`

**** NOT YET IMPLEMENTED ****
Finishes the current hardcopy file and sends it to the printer. If *`n`* is specified, prints the `hcp` file associated with window *`n`*; use `hcp_out (-1)` to print the default hardcopy file. Unless the `keep` keyword is supplied and non-zero, the file will be deleted after it is processed by `gist` and sent to `lpr`.

`hcpon ()`

The `hcpon` function causes every `fma` (frame advance) function call to do an implicit `hcp`, so that every frame is sent to the hardcopy file.

`hcpoff ()`

The `hcpoff` command reverts to the default ‘demand only’ mode.

3.2 Other Controls

3.2.1 `animate`: Control Animation Mode

Calling Sequence

```
animate ( [0/1])
```

Description

Without any arguments, toggle animation mode; with argument 0, turn off animation mode; with argument 1 turn on animation mode. In animation mode, the X window associated with a graphics window is actually an offscreen pixmap which is bit-blitted onscreen when an `fma()` command is issued. This is confusing unless you are actually trying to make a movie, but results in smoother animation if you are. Generally, you should turn animation on, run your movie, then turn it off.

3.2.2 `palette`: Set or Retrieve Palette

Calling Sequence

```
palette ( filename)
palette ( source_window_number)
palette ( red, green, blue[, gray][, query = 1]
          [, ntsc = 1/0])
```

Description

Set (or retrieve with `query = 1`) the palette for the current graphics window. The *`filename`* is the name of a Gist palette file; the standard palettes are `"earth.gp"`, `"stern.gp"`, `"rainbow.gp"`, `"heat.gp"`, `"gray.gp"`, and `"yarg.gp"`. Use the `maxcolors` keyword in the `pldefault` command to put an upper limit on the number of colors which will be read from the palette in *`filename`*.

In the second form, the palette for the current window is copied from window number *`source_window_number`*. If the X colormap for the window is private, there will still be two separate X colormaps for the two windows, but they will have the same color values.

In the third form, *`red`*, *`green`*, and *`blue`* are 1-D arrays of unsigned char (Python typecode `"b"`) and of the same length specifying the palette you wish to install; the values should vary between 0 and 255, and your palette should have no more than 240 colors. If `ntsc=0`, monochrome devices (such as most laser printers) will use the average brightness to translate your colors into gray; otherwise, the NTSC (television) averaging will be used (.30**red*+.59**green*+.11**blue*). Alternatively, you can specify *`gray`* explicitly.

Ordinarily, the palette is not dumped to a hardcopy file (color hardcopy is still rare and expensive), but you can force the palette to dump using the `window()` or `hcp_file()` commands.

3.2.3 `plsys`: Set Coordinate System

Calling Sequence

```
plsys (n)
```

Description

Set the current coordinate system to number *n* in the current graphics window. If *n* equals 0, subsequent elements will be plotted in absolute NDC coordinates outside of any coordinate system. The default style sheet `"work.gs"` defines only a single coordinate system, so the only other choice is *n* equal 1.

You can make up your own style sheet (using a text editor) which defines multiple coordinate systems. You need to do this if you want to display four plots side by side on a single page, for example. The standard style sheets `"work2.gs"` and `"boxed2.gs"` define two overlayed coordinate systems with the first labeled to the right of the plot and the second labeled to the left of the plot. When using overlayed coordinate systems, it is your responsibility to ensure that the x-axis limits in the two systems are identical.

3.2.4 `redraw`: Redraw X window

Calling Sequence

redraw ()

Description

Redraw the X window associated with the current graphics window.

CHAPTER 4: Plot Limits and Scaling

4.1 Setting Plot Limits

4.1.1 `limits`: Save or Restore Plot Limits

Calling Sequence

```
old_limits = limits()
old_limits = limits( xmin [, xmax[, ymin[, ymax]]]
     [, <keylist>] )
limits( old_limits )
```

Description

In the first form, restore all four plot limits to extreme values, and save the previous limits in the tuple *`old_limits`*.

In the second form, set the plot limits in the current coordinate system to *`xmin`*, *`xmax`*, *`ymin`*, *`ymax`*, which may each be a number to fix the corresponding limit to a specified value, or the string `"e"` to make the corresponding limit take on the extreme value of the currently displayed data. Arguments may be omitted from the right end only. (But see `ylimits`, below, to set limits on the y-axis.)

`limits()` always returns a tuple of 4 doubles and an integer; *`old_limits`*[0:3] are the previous *`xmin`*, *`xmax`*, *`ymin`*, and *`ymax`*, and *`old_limits`*[4] is a set of flags indicating extreme values and the `square`, `nice`, `restrict`, and `log` flags. This tuple can be saved and passed back to `limits()` in a future call to restore the limits to a previous state.

In an X window, the limits may also be adjusted interactively with the mouse. Drag left to zoom in and pan (click left to zoom in on a point without moving it), drag middle to pan, and click (and drag) right to zoom out (and pan). If you click just above or below the plot, these operations will be restricted to the x-axis; if you click just to the left or right, the operations are restricted to the y-axis. A shift-left click, drag, and release will expand the box you dragged over to fill the plot (other popular software zooms with this paradigm). If the rubber band box is not visible with shift-left zooming, try shift-middle or shift-right for alternate XOR masks. Such mouse-set limits are equivalent to a `limits` command specifying all four limits *except* that the `unzoom` command (see “Zooming Operations” on page 25) can revert to the limits before a series of mouse zooms and pans.

The limits you set using the `limits` or `ylimits` functions carry over to the next plot; that is, an

`fma` operation does *not* reset the limits to extreme values.

Keyword Arguments

The following keyword arguments can be specified with this function.

`square = 0/1`

If present, the `square` keyword determines whether limits marked as extreme values will be adjusted to force the x and y scales to be equal (`square=1`) or not (`square=0`, the default).

`nice = 0/1`

If present, the `nice` keyword determines whether limits will be adjusted to nice values (`nice=1`) or not (`nice=0`, the default).

`restrict = 0/1`

There is a subtlety in the meaning of "extreme value" when one or both of the limits on the OPPOSITE axis have fixed values: does the "extreme value" of the data include points which will not be plotted because their other coordinate lies outside the fixed limit on the opposite axis (`restrict=0`, the default), or not (`restrict=1`)?

4.1.2 `ylimits`: Set y-axis Limits

Calling Sequence

```
ylimits ( ymin[, ymax] )
```

Description

Set the y-axis plot limits in the current coordinate system to *`ymin`*, *`ymax`*, which may each be a number to fix the corresponding limit to a specified value, or the string `"e"` to make the corresponding limit take on the extreme value of the currently displayed data.

Arguments may be omitted only from the right. Use `limits( xmin, xmax )` to accomplish the same function for the x-axis plot limits.

Note that the corresponding Yorick function for `ylimits` is `range`. Since this word is a Python built-in function, the name has been changed to avoid the collision.

4.2 Scaling and Grid Lines

4.2.1 `logxy`: Set Linear/Log Axis Scaling

Calling Sequence

```
logxy( xflag[, yflag] )
```

Description

`logxy` sets the linear/log axis scaling flags for the current coordinate system. *`xflag`* and *`yflag`* may be 0 to select linear scaling, or 1 to select log scaling. *`yflag`* may be omitted (but not *`xflag`*).

4.2.2 `gridxy`: Specify Grid Lines

Calling Sequence

```
gridxy( flag )
gridxy( xflag, yflag )
```

Description

Turns on or off grid lines according to *`flag`*. In the first form, both the x and y axes are affected. In the second form, *`xflag`* and *`yflag`* may differ to have different grid options for the two axes. In either case, a *`flag`* value of 0 means no grid lines (the default), a value of 1 means grid lines at all major ticks (the level of ticks which get grid lines can be set in the style sheet), and a *`flag`* value of 2 means that the coordinate origin only will get a grid line. In styles with multiple coordinate systems, only the current coordinate system is affected. The keywords can be used to affect the style of the grid lines.

You can also turn the ticks off entirely. (You might want to do this to plot your own custom set of tick marks when the automatic tick generating machinery will never give the ticks you want. For example a latitude axis in degrees might reasonably be labeled "0, 30, 60, 90", but the automatic machinery considers 3 an "ugly" number - only 1, 2, and 5 are "pretty" - and cannot make the required scale. In this case, you can turn off the automatic ticks and labels, and use `plsys`, `pldj`, and `plt` to generate your own.)

To fiddle with the tick flags in this general manner, set the `0x200` bit of *`flag`* (or *`xflag`* or *`yflag`*), and "or-in" the `0x1ff` bits however you wish. The meaning of the various flags is described in the `"work.gs"` Gist style sheet. Additionally, you can use the `0x400` bit to turn on or off the frame drawn around the viewport. Here are some examples:

`gridxy(0x233)`	`work.gs` default setting
`gridxy(0, 0x200)`	like `work.gs`, but no y-axis ticks or labels
`gridxy(0, 0x231)`	like `work.gs`, but no y-axis ticks on right
`gridxy(0x62b)`	`boxed.gs` default setting

4.3 Zooming Operations

Calling Sequences

```
zoom_factor( factor )
unzoom()
```

Descriptions

`zoom_factor` sets the zoom factor for mouse-click zoom in and zoom out operations. The default *`factor`* is 1.5; *`factor`* should always be greater than 1.0.

`unzoom` restores limits to their values before zoom and pan operations performed interactively using the mouse. Use

```
old_limits = limits()
     ...
limits( old_limits )
```

to save and restore plot limits generally.

CHAPTER 5: Two-Dimensional Plotting Functions

This chapter describes the Gist output primitives are available for drawing two-dimensional plots. Keyword arguments that apply only to a single function are described with that function; those that apply to several are collected in a separate section at the end of the chapter.

5.1 Output Primitives

5.1.1 `plg`: Plot a Graph

Calling Sequence

```
plg( y [, x][, <keylist>] )
```

Description

Plot a graph of *y* versus *x*. *y* and *x* must be 1-D arrays of equal length. If *x* is omitted, it defaults to [1, 2, ..., `len(`*y*`)`].

Keyword Arguments

The following keyword argument(s) apply only to this function.

```
rspace = <float value>
rphase = <float value>
arroww = <float value>
arrowl = <float value>
```

Select the spacing, phase, and size of occasional ray arrows placed along polylines. The spacing and phase are in NDC units (0.0013 NDC equals 1.0 point); the default `rspace` is 0.13, and the default `rphase` is 0.11375, but `rphase` is automatically incremented for successive curves on a single plot. The arrowhead width, `arroww`, and arrowhead length, `arrowl` are in relative units, defaulting to 1.0, which translates to an arrowhead 10 points long and 4 points in half-width.

The following additional keyword arguments can be specified with this function.

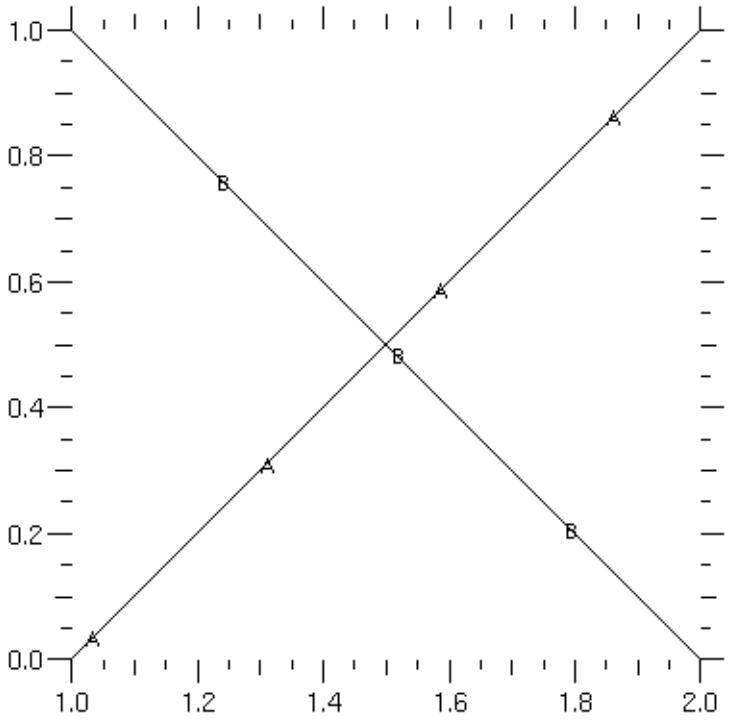
`legend, hide, type, width, color, closed, smooth, marks, marker, mspace, mphase, rays`

See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords.

Examples

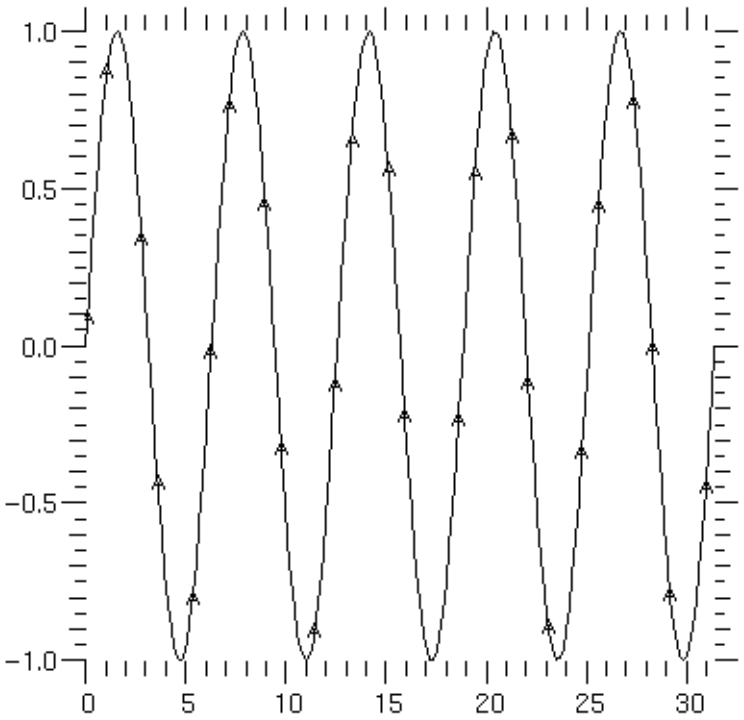
The following example simply plots two straight lines..

```
>>> from gist import *
>>> window (0, wait=1, dpi=75)
0
>>> plg([0, 1])
>>> plg([1, 0])
```



The following draws the graph of a sine curve:

```
fma()
x = 10*pi*arange(200, typecode = Float)/199.0
plg(sin(x), x)
```



5.1.2 `plmesh`: Set Default Mesh

Calling Sequence

```
plmesh( [y, x][, ireg][, triangle=tri_array] )
plmesh()
```

Description

Set the default mesh for subsequent `plm`, `plc`, `plv`, `plf`, and `plfc` calls. In the second form, `plmesh` deletes the default mesh (until you do this, or switch to a new default mesh, the default mesh arrays persist and takes up space in memory). The *`y`*, *`x`*, and *`ireg`* arrays should all be the same shape; *`y`* and *`x`* will be converted to double, and *`ireg`* will be converted to int.

If *`ireg`* is omitted, it defaults to *`ireg`*`(0,)=`*`ireg`*`(,0)=0`, *`ireg`*`(1:,1:)=1`; that is, region number 1 is the whole mesh. The triangulation array *`tri_array`* is used by `plc` and `plfc`; the

correspondence between *tri_array* indices and zone indices is the same as for *ireg*, and its default value is all zero. The *ireg* or *tri_array* arguments may be supplied without *y* and *x* to change the region numbering or triangulation for a given set of mesh coordinates. However, a default *y* and *x* must already have been defined if you do this. If *y* is supplied, *x* must be supplied, and vice-versa.

Example

The following example creates a mesh whose graph we will see later (see the example on page 31). For convenience, we show the functions `span` and `a3`, which are used to build the data.

```
def span(lb,ub,n):
  if n < 2: raise ValueError, '3rd arg must be at least 2'
  b = lb
  a = (ub - lb)/(n - 1.0)
  return map(lambda x,A=a,B=b: A*x + B, range(n))
def a3(lb,ub,n):
  return reshape (array(n*span(lb,ub,n), Float), (n,n))
fma()
limits()
x = a3(-1, 1, 26)
y = transpose (x)
z = x+1j*y
z = 5.*z/(5.+z*z)
xx = z.real
yy = z.imaginary
plmesh(yy, xx)
```

5.1.3 `plm`: Plot a Mesh

Calling Sequence

```
plm( [y, x][, ireg][, <keylist>] )
```

Description

Plot a mesh of *y* versus *x*. *y* and *x* must be 2-D arrays with equal dimensions. If present, *ireg* must be a 2-D region number array for the mesh, with the same dimensions as *x* and *y*. The values of *ireg* should be positive region numbers, and zero for zones which do not exist. The first row and column of *ireg* never correspond to any zone, and should always be zero. The default *ireg* is 1 everywhere else.

The *y*, *x*, and *ireg* arguments may all be omitted to default to the mesh set by the most recent `plmesh` call.

Keyword Arguments

The following keyword argument(s) apply only to this function.

`boundary = 0/1`

If present, the `boundary` keyword determines whether the entire mesh is to be plotted (`boundary=0`, the default), or just the boundary of the selected region (`boundary=1`).

`inhibit = 0/1/2/3`

If present, the `inhibit` keyword causes the (*x*(,j),*y*(,j)) lines to not be plotted (`inhibit=1`), the (*x*(i,),*y*(i,)) lines to not be plotted (`inhibit=2`), or both sets of lines not to be plotted (`inhibit=3`). By default (`inhibit=0`), mesh lines in both logical directions are plotted.

The following additional keyword arguments can be specified with this function.

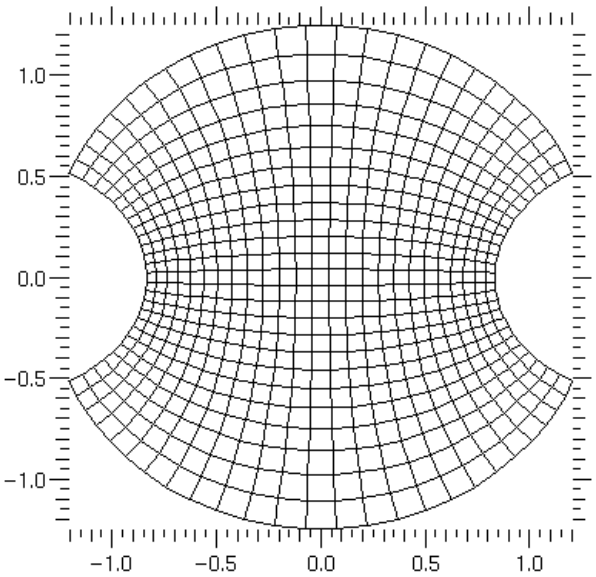
`legend, hide, type, width, color, region`

See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords.

Example

The mesh set by the `plmesh` function call in the preceding example (page 30) may be plotted simply by calling `plm` with no arguments:

```
plm ()
```



5.1.4 `plc`: Plot Contours

Calling Sequence

```
plc( z[, y, x][, ireg][, <keylist>] )
```

Description

Plot contours of *z* on the mesh *y* versus *x*. *y*, *x*, and *ireg* are as for `plm`. The *z* array must have the same shape as *y* and *x*. The function being contoured takes the value *z* at each point (*x*,*y*); that is, the *z* array is presumed to be point-centered. The *y*, *x*, and *ireg* arguments may all be omitted to default to the mesh set by the most recent `plmesh` call.

Keyword Arguments

The following keyword argument(s) apply only to this function.

`levs = z_values`

The `levs` keyword specifies a list of the values of `z` at which you want contour curves. The default is eight contours spanning the range of `z`.

`triangle = triangle`

Set the triangulation array for a contour plot. *triangle* must be the same shape as the `ireg` (region number) array, and the correspondence between mesh zones and indices is the same as for `ireg`. The triangulation array is used to resolve the ambiguity in saddle zones, in which the function `z` being contoured has two diagonally opposite corners high, and the other two corners low. The triangulation array element for a zone is 0 if the algorithm is to choose a triangulation, based on the curvature of the first contour to enter the zone. If zone (i,j) is to be triangulated from point (i-1,j-1) to point (i,j), then *triangle*(i,j)=1, while if it is to be triangulated from (i-1,j) to (i,j-1), then *triangle*(i,j)=-1. Contours will never cross this ‘‘triangulation line’’.

You should rarely need to fiddle with the triangulation array; it is a hedge for dealing with pathological cases.

The following additional keyword arguments can be specified with this function.

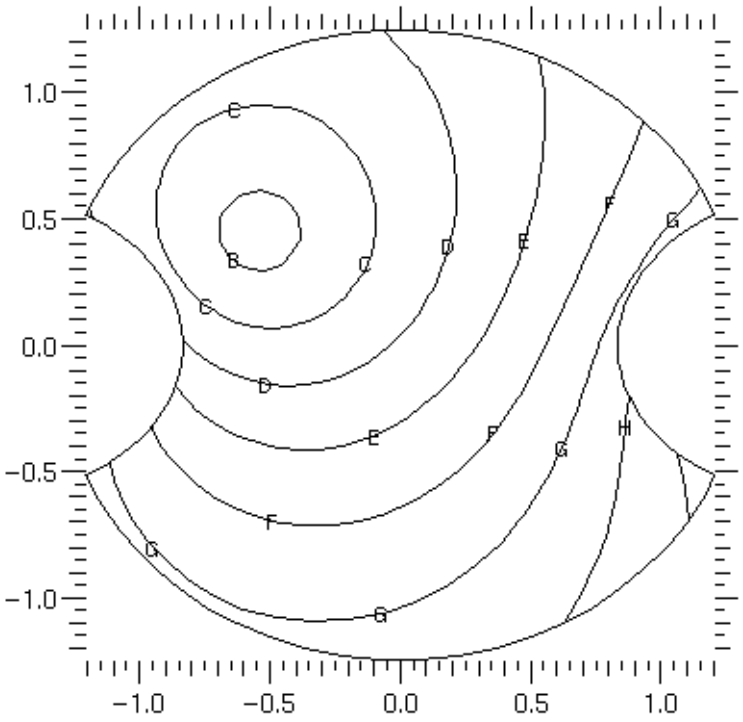
legend, hide, type, width, color, smooth, marks, marker, mspace, mphase, region

See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords.

Examples

The following example gives a contour plot of the same mesh used in the preceding two examples. Calling plm with boundary = 1 and region = 1 plots the boundary of the mesh (which, by default, is one region); then calling plc plots a default number of contours (8).

```
fma()
def mag(*args):
  r = 0
  for i in range(len(args)):
    r = r + args[i]*args[i]
  return sqrt(r)
plm(region=1,boundary=1)
plc (mag(x+.5,y-.5), marks=1, region=1)
plm(inhibit=3,boundary=1,region=1)
plm(boundary=1,region=1)
```



5.1.5 `plv`: Plot a Vector Field

Calling Sequence

```
plv( vy, vx[, y, x][, ireg][, <keylist>] )
```

Description

Plot a vector field (*vx*,*vy*) on the mesh (*x*,*y*). *y*, *x*, and *ireg* are as for `plm`. The *vy* and *vx* arrays must have the same shape as *y* and *x*. The *y*, *x*, and *ireg* arguments may all be omitted to default to the mesh set by the most recent `plmesh` call.

Keyword Arguments

The following keyword argument(s) apply only to this function.

`scale = dt`

The `scale` keyword is the conversion factor from the units of (*vx*,*vy*) to the units of (*x*,*y*) -- a time interval if (*vx*,*vy*) is a velocity and (*x*,*y*) is a position -- which determines the length of the vector "darts" plotted at the (*x*,*y*) points.

If omitted, `scale` is chosen so that the longest ray arrows have a length comparable to a "typical" zone size. You can use the `scalem` keyword in `pledit` to make adjustments to the `scale` factor computed by default.

`hollow = 0/1`
`aspect = <float value>`

Set the appearance of the "darts" of a vector field plot. The default darts, `hollow=0`, are filled; use `hollow=1` to get just the dart outlines. The default is `aspect=0.125`; `aspect` is the ratio of the half-width to the length of the darts. Use the `color` keyword to control the color of the darts.

The following additional keyword arguments can be specified with this function.

`legend, hide, type, width, color, smooth, marks, marker, mspace, mphase, triangle, region`

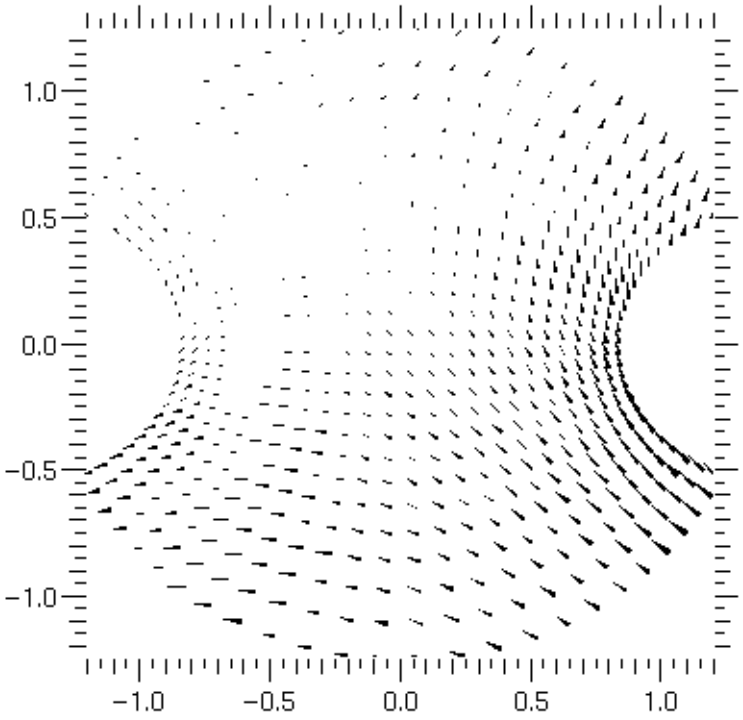
See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords.

Example

This example applies to the same mesh that we have considered in the last three examples.

```
plv(x+.5, y-.5)
```

The plot appears on the next page.



5.1.6 `plf`: Plot a Filled Mesh

Calling Sequence

```
plf( z[, y, x][, ireg][, <keylist>] )
```

Description

Plot a filled mesh *y* versus *x*. *y*, *x*, and *ireg* are as for `plm`. The *z* array must have the same shape as *y* and *x*, or one smaller in both dimensions. If *z* is of type unsigned char (Python typecode `'b'`), it is used "as is"; otherwise, it is linearly scaled to fill the current palette, as with the `bytscl` function. The mesh is drawn with each zone in the color derived from the *z* function and the current palette; thus `z` is interpreted as a zone-centered array. The *y*, *x*, and *ireg* arguments may all be omitted to default to the mesh set by the most recent `plmesh` call.

A solid edge can optionally be drawn around each zone by setting the `edges` keyword non-zero. `ecolor` and `ewidth` determine the edge color and width. The mesh is drawn zone by zone in order from *ireg*`(2+imax)` to *ireg*`(jmax*imax)` (the latter is *ireg*`(imax,jmax)`), so you can achieve 3D effects by arranging for this order to coincide with back-to-front order. If *z* is nil, the mesh zones are filled with the background color, which you can use to produce 3D wire frames.

Keyword Arguments

The following keyword argument(s) apply only to this function.

```
edges = 0/1
ecolor = <color value>
ewidth = <float value>
```

Set the appearance of the zone edges in a filled mesh plot (`plf`). By default, `edges=0`, and the zone edges are not plotted. If `edges=1`, a solid line is drawn around each zone after it is filled; the edge color and width are given by `ecolor` and `ewidth`, which are `"fg"` and 1.0 by default.

The following additional keyword arguments can be specified with this function.

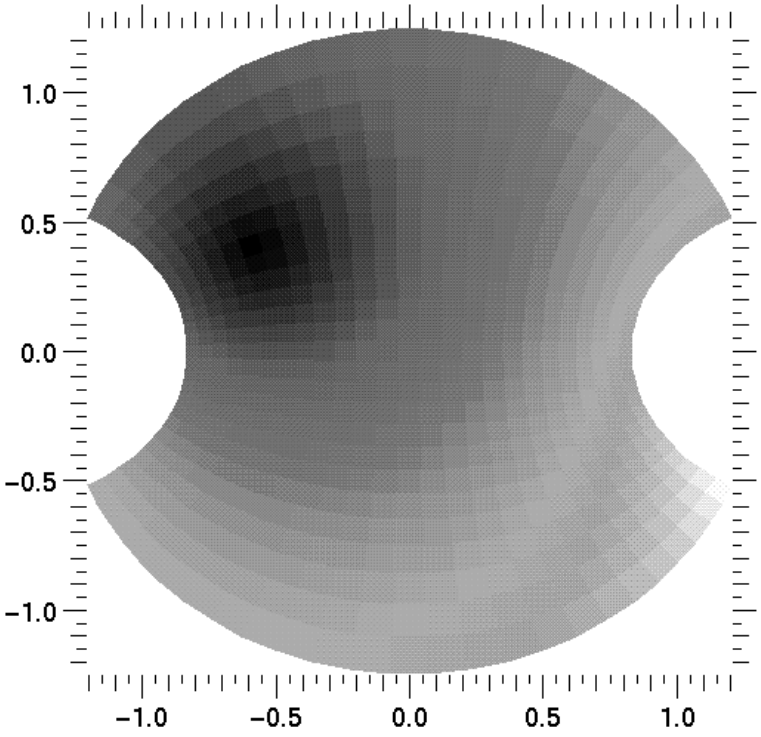
`legend, hide, region, top, cmin, cmax`

See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords. (See the `bytscl` function description on page 52 for explanation of `top`, `cmin`, `cmax`.)

Examples

The following gives a filled mesh plot of the same mesh we have been considering in the preceding examples.

```
plf (mag(x+.5,y-.5))
```



5.1.7 `plfc`: Plot filled contours

Calling Sequence

```
plfc (z, y, x, ireg, contours = 20, colors = None,
   region = 0, triangle = None, scale = "lin")
```

Description

Unlike the other plotting primitives, `plfc` is implemented in Python code. It calls a C module to compute the contours, then uses `plfp` (described in the next subsection) to draw the filled contour lines. It does not use the mesh plotting routines; hence the arguments `z`, `y`, `x`, and `ireg` must be given explicitly. They will not default to the values set by `plmesh`.

Keyword Arguments

The values given above for the keyword arguments are the defaults. The meanings of the keywords are as follows:

`contours`

If an integer, specifies the number of contour lines desired. The contour levels will be computed automatically. If an array of floats, specifies the actual contour levels.

`colors`

An array of unsigned char (Python typecode 'b') with values between 0 and 199 specifying the indices into the current palette of the fill colors to use. The size of this array (if present) must be one larger than the number of contours specified.

`triangle`

As described for the mesh plots.

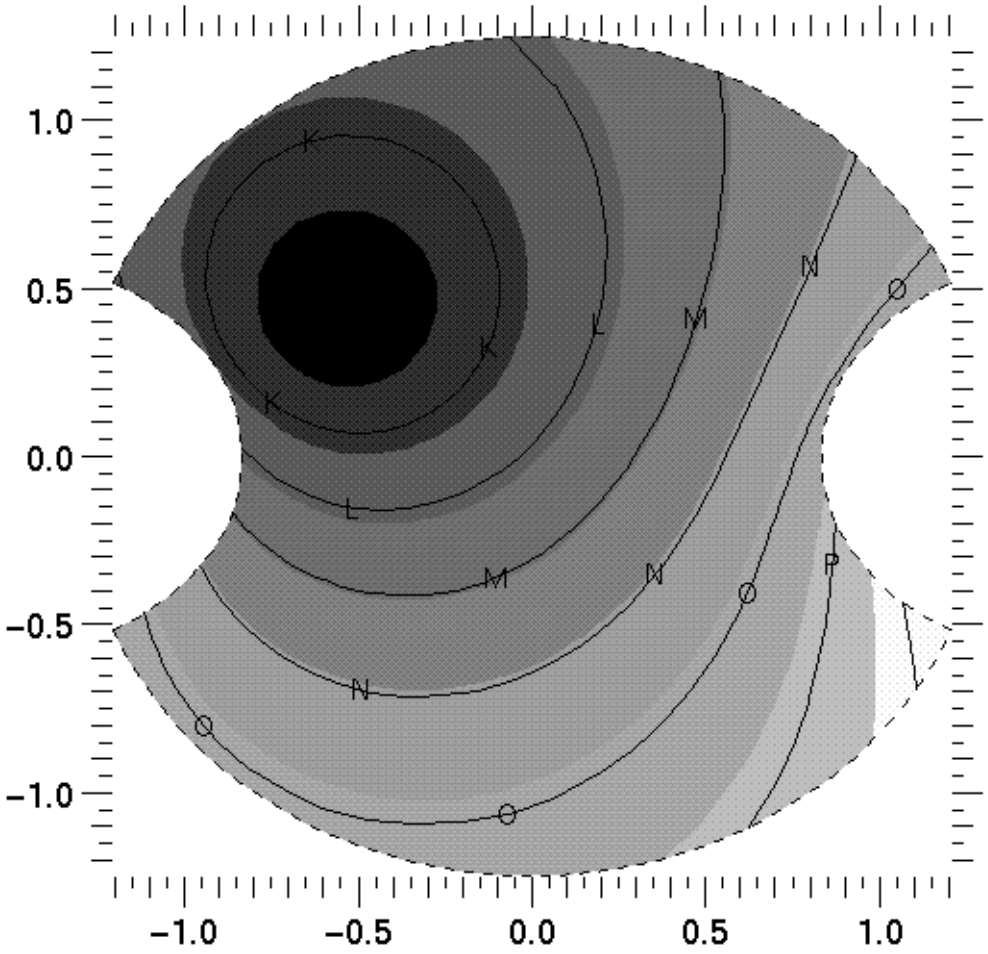
`scale`

If the number of contours was given, this keyword specifies how they are to be computed: `"lin"` (linearly), `"log"` (logarithmically) and `"normal"` (based on the normal distribution; the minimum and maximum contours will be two standard deviations from the mean).

Example

In the following example, we have to explicitly compute and pass an `ireg` array. We plot filled contours and then plot contour lines on top of them. Note that the contour divisions do not coincide, since the two routines use different algorithms for computing contour levels. Perhaps someday this defect will be remedied.

```
ireg = ones (xx.shape, Int)
ireg [0, :] = 0
ireg [:, 0] = 0
plfc(mag(x+.5,y-.5),yy,xx,ireg,contours=8)
plc (mag(x+.5,y-.5), marks=1)
```



5.1.8 `plfp`: Plot a List of Filled Polygons

Calling Sequence

```
plfp( z, y, x, n[, <keylist>] )
```

Description

Plot a list of filled polygons *y* versus *x*, with colors *z*. The *n* array is a 1D list of lengths (number of corners) of the polygons; the 1D colors array *z* has the same length as *n*. The *x* and *y* arrays have length equal to the sum of all dimensions of *n*.

If *z* is of type unsigned char (Python typecode `"b"`), it is used ‘‘as is’’; otherwise, it is linearly scaled to fill the current palette, as with the `bytscl` function.

Keyword Arguments

The following keyword arguments can be specified with this function.

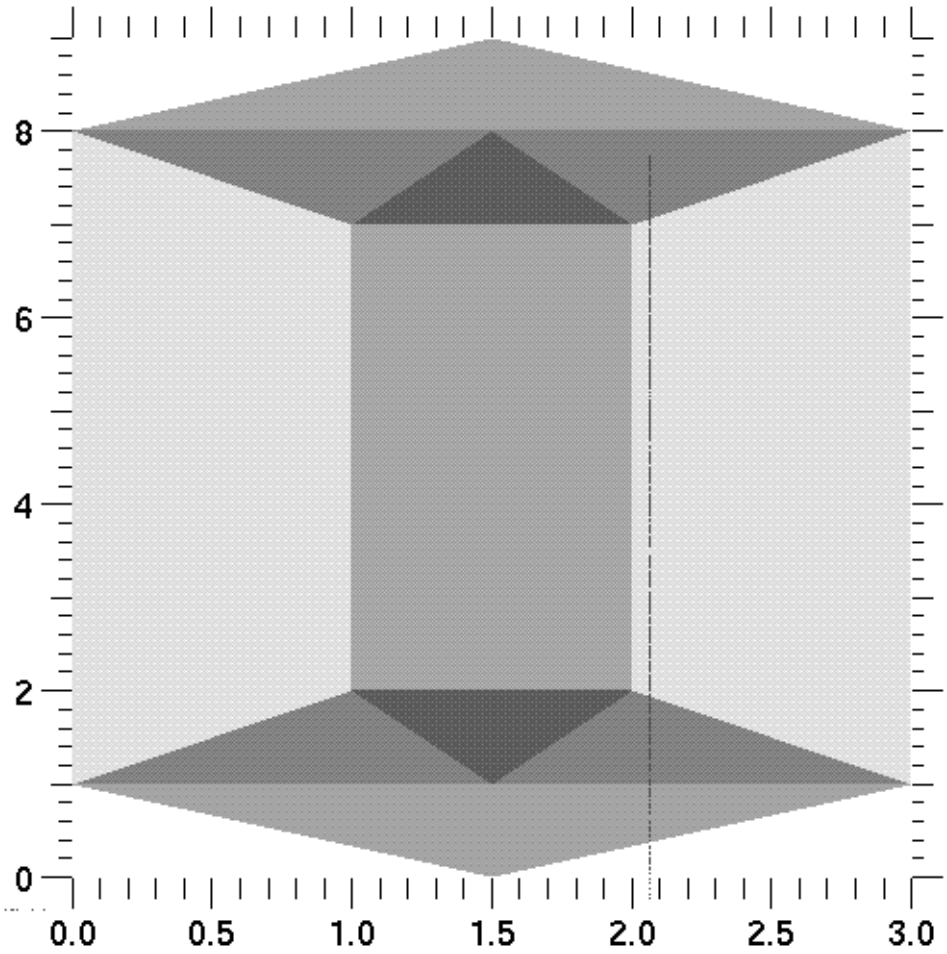
`legend, hide, top, cmin, cmax`

See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords. (See the `bytscl` function description on page 52 for explanation of `top`, `cmin`, `cmax`.)

Example

This example gives a sort of "stained glass window" effect;.

```
z = array([190,100,130,100,50,190,160,100,50,100,130],'b')
y = array ([1.0, 2.0, 7.0, 8.0, 1.0, 1.0, 2.0, 0.0, 1.0, 1.0,
1.0, 1.0, 2.0, 1.0, 2.0, 2.0, 2.0, 1.0, 8.0, 7.0, 2.0, 2.0,
7.0, 7.0, 7.0, 8.0, 8.0, 7.0, 7.0, 8.0, 7.0, 8.0, 8.0, 8.0,
8.0, 9.0])
x = array ([0.0, 1.0, 1.0, 0.0, 0.0, 1.5, 1.0, 1.5, 3.0, 0.0,
1.5, 3.0, 2.0, 1.5, 2.0, 1.0, 2.0, 3.0, 3.0, 2.0, 1.0, 2.0,
2.0, 1.0, 2.0, 3.0, 1.5, 1.0, 2.0, 1.5, 1.0, 1.5, 0.0, 0.0,
3.0, 1.5])
n = array ([4, 3, 3, 3, 3, 4, 4, 3, 3, 3, 3])
plfp (z, y, x, n)
```



5.1.9 `pli`: Plot a Cell Array

Calling Sequence

```
pli( z[[, x0, y0], x1, y1][, <keylist>] )
```

Description

Plot the image *z* as a cell array: an array of equal rectangular cells colored according to the 2-D array *z*. The first dimension of *z* is plotted along x, the second dimension is along y.

If *z* is of type unsigned char (Python typecode `"b"`), it is used ‘‘as is’’; otherwise, it is linearly scaled to fill the current palette, as with the `bytscl` function.

If *x1* and *y1* are given, they represent the coordinates of the upper right corner of the image. If *x0*, and *y0* are given, they represent the coordinates of the lower left corner, which is at (0,0) by de-

fault. If only the *z* array is given, each cell will be a 1x1 unit square, with the lower left corner of the image at (0,0).

Keyword Arguments

The following keyword arguments can be specified with this function.

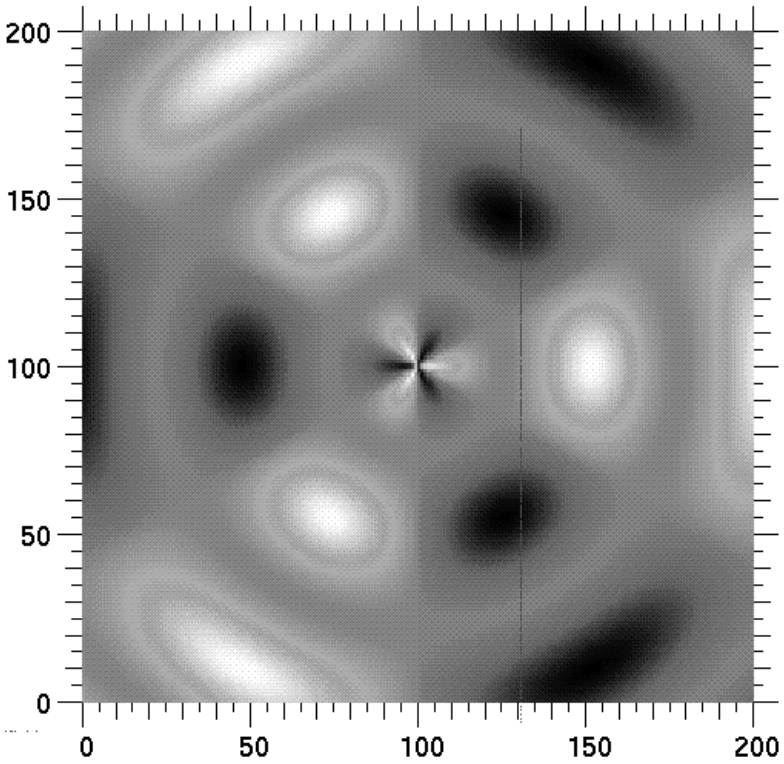
`legend, hide, top, cmin, cmax`

See "Plot Function Keywords" on page 45 for detailed descriptions of these keywords. (See the `bytscl` function description on page 52 for explanation of `top`, `cmin`, `cmax`.)

Example

The following example computes and draws an interesting cell array.

```
fma()
unzoom()
x = a3 (-6,6,200)
y = transpose (x)
r = mag(y,x)
theta = arctan2 (y, x)
funky = cos(r)**2 * cos(3*theta)
pli(funky)
```



5.1.10 `pldj`: Plot Disjoint Lines

Calling Sequence

```
pldj( x0, y0, x1, y1[, <keylist>] )
```

Description

Plot disjoint lines from (*x0*,y0) to (*x1*,*y1*). *x0*, y0, *x1*, and *y1* may have any dimensionality, but all must have the same number of elements.

Keyword Arguments

The following keyword arguments can be specified with this function.

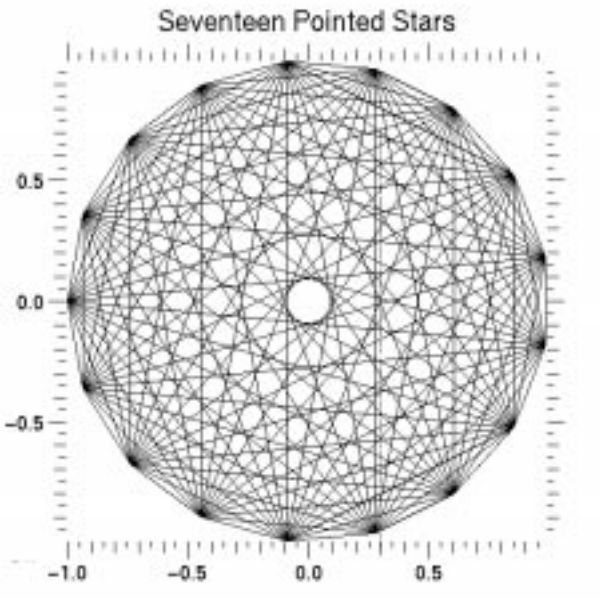
`legend, hide, type, width, color`

See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords. (See the `bytscl` function description on page 52 for explanation of `top`, `cmin`, `cmax`.)

Example

This example draws a set of seventeen-pointed stars.

```
theta = a2(0, 2*pi, 18)
x = cos(theta)
y = sin(theta)
pldj(x, y, transpose (x), transpose (y))
pltitle("Seventeen Pointed Stars")
limits(square = 1)
```



5.1.11 `plt`: Plot Text

Calling Sequence

```
plt( text, x, y[, <keylist>] )
```

Description

Plot *`text`* (a string) at the point (*x*,*y*). The exact relationship between the point (*x*,*y*) and the *`text`* is determined by the `justify` keyword. *`text`* may contain newline (`"\n"`) characters to output multiple lines of text with a single call.

The coordinates (*x*,*y*) are NDC coordinates (outside of any coordinate system) unless the `tosys` keyword is present and non-zero, in which case the *`text`* will be placed in the current coordinate system. However, the character height is *never* affected by the scale of the coordinate system to which the text belongs.

Note that the `pledit` command (see "pledit: Change Plotting Properties" on page 49) takes `dx` and/or `dy` keywords to adjust the position of existing text elements.

Keyword Arguments

The following keyword argument(s) apply only to this function.

`tosys = 0/1`

Establish the interpretation of (*x*,*y*). If `tosys=0` (the default), use Normalized Device Coordinates; if nonzero, use the current coordinate system.

```
font = <font value>
height = <float value>
opaque = 0/1
path = 0/1
orient = <integer value>
justify = (see text description)
```

Select text properties. The `font` can be any of the strings `"courier"`, `"times"`, `"helvetica"` (the default), `"symbol"`, or `"schoolbook"`. Append `"B"` for boldface and `"I"` for italic, so `"courierB"` is boldface Courier, `"timesI"` is Times italic, and `"helveticaBI"` is bold italic (oblique) Helvetica. Your X server should have the Adobe fonts (available free from the MIT X distribution tapes) for all these fonts, preferably at both 75 and 100 dpi. Occasionally, a PostScript printer will not be equipped for some fonts; often New Century Schoolbook is missing. The `font` keyword may also be an integer: 0 is Courier, 4 is Times, 8 is Helvetica, 12 is Symbol, 16 is New Century Schoolbook, and you add 1 to get boldface and/or 2 to get italic (or oblique).

The `height` is the font size in points; 14.0 is the default. X windows only has 8, 10, 12, 14, 18, and 24 point fonts, so don't stray from these sizes if you want what you see on the screen to be a reasonably close match to what will be printed.

By default, `opaque=0` and text is transparent. Set `opaque=1` to white-out a box before drawing the text.

The default path (`path=0`) is left-to-right text; set `path=1` for top-to-bottom text.

The default text justification, `justify="NN"` is normal in both the horizontal and vertical directions. Other possibilities are `"L"`, `"C"`, or `"R"` for the first character, meaning left, center, and right horizontal justification, and `"T"`, `"C"`, `"H"`, `"A"`, or `"B"` for the second character, meaning top, capline, half, baseline, and bottom vertical justification. The normal justification `"NN"` is equivalent to `"LA"` if `path=0`, and to `"CT"` if `path=1`. Common values are `"LA"`, `"CA"`, and `"RA"` for garden variety left, center, and right justified text, with the y coordinate at the baseline of the last line in the string presented to `plt`. The characters labeling the right axis of a plot are `"RH"`, so that the y value of the text will match the y value of the corresponding tick. Similarly, the characters labeling the bottom axis of a plot are `"CT"`. The justification may also be a number, *horizontal+vertical*, where *horizontal* is 0 for `"N"`, 1 for `"L"`, 2 for `"C"`, or 3 for `"R"`, and *vertical* is 0 for `"N"`, 4 for `"T"`, 8 for `"C"`, 12 for `"H"`, 16 for `"A"`, or 20 for `"B"`.

The integer value `orient` (default 0) specifies one of four angles that the text makes with the horizontal (0 is horizontal, 1 is ninety degrees, 2 is 180 degrees, and 3 is 270 degrees).

The following additional keyword arguments can be specified with this function.

`legend, hide, color`

See “Plot Function Keywords” on page 45 for detailed descriptions of these keywords.

Example

Description of example(s).

```
first line of code
middle lines of code
last line of code
```

Whatever.

5.1.12 `pltitle`: Plot a Title

Calling Sequence

```
pltitle( title )
```

Description

Plot *`title`* centered above the coordinate system for any of the standard Gist styles. You will need to customize this for other plot styles.

Example

Description of example(s).

```
first line of code
middle lines of code
last line of code
```

Whatever.

5.2 Plot Function Keywords

In addition to the keyword arguments described above with individual Gist primitive plotting commands, the following keywords are available to modify the details of the plots.

`legend = "text destined for the legend"`

Set the legend for a plot. There are no default legends in PyGist. Legends are never plotted to the X window; use the `plq` command to see them interactively. Legends will appear in hardcopy output unless they have been explicitly turned off.

Plotting Commands: `plg`, `plm`, `plc`, `plv`, `plf`, `pli`, `plt`, `pldj`

See Also: `hide`

`hide = 0/1`

Set the visibility of a plotted element. The default is `hide=0`, which means that the element will be visible. Use `hide=1` to remove the element from the plot (but not from the display list).

Plotting Commands: `plg`, `plm`, `plc`, `plv`, `plf`, `pli`,`plt`, `pldj`

See Also: `legend`

`type = <line type value>`

Select line type. Valid values are the strings `"solid"`, `"dash"`, `"dot"`, `"dashdot"`, `"dashdotdot"`, and `"none"`. The `"none"` value causes the line to be plotted as a polymarker. The type value may also be a number; 0 is `"none"`, 1 is `"solid"`, 2 is `"dash"`, 3 is `"dot"`, 4 is "`dashdot"`, and 5 is `"dashdotdot"`.

Plotting Commands: `plg`, `plm`, `plc`, `pldj`

See Also: `width`, `color`, `marks`, `marker`, `rays`, `closed`, `smooth`

`width = <floating point value>`

Select line width. Valid values are positive floating point numbers giving the line thickness relative to the default line width of one half point, which is `width = 1.0`.

Plotting Commands: `plg`, `plm`, `plc`, `pldj`, `plv` (only if `hollow=1`)

See Also: `type`, `color`, `marks`, `marker`, `rays`, `closed`, `smooth`

`color = <color value>`

Select line or text color. Valid values are the strings `"bg"`, `"fg"`, `"black"`, `"white"`, `"red"`, `"green"`, `"blue"`, `"cyan"`, `"magenta"`, `"yellow"`, or a 0-origin index into the current palette. The default is `"fg"`. Negative numbers may be used instead of the strings: -1 is `"bg"` (background), -2 is `"fg"` (foreground), -3 is black, -4 is white, -5 is red, -6 is green, -7 is blue, -8 is cyan, -9 is magenta, and -10 is yellow.

Plotting Commands: `plg`, `plm`, `plc`, `pldj`, `plt`

See Also: `type`, `width`, `marks`, `marker`, `mcolor`, `rays`, `closed`, `smooth`

`marks = 0/1`

Select unadorned lines (`marks=0`), or lines with occasional markers (`marks=1`). Ignored if `type` is `"none"` (indicating polymarkers instead of occasional markers). The spacing and phase of the occasional markers can be altered using the `mspace` and `mphase` keywords; the character used to make the mark can be altered using the `marker` keyword.

Plotting Commands: `plg`, `plc`

See Also: `type`, `width`, `color`, `marker`, `rays`, `mspace`, `mphase`, `msize`, `mcolor`

`marker = <character or integer value>`

Select the character used for occasional markers along a polyline, or for the polymarker if `type="none"`. The special values `'\1'`, `'\2'`, `'\3'`, `'\4'`, and `'\5'` stand for point, plus, asterisk, circle, and cross, which are prettier than text characters on output to some devices. The default marker is the next available capital letter: `'A'`, `'B'`, ..., `'Z'`.

Plotting Commands: `plg`, `plc`

See Also: `type`, `width`, `color`, `marks`, `rays`, `mspace`, `mphase`, `msize`, `mcolor`

```
mspace = <float value>
mphase = <float value>
msize =  <float value>
```

Select the spacing, phase, and size of occasional markers placed along polylines. The `msize` also selects polymarker size if `type` is `"none"`. The spacing and phase are in NDC units (0.0013 NDC equals 1.0 point); the default `mspace` is 0.16, and the default `mphase` is 0.14, but `mphase` is automatically incremented for successive curves on a single plot. The `msize` is in relative units, with the default `msize` of 1.0 representing 10 points.

Plotting Commands: `plg`, `plc`

See Also: `type`, `width`, `color`, `marks`, `marker`, `rays`

`mcolor =  <color value>`

The `mcolor` keyword is the same as the `color` keyword, but controls the marker color instead of the line color. Setting the `color` automatically sets the `mcolor` to the same value, so you only need to use `mcolor` if you want the markers for a curve to be a different color than the curve itself.

Plotting Commands: `plg`, `plc`

See Also: `type`, `width`, `color`, `marks`, `marker`, `rays`

`rays = 0/1`

Select unadorned lines (`rays=0`), or lines with occasional ray arrows (`rays=1`). Ignored if `type` is `"none"`. The spacing and phase of the occasional arrows can be altered using the `rspace` and `rphase` keywords; the shape of the arrowhead can be modified using the `arroww` and `arrowl` keywords.

Plotting Commands: `plg`, `plc`

See Also: `type`, `width`, `color`, `marker`, `marks`, `rspace`, `rphase`, `arroww`, `arrowl`

`closed = 0/1`
`smooth = 0/1/2/3/4`

Select closed curves (`closed=1`) or default open curves (`closed=0`), or Bezier smoothing (`smooth>0`) or default piecewise linear curves (`smooth=0`). The value of `smooth` can be 1, 2, 3, or 4 to get successively more smoothing. Only the Bezier control points are plotted to an X window; the actual Bezier curves will show up in PostScript hardcopy files. Closed curves join correctly, which becomes more noticeable for wide lines; non-solid closed curves may look bad because the dashing pattern may be incommensurate with the length of the curve.

PLOTTING COMMANDS: `plg`, `plc` (`smooth` only)

SEE ALSO: `type`, `width`, `color`, `marks`, `marker`, `rays`

`region = <region number>`

Select the part of mesh to consider. The region should match one of the numbers in the `ireg` array. Putting `region=0` (the default) means to plot the entire mesh; that is, everything EXCEPT region zero (non-existent zones). Any other number means to plot only the specified region number; `region=3` would plot region 3 only.

Plotting Commands: `plm`, `plc`, `plv`, `plf`

CHAPTER 6: Inquiry and Miscellaneous Functions

This chapter describes functions that are available to inquire about the state of PyGist control variables and set their values. It also describes other miscellaneous functions.

6.1 Inquiry and Editing Functions

6.1.1 `plq`: Query Plot Element Status

Calling Sequence

```
plq()
legend_list = plq() **** RETURN VALUE NOT YET IMPLEMENTED ****
plq( n_element[, n_contour] )
properties = plq(n_element[, n_contour])
```

Description

Called as a subroutine, `plq` prints the list of legends for the current coordinate system (with an `"(H)"` to mark hidden elements), or prints a list of current properties of element *`n_element`* (such as line type, width, font, etc.), or of contour number *`n_contour`* of element number *`n_element`* (which must be contours generated using the `plc` command). Elements and contours are both numbered starting with one; hidden elements or contours are included in this numbering.

The `plq` function always operates on the current coordinate system in the current graphics window; use `window` and `plsys` to change these.

6.1.2 `pledit`: Change Plotting Properties

Calling Sequence

```
pledit( [n_element[, n_contour],] <keylist> )
```

where, as usual, `<keylist>` has the form `key1=`*`value1`*`, key2=`*`value2`*`, ...`

Description

`pledit` changes some property or properties of element number *`n_element`* (and contour number *`n_contour`* of that element). If *`n_element`* and *`n_contour`* are omitted, the default is the most recently added element, or the element specified in the most recent `plq` query command.

The keywords can be any of the keywords that apply to the current element. These are:

```
plg:  color, type, width, marks, mcolor, marker,
      msize, mspace, mphase, rays, rspace, rphase, arrowl,
      arroww, closed, smooth
plm:  region, boundary, inhibit, color, type, width
plc:  region, color, type, width, marks, mcolor, marker,
      msize, mspace, mphase, smooth, levs
```

(For contours, if you aren't talking about a particular *`n_contour`*, any changes will affect ALL the contours.)

```
plv:  region, color, hollow, width, aspect, scale
plf:  region
pldj: color, type, width
plt:  color, font, height, path, justify, opaque
```

A `plv` (vector field) element can also take the `scalem` keyword to multiply all vector lengths by a specified factor.

A `plt` (text) element can also take the `dx` and/or `dy` keywords to adjust the text position by (dx,dy).

6.1.3 `pldefault`: Set Default Values

Calling Sequence

```
pldefault( key1=value1, key2=value2, ... )
```

Description

Set default values for the various properties of graphical elements.

The keywords can be most of the keywords that can be passed to the plotting commands:

```
plg:  color, type, width, marks, mcolor, msize, mspace,
      mphase, rays, rspace, rphase, arrowl, arroww
plm:  color, type, width
plc:  color, type, width, marks, mcolor, marker, msize,
      mspace, mphase
plv:  color, hollow, width, aspect
plf:  edges, ecolor, ewidth
pldj: color, type, width
plt:  color, font, height, path, justify, opaque
```

The initial default values are:

```
color="fg", type="solid", width=1.0 (1/2 point),
marks=1, mcolor="fg", msize=1.0 (10 points), mspace=0.16,
     mphase=0.14,
rays=0, arrowl=1.0 (10 points), arroww=1.0 (4 points), rspace=0.13,
     rphase=0.11375,
font="helvetica", height=12.0, path=0, justify="NN",
     opaque=0,
hollow= 0, aspect=0.125,
edges=0, ecolor="fg", ewidth=1.0 (1/2 point)
```

Additional default keywords are:

`dpi, style, legends`	(see `window` command)
`palette`	(to set default `filename` as in `palette` command)
`maxcolors`	(default 200)

6.2 Miscellaneous Functions

6.2.1 `bytscl`: Convert to Color Array

Calling Sequence

```
bytscl( z[, top=max_byte][, cmin=lower_cutoff]
          [, cmax=upper_cutoff] )
```

Description

`bytscl` returns an unsigned char array of the same shape as *z*, with values linearly scaled to the range 0 to one less than the current palette size. If *max_byte* is specified, the scaled values will run from 0 to *max_byte* instead.

If *lower_cutoff* and/or *upper_cutoff* are specified, *z* values outside this range are mapped to the cutoff value; otherwise the linear scaling maps the extreme values of *z* to 0 and *max_byte*.

6.2.2 histeq_scale: Histogram Equalized Scaling

**** NOT YET IMPLEMENTED ****

Calling Sequence

```
histeq_scale(z[, top=top_value][, cmin=cmin][, cmax=cmax] )
```

Description

`histeq_scale` returns a byte-scaled version of the array *z* having the property that each byte occurs with equal frequency (*z* is histogram equalized). The result bytes range from 0 to *top_value*, which defaults to one less than the size of the current palette (or 255 if no `pli`, `plf`, or `palette` command has yet been issued).

If non-nil *cmin* and/or *cmax* is supplied, values of *z* beyond these cutoffs are not included in the frequency counts.

6.2.3 `mesh_loc`: Get Mesh Location

Calling Sequence

```
mesh_loc( y0, x0[, y, x[, ireg]] )
```

Description

`mesh_loc` returns the zone index (`=i+imax*(j-1)`) of the zone of the mesh (*x*,*y*) (with optional region number array *ireg*) containing the point (*x0*,*y0*). If (*x0*,*y0*) lies outside the mesh, returns 0. For example, *ireg*`(mesh_loc(`*x0*`,`*y0*`,`*y*`,`*x*`,`*ireg*`))` is the region number of the region containing (*x0*,*y0*). If no mesh specified, uses default. *x0* and *y0* may be arrays as long as they are conformable.

6.2.4 `mouse`: Handle Mouse Click

This function is useful in developing interactive graphics applications.

Calling Sequence

```
result = mouse(system, style, prompt)
```

Description

`mouse` displays the specified *prompt*, then waits for a mouse button to be pressed, then released. It returns a tuple of length eleven:

```
result = [x_pressed, y_pressed, x_released, y_released,
          xndc_pressed, yndc_pressed, xndc_released,
          yndc_released, system, button, modifiers]
```

If *system*`>=0`, the first four coordinate values will be relative to that coordinate system. For *system*`<0`, the first four coordinate values will be relative to the coordinate system under the mouse when the button was pressed.

The second four coordinates are always normalized device coordinates, which start at (0,0) in the lower left corner of the 8.5x11 sheet of paper the picture will be printed on, with 0.0013 NDC unit being 1/72.27 inch (1.0 point). Look in the style sheet for the location of the viewport in NDC coordinates (see the `style` keyword).

If *style* is 0, there will be no visual cues that the `mouse` command has been called; this is intended for a simple click. If *style* is 1, a rubber band box will be drawn; if *style* is 2, a rubber band line will be drawn. These disappear when the button is released.

Clicking a second button before releasing the first cancels the mouse function, which will then return nil. Ordinary text input also cancels the mouse function, which again returns nil.

The left button reverses forground for background (by XOR) in order to draw the rubber band (if any). The middle and right buttons use other masks, in case the rubber band is not visible with the left button.

`result[8]` is the coordinate system in which the first four coordinates are to be interpreted.

`result[9]` is the button which was pressed, 1 for left, 2 for middle, and 3 for right (4 and 5 are also possible).

`result[10]` is a mask representing the modifier keys which were pressed during the operation:

1 for shift, 2 for shift lock, 4 for control, 8 for mod1 (alt or meta), 16 for mod2, 32 for mod3, 64 for mod4, and 128 for mod5.

6.2.5 `moush`: Mouse in a Mesh

Calling Sequence

```
moush( [y, x[, ireg]] )
```

Description

`moush` returns the 1-origin zone index for the point clicked in for the default mesh, or for the mesh (*x*,*y*) (region array *ireg*).

6.2.6 `pause`: Pause

Calling Sequence

```
pause( milliseconds )
```

Description

Pause for the specified number of milliseconds of wall clock time, or until input arrives from the keyboard. This is intended for use in creating animated sequences.

Examples

Description of example(s).

```
first line code
middle lines of code
last line of code
```

Whatever.

CHAPTER 7: Three-Dimensional Plotting Functions

The PyGist 3-D graphics uses the PyGist 2-D graphics to draw its pictures; most of the 3-D routines are computational, and take 3-D data in one form or another and massage it until, when plotted, it will appear to be a correct two-dimensional projection of a three-dimensional graph. The usual order of operation in 3-D PyGist is

- retrieve or compute your data;
- tell PyGist orientation and lighting information;
- call the appropriate PyGist computational routines;
- call one or more PyGist 3-D plotting routines;
- call the master function `draw3`, which actually displays the graph.

PyGist builds a list of information about the graph which you wish to plot, but in its normal operating mode, does not actually draw the graph until you ask it to do so, by invoking `draw3`. Meanwhile, it stores the information about the graph in a Python list. In this chapter we shall describe the contents of this list in general terms, and the commands which you use to build it (orientation and lighting functions); the setup functions for complicated 3-D plots; and the plotting functions themselves. In a final section, for people who may some day be maintaining or adding to this code, we describe the auxiliary functions which everyday users will seldom if ever use.

7.1 Setting Up For 3-D Graphics

7.1.1 The Plotting List

The 3-D PyGist graphics keeps an internal list called `_draw3_list` containing complete information about the currently active frame (which may or may not be visible depending on whether `draw3` has been invoked). Regular users should never need to access this list; however, there is an access function available called `get_draw3_list_` which code developers and maintainers may use to get at the list; `get_draw3_n_` returns the number of elements in the viewing and lighting portion of the list, described below. Likewise, ordinary users do not really need to know the structure of this list in detail; however, every user of the 3-D graphics should be aware of the contents of the list, how it affects the graph, and what functions to use to alter it.

`_draw3_list` is a Python list, organized as follows:

```
[rotation, origin, camera_dist, ambient, diffuse, specular,
spower, sdir, fnc1, args1, fnc2, args2,...]
```

The elements of this list are divided into the *viewing* transformation, *lighting* specifications, and *display* information, as follows:

Viewing:

`rotation`: a 3-by-3 rotation matrix giving the angles of view.
`origin`: a 3-vector giving the coordinates of the origin in the user's coordinate system.
`camera_dist`: A real number giving the camera distance; the value `None` (the default) translates to infinity.

Lighting:

`ambient`: a light level (in arbitrary units) that is added to every part of the surface regardless of its orientation. It might be said to be the amount of light which a surface exudes on its own. A surface with `ambient` of 0 is totally black unless illuminated.
`diffuse`: a light level which is proportional to cos(theta), where theta is the angle between the surface normal and the viewing direction, so that surfaces directly facing the viewer are bright, while surfaces viewed edge on are unlit (and surfaces facing away, if drawn, are shaded as if they faced the viewer).
`specular`: a light level proportional to a high power **`spower`** of 1 + cos (alpha), where alpha is the angle between the specular reflection angle and the viewing direction. The light source for the calculation of alpha lies in the direction **`sdir`** (a 3 element vector) in the viewer's coordinate system at infinite distance. You can have `ns` light sources by making `specular`, `spower`, and `sdir` (or any combination) be vectors of length `ns` (3-by-`ns` in the case of `sdir`).

Display:

$\texttt{fnc}_1$, $\texttt{fnc}_2$, etc.: Plotting function(s) (whose argument lists are $\texttt{arg}_1$, $\texttt{arg}_2$, etc., respectively) defining the component(s) of this graph. During its normal operating mode, the 3-D graphics accumulates information about calls to plotting functions until the user calls the function `draw3`. These calls are then executed when `draw3` is invoked.

7.1.2 Functions For Setting Viewing Parameters

Angular orientation

$\texttt{orient3 (phi = angle}_1\texttt{, theta = angle}_2\texttt{)}$
$\texttt{rot3 (xa = angle}_x\texttt{, ya = angle}_y\texttt{, za = angle}_z\texttt{)}$

Description

Note that most of the functions in 3-D PyGist accept keyword arguments. These arguments may be entered in any order; omitted arguments will default to a sensible value.

`orient3` sets the orientation of the object to ($\texttt{angle}_1$, $\texttt{angle}_2$). Orientations are a subset of the

possible rotation matrices in which the z axis of the object appears vertical on the screen (that is, the object z axis projects onto the viewer y axis). The `theta` angle is the angle from the viewer y axis to the object z axis, positive if the object z axis is tilted towards you (toward viewer +z). `phi` is zero when the object x axis coincides with the viewer x axis. If neither `phi` nor `theta` is specified, `phi` defaults to `- pi / 4` and `theta` defaults to `pi / 6`. If only `phi` is specified, `theta` remains unchanged, unless the current `theta` is near `pi / 2`, in which case `theta` returns to `pi / 6`, or unless the current orientation does not have a vertical z axis, in which case theta returns to its default. If only `theta` is specified, `phi` retains its current value. Unlike `rot3`, `orient3` is not a cumulative operation.

`rot3` rotates the current 3D plot by $\texttt{angle}_x$ about viewer's x axis, $\texttt{angle}_y$ about viewer's y axis, and $\texttt{angle}_z$ about viewer's z-axis.

Physical orientation

```
mov3 (xa = val1, ya = val2, za = val3)
aim3 (xa = val1, ya = val2, za = val3)
setz3 (zc = dist)
```

Description

`mov3` moves the current 3D plot by $\texttt{val}_1$ along the viewer's x axis, $\texttt{val}_2$ along the viewer's y axis, and $\texttt{val}_3$ along the viewer's z axis. `aim3` moves the current 3D plot to put the point ($\texttt{val}_1$, $\texttt{val}_2$, $\texttt{val}_3$) in object coordinates at the point (0, 0, 0) -- the aim point -- in the viewer's coordinates. In both functions, if any of the $\texttt{val}_1$, $\texttt{val}_2$, or $\texttt{val}_3$ is missing, it defaults to 0.

`setz3` sets the camera position to `dist` (x = y = 0) in the viewer's coordinate system. If `dist` is `None` or if `zc` is missing, set the camera to infinity (default).

Examples

Our examples are postponed until later in the chapter, when we have covered enough material to give complete sequences of computations and PyGraph function calls, and show the resulting plots.

7.1.3 Lighting Parameters

Calling Sequence

```
light3 (ambient=a_level, diffuse=d_level, specular=s_level,
   spower=n, sdir=xyz)
```

This function is used to set the lighting parameters for the current drawing list.

7.1.4 Display List

Calling Sequences

```
<plot function> (arg1, arg2, arg3, ...)
clear3 ( )
```

When one of the plotting functions (`plwf`, `pl3surf`, `pl3tree`) is called and the internal variable `_draw3` has been set to zero, or else if it is nonzero and the idler is a do-nothing routine, Then this plot call will add `<plot function>` to the display list, and will process the arguments into a Python list, which will be added to the display list after the function name.

The function `clear3` clears the display list of all plotting functions. It leaves orientation and lighting information unchanged.

7.2 3-D Graphics Control Functions

7.2.1 Getting a Window

Calling Sequence

```
window3 ( [n] [, dump = val] [, hcp = filename])
```

Description

If `n` is specified, make window `n` the active window (open a window if necessary). If `n` is not specified, connect to the active window, or open one if none is active. Associate the hardopy file named `filename` with the window if `hcp` is specified; this will be postscript if the name ends in `.ps`, or cgm if it ends in `.cgm`. The style sheet associated with the window will be `"nobox.gs"`, i. e., a plain window with no axes (except possibly a gnomon). The `dump` keyword, if 1, causes the color palette to be dumped to the hcp file with each frame that is sent there (otherwise hardcopy plots will be in greyscale).

7.2.2 Displaying the Gnomon

Webster's defines a *gnomon* as ''an object that by its position...serves as an indicator.'' In 3-D PyGist, the gnomon is a small diagram of the coordinate axes that appears in the lower left corner of a 3-D plot, if this capability has been turned on.

Calling Sequence

```
gnomon ( [onoff] [, chr = <labels>] )
set_default_gnomon ( [onoff])
```

Description

gnomon toggles the gnomon display if onoff is omitted. If onoff is present and non-zero turn on the gnomon. If zero, turn it off. set_default_gnomon allows the user to specify what the default gnomon is to be when the default idler is called (see the discussion in “The variable _draw3 and the idler” on page 60, and “The Default Idler” on page 60.)

The gnomon shows the x, y, and z axis directions in the object coordinate system. The directions are labeled. The labels default to X, Y, and Z, but may be specified to be something else by using the keyword chr. <labels> must be a Python list consisting of three character strings.The gnomon is always infinitely far behind the object (away from the camera).

There is a mirror-through-the-screen-plane ambiguity in the display which is resolved in two ways: (1) the (x, y, z) coordinate system is right-handed, and (2) If the tip of an axis projects into the screen, its label is drawn in opposite polarity to the other text in the screen.

7.2.3 Plotting the Display List

The only way that the display list can be plotted is by an invocation of the function draw3. The user may control when this function gets called. To have a new plot appear totally under user control, set _draw3 to 0 (i. e., execute set_draw3_ (0)) and then call draw3 only when you want the plot to appear. To have a plot appear automatically after each plot command is given, _draw3 should be set to 1 and the idler should be set to some function which calls draw3. The details are in “The variable _draw3 and the idler” on page 60.

Calling Sequence

```
[lims = ] draw3 ( [called_as_idler = <val>])
limits (lims [0], lims [1], lims [2], lims [3])
```

Description

The function draw3 traverses the display list and executes each function on the list with the list of arguments supplied. Assuming that the list is not empty, this means that the frame specified by this list will be displayed. If the parameter called_as_idler is present and is nonzero, then a fma (frame advance) call will be made first, meaning that the current display will be erased before the new one is plotted. Otherwise the new display will appear on top of the old.

draw3 always attempts to return a list of four items [xmin, xmax, ymin, ymax] which give the maximum and minimum of the x and y coordinates actually plotted to the PyGist window. Calling the limits function with these four values as limits will scale the graph properly. One could also perform computations with these limits (for example, to force x and y to the same scale, or to shrink the graph a little to force it well inside the borders of the window). If you like the way your graphs look, then there is no reason to deal with these numbers.

We apologize for this messy kludge; we have encountered timing problems and other difficulties with the Gist limits calculating process which we have not been able to solve except by computing our own limits.

7.2.4 The variable _draw3 and the idler

_draw3 is an internal 3-D PyGist variable accessible to the user only by means of the access functions described below. _draw3, in conjunction with a function called an idler, determines whether, after a plot function and its arguments have been placed on the display list, some further action takes place. The *default idler* (see below) will cause the graph to be plotted each time it is called; and it will be called immediately after the plot function has been added to the display list, provided _draw3 is nonzero.

Calling Sequences for _draw3 Access Functions

```
set_draw3 (n)
n = get_draw3 ( )
```

Description

The first function is used to set _draw3 to n (default 0), and the second, to read its current setting.

Calling Sequences to Set Idlers

```
clear_idler ( )
set_idler (func_name)
set_default_idler ( )
call_idler ( )
```

Description

The function clear_idler sets the idler function to a routine which does nothing. It will be called after each plot function adds to the display list (if _draw3 is nonzero), but will do nothing. set_idler allows the user to define an action for 3-D PyGist to take after each plot function call adds to the display list. func_name must be callable with no arguments. It will be called only if _draw3 is nonzero. set_default_idler will set the idler to call the function whose code is given below. call_idler gives you the capability to call the idler yourself, if you wish.

The Default Idler

Below is the code for the default idler.

```
def _draw3_idler ( ) :
   global _default_gnomon
   orient3 ()
   if current_window () == -1 :
      window3 (0)
   else :
      window3 (current_window ())
   gnomon (_default_gnomon)
   lims = draw3 (1)
```

```
if lims == None :
   return
else :
   limits (lims [0], lims [1], lims [2], lims [3])
```

7.3 Data Setup Functions for Plotting

7.3.1 Creating a Plane

Calling Sequence

```
plane3 (<normal>, <point>)
```

Description

This function returns the coefficients of the equation of a plane as a vector of length four. This is the form of a plane argument as expected by the slicing functions. `<normal>` is a vector of length three giving the direction numbers of the normal to the plane; `<point>` is a vector of length three giving the coordinates of a point in the plane.

7.3.2 Creating a `mesh3` argument

The function `mesh3` is used to create a `mesh3` object from your data. A `mesh3` object is required as an input to a number of routines, most importantly, the various slicing functions.

Calling Sequence (1)

```
mesh3 (x, y, z)
mesh3 (x, y, z, funcs = [f1, f2, ...], [verts = <spec>])
```

Description

`mesh3` creates a `mesh3` object as expected by the various functions `slice3`, `xyz3`, `getv3`, etc. The form of a `mesh3` object will be described below (See “Description of a mesh3 object” on page 63). Note that Python is able to determine which of the above calls is intended because it can check for the presence of optional and keyword arguments and can check the dimensions and types of the arguments.

In the first two forms of the call, `x`, `y`, and `z` are coordinate arrays specifying the mesh. If `x`, `y`, and `z` are three dimensional of the same shape, then they represent the coordinates of the vertices of a regular rectangular mesh. If `x`, `y`, and `z` are one dimensional of the same size, then the keyword argument verts determines how they are interpreted. If `verts` is not present, then we have a structured reectangular mesh with unequally spaced nodes. If `verts` is present, then they represent the coordinates of an unstructured mesh, and the keyword argument `verts` must be used to pass information about the cells to the `mesh3` function. `<spec>` can be either a single two dimensional array of integer subscripts into `x`, `y`, and `z`, or a Python list of up to four such objects, one for each type of cell in the mesh. The

format of the two dimensional array for each type of cell shape is as follows:

- hexahedra: the array is `no_hex_cells` by 8. The first subscript is the hexahedron cell number; for each value of this subscript, the second indexes the vertices in canonical order (the first side in outward normal order, the opposite side's correcponding vertices in inward normal order).
- prisms: the array is `no_prism_cells` by 6. The first subscript is the prism cell number; for each value of this subscript, the second indexes the vertices in canonical order (the first side in outward normal order, the opposite side's correcponding vertices in inward normal order).
- pyramids: the array is `no_pyr_cells` by 5. The first subscript is the pyramid cell number; for each value of this subscript, the second indexes first the apex, then the vertices of the base in inward normal order.
- tetrahedra: the array is `no_tet_cells` by 4. The first subscript is the tetrahedron cell number; for each value of this subscript, the second indexes first some arbitrary cell as the apex, then the vertices of the base in inward normal order.

Each type of cell has a relative cell number running from 0 to `no_celltype_cells - 1`. The cells are also assumed to have absolute cell numbers, which depend on the order in which the defining arrays appear, but will run consecutively starting from 0 in the first cell of the first type up to the total number of cells `- 1` for the last cell of the last type.

The optional keyword `funcs` defines `f1`, `f2`, etc., which are arrays of function values (e.g. density, temperature) defined on the mesh. In the case of a regular (or structured) rectangular mesh, these functions are 3-D arrays. If they represent cell-centered data, they will have one less value along each dimension than the coordinate arrays. If they are vertex-centered data, then they will have the same dimensions. In the case of an unstructured mesh, `f1`, `f2`, etc. are one-dimensional arrays. If they represent cell-centered data, then they are indexed by the absolute cell number, and must be the same length as the number of cells. If they represent vertex-centered data, then they are indexed the same as the vertices, and must be the same length as the vertex arrays.

Calling Sequence (2)

```
mesh3 (xyz, funcs = [f1, f2, ...])
```

Description

In this case `xyz` is a four dimensional array specifying the mesh; `xyz [0]` is the three dimensional `x` coordinate, `xyz [1]` is the three dimensional `y` coordinate, and `xyz [2]` is the three dimensional `z` coordinate. (`mesh3` actually converts the `x`, `y`, `z` arguments of the first two calls into this `xyz` form in a `mesh3` object; see "Description of a mesh3 object" on page 63. The `funcs` keyword operates as previously described.

Calling Sequence (3)

```
mesh3 (nxnynz, dxdydz, x0y0z0, funcs = [f1, f2, ...])
```

Description

nxnynz is a vector of 3 integers, specifying the number of *cells* of a uniform 3D mesh in the x, y, and z directions, respectively. dxdydz is an array of three reals, specifying the size of the entire mesh, not the size of one cell, in each of the three directions, and x0y0z0 is an array of three reals, representing the point of minimum x, y, and z where the mesh begins. The funcs keyword operates as previously described.

Description of a mesh3 object

The form of a mesh3 object varies according to whether the mesh specified was uniform, structured, or unstructured.

Uniform case, node equally spaced:

```
[[xyz3_unif, getv3_rect, getc3_rect, iterator3_rect],
[ (nxnynz [0], nxnynz [1], nxnynz [2]),
array ( [dxdydz, x0y0z0])], [f1, f2, ...]]
```

The four items in the first list are the names of functions. The details of these need not concern us at this time except in their broad outlines. The iterator3 function will split the mesh into chunks for processing by the slicing functions, if necessary, in order to save space. xyz3 returns the vertex coordinates of a chunk. getv3 returns the vertex values of a function on the chunk; getc3 returns cell values. Because these routines necessarily differ depending on the type of mesh, their names are passed along with the mesh specifications to that the apporopriate ones can be called. The remainder of the items in the object specify the mesh and the function(s) defined on the mesh (if any; if there are none, the final list will be []).

Uniform case, nodes unequally spaced:

```
[[xyz3_unif, getv3_rect, getc3_rect, iterator3_rect],
[ (len (x) - 1, len (y) - 1, len (z) - 1),
array ( [x, y, z])], [f1, f2, ...]]
```

The functions' purpose is as described above. x, y, and z are one-dimensional arrays, possibly of different lengths, specifying the node coordinates of a uniform rectangular mesh, which might be unequally spaced. The triple consisting of the three array lengths minus one gives the size of the mesh in cells.

Structured case:

```
[[xyz3_rect, getv3_rect, getc3_rect, iterator3_rect],
[dim_cell, xyz], [f1, f2, ...]]
```

The functions' purpose is as described above. dim_cell is an integer vector of length three giving the size of the mesh in cells, dim_cell [0] being the x direction size, dim_cell [1] the y, and dim_cell [2] the z. xyz is a four dimensional array of coordinates; xyz [0] is the three dimensional x coordinate array, xyz [1] is the three dimensional y coordinate array, and xyz [2] is the three dimensional z coordinate array.

Unstructured case:

```
[[xyz3_irreg, getv3_irreg, getc3_irreg, iterator3_irreg],
[dims, array ( [x, y, z]), sizes, totals], [f1, f2, ...]]
```

The functions' purpose is as described above. `dims` is the value of the keyword argument `verts`, i. e., it represents one array, or a list of up to four arrays, specifying the subscripts of the cell vertices into arrays `x`, y, and `z` in canonical order. If there is only one type of cell in the unstructured mesh, then `sizes` and `totals` will not be present; otherwise, they are used to help recover the absolute cell number from a cell's index in the list of cells of the same type. `sizes [i]` is the number of cells of type `i`; `totals [i]` is the total number of cells up to and including type `i`.

7.4 The Slicing Functions

The slicing functions must be called in order to create data appropriate for the `pl3surf` (plot a 3-D surface) and `pl3tree` (add a plot to a tree) routines. In general, the slicing routines take a mesh specification of some sort and return a list of the form

```
[nverts, xyzverts, color]
```

which specifies a set of polygonal cells and how to color them.

`nverts` is `no_cells` long and the i^{th} entry tells how many vertices the i^{th} cell has.

`xyzverts` is `sum (nverts)` by `3` and gives the vertex coordinates of the cells in order, i. e., the first `nverts [0]` entries in `xyzverts` are the coordinates of the first polygon's vertices, the next `nverts [1]` entries are the coordinates of the second polygon's vertices, etc.

`color`, if present, is `no_cells` long and contains a color value for each cell in the mesh.

7.4.1 `slice3mesh`: Pseudo-slice for a surface

The function `slice3mesh` is designed specifically to produce an input argument for `pl3surf`, although if you want more than one surface in a picture, it can also be fed to `pl3tree`. It has several distinct calling sequences, which Python can distinguish with its type savvy.

Calling Sequence (1)

```
slice3mesh (z [, color])
```

Description

`z` is a two dimensional array of function values, assumed to be on a uniform mesh `nx` by `ny` cells (assuming `z` is `nx` by `ny`) `nx` being the number of cells in the `x` direction, `ny` the number in the `y` direction. `color`, if specified, is either an `nx` by `ny` array of cell-centered values by which the surface is to be colored, or an `nx + 1` by `ny + 1` array of vertex-centered values, which will be averaged over each cell to give cell-centered values.

Calling Sequence (2)

```
slice3mesh (nxny, dxdy, x0y0, z [, color])
```

Description

In this case, `slice3mesh` accepts the specification for a regular 2-D mesh: `nxny` is the number of cells in the `x` direction and the `y` direction; `x0y0` are the initial values of `x` and `y`; and `dxdy` are the *increments* in the two directions. `z` is the height of a surface above the `xy` plane and must be dimensioned `nx + 1` by `ny + 1`. `color`, if specified, is as above.

Calling Sequence (3)

```
slice3mesh (x, y, z [, color])
```

Description

`z` is as above, an `nx` by `ny` array of function values on a mesh of the same dimensions. There are two choices for `x` and `y`: they can both be one-dimensional, dimensioned `nx` and `ny` respectively, in which case they represent a mesh whose edges are parallel to the axes; or else they can both be `nx` by `ny`, in which case they represent a general quadrilateral mesh.

Examples

Postponed until later in the chapter.

7.4.2 `slice3`: Plane and Isosurface Slices of a 3-D mesh

Calling Sequence

```
[nverts, xyzverts, color] = \
   slice3 (m3, fslice, nv, xyzv [, fcolor [, flg1]]
   [, value = <val>] [, node = flg2])
```

Description

Slice the 3-D mesh `m3` as specified by `fslice`, returning the list `[nverts, xyzverts, color]`. `nverts` is the number of vertices in each polygon of the slice, and `xyzverts` is the `3`-by-`sum (nverts)` list of polygon vertices. If the `fcolor` argument is present, the values of that coloring function on the polygons are returned as the value of `color`. `color` will have the same size as `nverts`, i. e., the number of polygons in the slice, except that the keyword argument `node`, if present and nonzero, is a signal to return node-centered values rather than cell-centered values. In the latter case `color` will be `sum (nverts)` long and entries in `color` will be associated with the corresponding coordinates in `xyzverts`. `nv` and `xyzv` are not needed; `None` should be passed as their values (this is a leftover from an older version of the code).

`fslice` can be a function, a vector of 4 reals, or an integer number. If `fslice` is a function, it

should be of the form:

```
def fslice (m3, chunk)
```

or, in the case of an isosurface slice,

```
def fslice (m3, chunk, iso_index, _value)
```

or for a plane slice,

```
def fslice (m3, chunk, normal, projection)
```

and should return a list of function values on the specified chunk of the mesh `m3`. Module `slice3` offers plane and isosurface slicers (for descriptions, see page 110). If you wish to write your own slice routine, you should bear in mind that the format of `chunk` depends on the type of `m3` mesh, so you should use only the approriate mesh functions `xyz3` and `getv3` which take that type of `m3` and `chunk` as arguments. The return value of `fslice` should have the same dimensions as the return value of `getv3`; the return value of `xyz3` has an additional first dimension of length 3.

If `fslice` is a list of 4 reals, it is taken as a slicing plane as returned by `plane3`.

If `fslice` is a single integer, the slice will be an isosurface for the `fslice`th function associated with the mesh `m3`. In this case, the keyword `value` must also be present, representing the value of that function on the isosurface.

If `fcolor` is omitted or has value `None`, then `slice3` returns `None` as the value of `color`.. If you want to color the polygons in a manner that depends only on their vertex coordinates (e. g., by a 3-D shading calculation), use this mode.

`fcolor` can be a function or a single integer. If `fcolor` is a function, it should be of the form:

```
def fcolor (m3, cells, l, u, fsl, fsu, ihist)
```

and should return a list of function values on the specified cells of the mesh `m3`. If the optional argument `flg`$_1$ after `fcolor` is not missing or `None` and is non-zero, then the `fcolor` function is called with only two arguments:

```
def fcolor (m3, cells)
```

The `cells` argument will be the list of cell indices in `m3` at which values are to be returned. `l`, `u`, `fsl`, `fsu`, and `ihist` are interpolation coefficients which can be used to interpolate from vertex centered values to the required cell centered values, ignoring the `cells` argument. See `getc3` source code. The return values should always have the same size and shape as `cells`.

If `fcolor` is a single integer, then the slice will be an isosurface for the `fcolor`th variable associated with the mesh `m3`.

7.4.3 `slice2` and `slice2x`: Slicing Surfaces with planes

The functions `slice2` and `slice2x` allow one to slice surfaces specified by `slice3`-type output. `slice2` will return the portion on one side of the slicing plane; `slice2x` will return both portions.

Calling Sequences

```
[nverts, xyzverts, values] = slice2 (plane, nv,
     xyzv, vals)
[nverts, xyzverts, values, nvertb, xyzvertb, valueb] =
     slice2x (plane, nv, xyzv, vals)
```

Description

The argument `plane` can be either a scalar or a `plane3` (see “Creating a Plane” on page 61); `nv` is an array of integers, the i^{th} entry of which gives the number of vertices of the i^{th} polygonal cell; `xyzv` are the vertices of the coordinatesof the cells, with each consecutive `nv [i]` entries representing the vertices of the i^{th} cell; and `vals` being a set of values as explained below. These arguments are the same format as returned by `slice3` and `slice3mesh`.

If `plane` is a `plane3`, then `vals` (if not `None`) is a cell-centered set of values expressing the color of each cell, and the outputs `nverts`, `xyzverts`, and `values` represent the polygons and their colors (if any) describing the portion of the sliced surface that is on the positive side of the plane. That’s all you get with `slice2`. With `slice2x`, you get in addition `nvertb`, `xyzvertb`, and `valueb`, which describe the part of the surface on the negative side of the slicing plane. Warning: one of these specifications could be `None`, `None`, `None` if the entire surface lies on one side of the plane.

If `plane` is a scalar value, then `vals` must be present and must be node-centered. In this case, the outputs `nverts`, `xyzverts`, and `values` represent the polygons and their colors (if any) describing the portion of the sliced surface where `vals` on the vertices are greater than or equal to the scalar value `plane`. (This actually allows you to form an arbitrary two-dimensional slice of a surface.) With `slice2x`, you get in addition `nvertb`, `xyzvertb`, and `valueb`, which describe the part of the surface where `vals` on the vertices are less than the scalar value `plane`.

7.5 At Last - the 3-D Plotting Functions

7.5.1 `plwf`: plot a wire frame

Calling Sequence

```
plwf (z [, y, x] [, <keylist>] )
```

Description

`plwf` plots a 3-D wire frame of the given 2-D array `z`. If `x` and `y` are given, then they must be the same shape as `z` or else `len (x)` should be the first dimension of `z` and `len (y)` the second. If `x` and `y` are not given, they default to the first and second indices of `z`, respectively. `plwf` calls `clear3` before putting the plot command on the display list, which means that PyGist can only show one wire frame at a time using this function. (See `pl3tree` for graphs with multiple components).

`plwf` accepts the following keyword arguments:

`fill, shade, edges, ecolor, ewidth, cull, scale, cmax`

A description of the keywords follows:

`fill`: optional colors to use (default is to make zones have background color), same dimension options as for z argument to plf function, i. e., it should be the same dimension as the mesh (vertex-centered values) or one smaller in each dimension (cell-centered values).

`shade`: set non-zero to compute shading from the current 3-D lighting sources.

`edges`: default is 1 (draw edges), but if you provide fill colors, you may set to 0 to supress the edges.

`ecolor`, `ewidth`: color and width of edges.

`cull`: default is 1 (cull back surfaces), but if you want to see the ‘‘underside’’ of the model, set to 0.

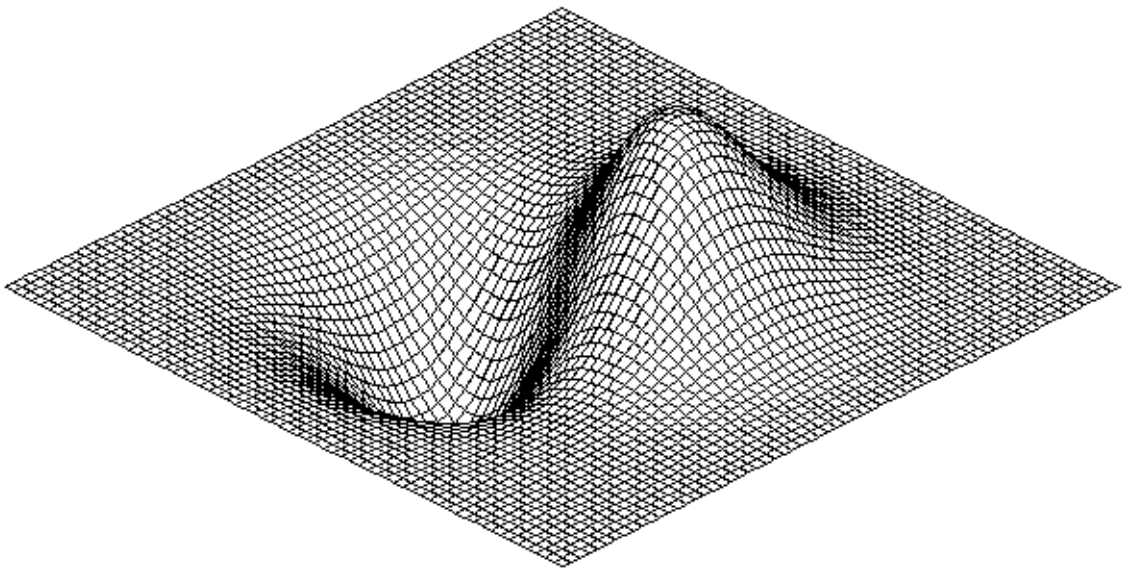
`scale`: by default, `z` is scaled to ‘‘reasonable’’ maximum and minimum values related to the scale of `(x, y)`. This keyword alters the default scaling factor, in the sense that `scale = 2.0` will produce twice the `z`-relief of the default `scale = 1.0`.

`cmax`: the `ambient` keyword in `light3` can be used to control how dark the darkest surface is; use this to control how light the lightest surface is. The `lightwf` routine can change this parameter interactively.

Examples

The following example computes the information for a surface with a peak and a valley, and then plots the resulting wire frame with various options. In the first case, we see simply an opaque wire frame.

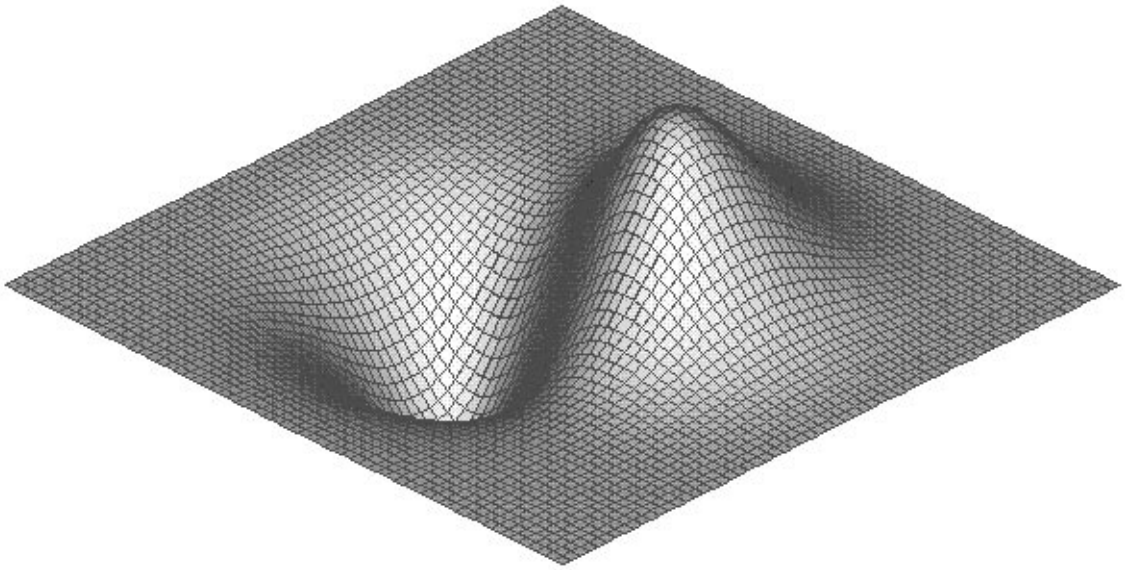
```
set_draw3_ (0)
x = span (-1, 1, 64, 64)
y = transpose (x)
z = (x + y) * exp (-6.*(x*x+y*y))
orient3 ( )
light3 ( )
plwf (z, y, x)
[xmin, xmax, ymin, ymax] = draw3(1)
limits (xmin, xmax, ymin, ymax)
plt("opaque wire mesh", .30, .42)
```



opaque wire mesh

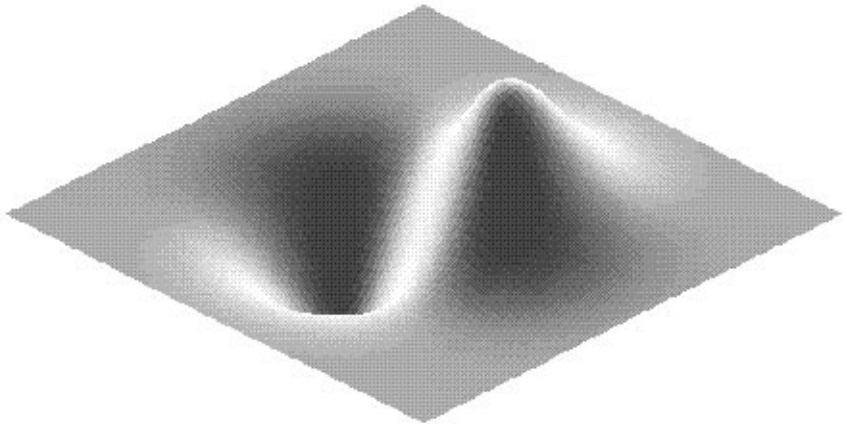
Next, we see the same surface shaded from a default light source (roughly over the viewer's right shoulder) and with the mesh lined in red.

```
plwf(z,y,x,shade=1,ecolor="red")
[xmin, xmax, ymin, ymax] = draw3(1)
limits (xmin, xmax, ymin, ymax)
```



Finally, the following sequence plots the same surface with no edges, and with lighting coming from the back.

```
plwf(z,y,x,shade=1,edges=0)
light3 ( diffuse=.1, specular=1., sdir=array([0,0,-1]))
[xmin, xmax, ymin, ymax] = draw3(1)
limits (xmin, xmax, ymin, ymax)
```



7.5.2 `pl3surf`: plot a 3-D surface

Calling Sequence

```
pl3surf (nverts, xyzverts [, values] [, <keylist>])
```

Description

Perform simple 3-D rendering of an object created by `slice3` (possibly followed by `slice2`). `nverts` and `xyzverts` are polygon lists as returned by `slice3`, so `xyzverts` is `sum(nverts)`-by-3, where `nverts` is a list of the number of vertices in each polygon. If present, the `values` should have the same length as `nverts`; they are used to color the polygon. If `values` is not specified, the 3-D lighting calculation set up using the `light3` function will be carried out. Keywords `cmin` and `cmax` as for `plf`, `pli`, or `plfp` are also accepted. (If you do not supply `values`, you probably want to use the `ambient` keyword to `light3` instead of `cmin` here, but `cmax` may still be useful.)

`pl3surf` calls `clear3` before putting the plot command on the display list, which means that PyGist can only show one surface at a time using this function. (See `pl3tree` below for graphs with multiple components).

Example

The following example is the familiar sombrero function. The first few lines of code compute its value.

```
nc1 = 100
```

```
nv1 = nc1 + 1
br = - (nc1 / 2)
tr = nc1 / 2 + 1
x = arange (br, tr, typecode = Float) * 40. / nc1
y = arange (br, tr, typecode = Float) * 40. / nc1
z = zeros ( (nv1, nv1), Float)
r = sqrt (add.outer ( x ** 2, y **2)) + 1e-6
z = sin (r) / r
```

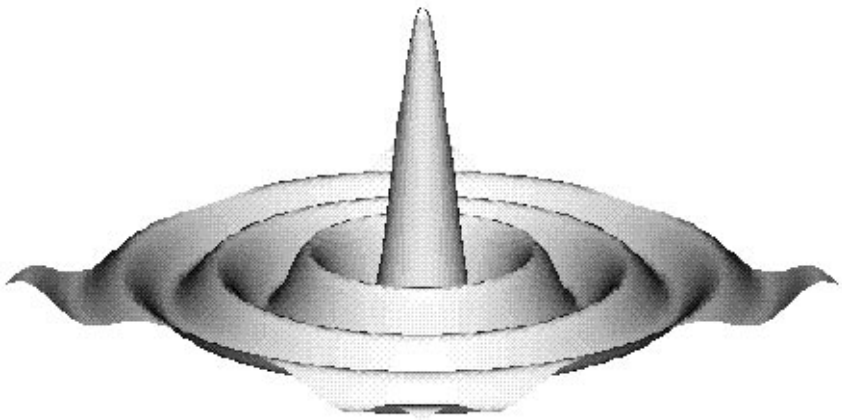
In order to use `pl3surf`, we need to construct a mesh using `mesh3`. The way we shall do that is to define a function on the 3d mesh so that the sombrero function is its 0-isosurface.

```
z0 = min (ravel (z))
z0 = z0 - .05 * abs (z0)
maxz = max (ravel (z))
maxz = maxz + .05 * abs (maxz)
zmult = max (max (abs (x)), max (abs (y)))
dz = (maxz - z0)
nxnynz = array ( [nc1, nc1, 1], Int)
dxdydz = array ( [1.0, 1.0, zmult*dz], Float )
x0y0z0 = array ( [float (br), float (br), z0*zmult], Float )
meshf = zeros ( (nv1, nv1, 2), Float )
meshf [:, :, 0] = zmult*z - (x0y0z0 [2])
meshf [:, :, 1] = zmult*z - (x0y0z0 [2] + dxdydz [2])
```

Finally, we create the mesh and call the plotting functions.

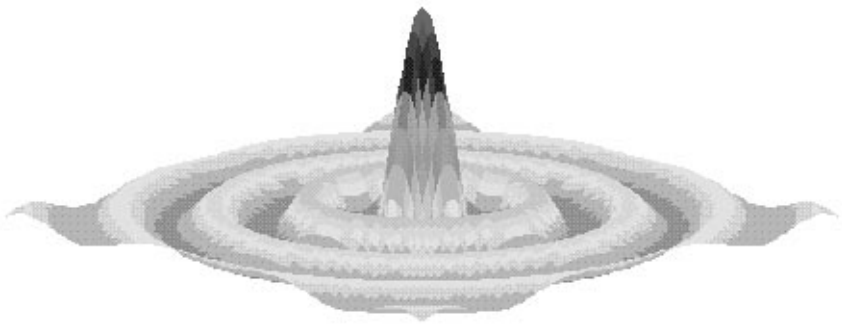
```
m3 = mesh3 (nxnynz, dxdydz, x0y0z0, funcs = [meshf])
fma ()
# Make sure we don't draw till ready
set_draw3_ (0)
pldefault(edges=0)
[nv, xyzv, col] = slice3 (m3, 1, None, None, value = 0.)
orient3 () # (default orientation)
pl3surf (nv, xyzv)
lim = draw3 (1)
dif = 0.5 * (lim [3] - lim [2])
# dif is used to compress the y scale a bit.
limits (lim [0], lim [1], lim [2] - dif, lim [3] + dif)
palette ("gray.gp")
```

The graph that results from this sequence of code is on the next page.



This next sequence of functions uses slice3mesh to draw the same surface; this time the polygons that make up the surface are colored according to height (using the rainbow palette).

```
# Try new slicing function to get color graph
[nv, xyzv, col] = slice3mesh (nxnynz [0:2], dxdydz [0:2],
    x0y0z0 [0:2], zmult * z, color = zmult * z)
pl3surf (nv, xyzv, values = col)
lim = draw3 (1)
dif = 0.5 * (lim [3] - lim [2])
limits (lim [0], lim [1], lim [2] - dif, lim [3] + dif)
palette ("rainbow.gp")
```



7.5.3 `pl3tree`: add a surface to a plotting tree

`pl3tree` accepts surfaces and slices of surfaces in the `slice2`/`slice3` format, and, as its name suggests, builds a b-tree. Its purpose is to attempt to analyze multiple surface plots in such a way as to determine the order of plotting, so that hidden portions of the surfaces will be graphed first, and this covered by later portions. `pl3tree` may be called multiple times to build plots of arbitrary complexity.

Calling Sequence

```
pl3tree (nverts, xyzverts [, values] [, <keylist>])
```

Description

`pl3tree` accepts the following keywords:

`plane, cmin, cmax, split`

`pl3tree` adds the polygon list specified by `nverts` (number of vertices in each polygon) and `xyzverts` (3-by-`sum (nverts)` vertex coordinates) to the currently displayed b-tree. If `values` is specified, it must have the same dimension as `nverts`, and represents the color of each polygon. If `values` is not specified, then the polygons are assumed to form an isosurface which will be shaded by the current 3-D lighting model; the isosurfaces are at the leaves of he b-tree, sliced by all of the planes. If `plane` (in the format returned by a call to `plane3`) is specified, then the `xyzverts` must all lie in that plane, and that plane becomes a new slicing plane in the b-tree.

Each leaf of the b-tree consists of a set of sliced isosurfaces. A node of the b-tree consists of some polygons in one of the planes, a b-tree or leaf entirely on one side of that plane, and a b-tree or leaf on the other side. The first plane you add becomes the root node, slicing any existing leaf in half. When you add an isosurface, it propagates down the tree, getting sliced at each node, until its pieces reach the existing leaves, to which they are added. When you add a plane, it also propagates down the tree, getting sliced at each node, until its pieces reach the leaves, which it slices, becoming the nodes closest to the leaves.

This structure is relatively easy to plot, since from any viewpoint, a node can always be plotted in the order from one side, then the plane, then the other side.

If keyword `split` is set nonzero (the default), then this routine assumes a ‘‘split palette’’; the current palette will be ‘‘split’’ or truncated so that its colors are numbered 0 to 99, while colors 100 to 199 will be greyscale. Colors for the `values` will be scaled to fit from color 0 to color 99, while the colors from the shading calculation will be scaled to fit from color 100 to color 199. (If values is specified as an unsigned char array (Python typecode `"b"`), however, it will be used without scaling.) You may specifiy a `cmin` or `cmax` keyword to affect the scaling; `cmin` is ignored if `values` is not specified (use the `ambient` keyword from `light3` for that case).

Example

In the following example, `nx`, `ny`, and `nz` are each 20. First we compute the mesh and some data on the mesh.

```
xyz = zeros ( (3, nx, ny, nz), Float)
xyz [0] = multiply.outer ( span (-1, 1, nx),
   ones ( (ny, nz), Float))
xyz [1] = multiply.outer ( ones (nx, Float),
   multiply.outer ( span (-1, 1, ny),
   ones (nz, Float)))
xyz [2] = multiply.outer ( ones ( (nx, ny), Float),
   span (-1, 1, nz))
r = sqrt (xyz [0] ** 2 + xyz [1] **2 + xyz [2] **2)
theta = arccos (xyz [2] / r)
phi = arctan2 (xyz [1] , xyz [0] + logical_not (r))
y32 = sin (theta) ** 2 * cos (theta) * cos (2 * phi)
m3 = mesh3 (xyz, funcs = [r * (1. + y32)])
```

Next we construct two isosorfaces, an inner (function value .5) and an outer (function value 1.0) using `slice3`.

```
[nv, xyzv, dum] = slice3 (m3, 1, None, None, value = .50)
          # (inner isosurface)
[nw, xyzw, dum] = slice3 (m3, 1, None, None, value = 1.)
          # (outer isosurface)
```

Now we create two planes, use one to form a plane slice through the mesh, then the second to slice the first in half.

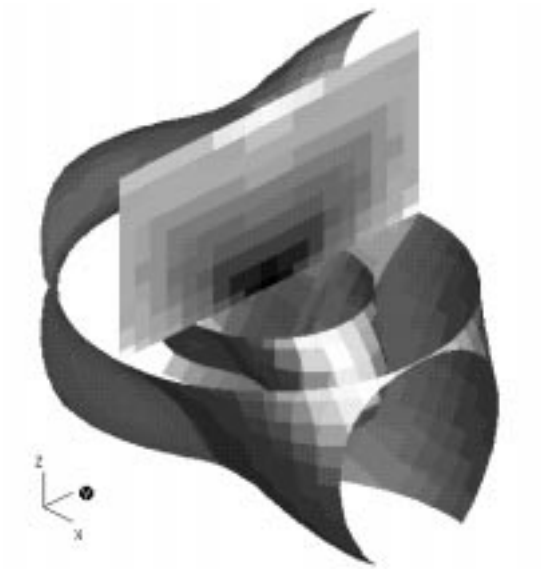
```
pxy = plane3 ( array ([0, 0, 1], Float ), zeros (3, Float))
pyz = plane3 ( array ([1, 0, 0], Float ), zeros (3, Float))
[np, xyzp, vp] = slice3 (m3, pyz, None, None, 1)
          # (pseudo-colored plane slice)
[np, xyzp, vp] = slice2 (pxy, np, xyzp, vp)
          # (cut slice in half)
```

Finally, we slice each isosurface in half, keeping both halves (`slice2x` calls), then slice the ‘‘top’’ half of each in half again, discarding the front of each (`slice2` calls).

```
[nv, xyzv, d1, nvb, xyzvb, d2] = \
          slice2x (pxy, nv, xyzv, None)
[nv, xyzv, d1] = slice2 (- pyz, nv, xyzv, None)
          # (...halve one of those halves)
[nw, xyzw, d1, nwb, xyzwb, d2] = \
          slice2x ( pxy , nw, xyzw, None)
          # (split outer in halves)
[nw, xyzw, d1] = slice2 (- pyz, nw, xyzw, None)
```

Now, a sequence of calls to `pl3tree` sets up the graph, and a call to `demo5_light` actually plots it. For completeness, we give the function `demo5_light` first.

```
making_movie = 0
def demo5_light (i) :
   global making_movie
   if i >= 30 : return 0
   theta = pi / 4 + (i - 1) * 2 * pi/29
   light3 (sdir = array ( [cos(theta), .25, sin(theta)],
      Float))
   draw3 ( not making_movie )
   return 1
fma ()
split_palette ("earth.gp")
gnomon (1)
clear3 ()
# Make sure we don't draw till ready
set_draw3_ (0)
pl3tree (np, xyzp, vp, pyz)
pl3tree (nvb, xyzvb)
pl3tree (nwb, xyzwb)
pl3tree (nv, xyzv)
pl3tree (nw, xyzw)
orient3 ()
light3 (diffuse = .2, specular = 1)
limits (square=1)
demo5_light (1)
```



7.6 Contour Plotting on Surfaces: `plzcont` and `pl4cont`

Contour lines can be plotted on a surface, or filled contours can be drawn, or both, by means of the two functions `plzcont` (plot z contours, i. e., contours according to height in the z direction) and `pl4cont` (plot 4D contours, i. e., contours determined by some other function defined on the surface.

Calling Sequences

```
plzcont (nverts, xyzverts, contours = 8, scale = "lin",
   clear = 1, edges = 0, color = None, cmin = None,
   cmax = None, zaxis_min = None, zaxis_max = 0, split = 0)
pl4cont (nverts, xyzverts, values, contours = 8, scale =
   "lin", clear = 1, edges = 0, color = None, cmin = None,
   cmax = None, caxis_min = None, caxis_max = 0, split = 0)
```

Description

`plzcont` plots `z` contours, and `pl4cont` plots contours derived from the function `values`. `nverts` and `xyzverts` specify the polygons which define the surface. `nverts` is an array of integers, the i^{th} entry of which gives the number of vertices of the i^{th} polygonal cell; `xyzverts` are the vertices of the coordinatesof the cells, with each consecutive `nv [i]` entries representing the vertices of the i^{th} cell; and `values` (for `pl4cont`) being a set of values, one for each vertex. These arguments are the same format as returned by `slice3` and `slice3mesh` (see Section 7.4.2 "slice3: Plane and Isosurface Slices of a 3-D mesh" on page 65). `plzcont` and `pl4cont` actually do repeated calls to `slice2x` (see Section 7.4.3 "slice2 and slice2x: Slicing Surfaces with planes" on page 66) in order to obtain the contour curves.

Keyword Arguments

`contours`

can be one of the following: `N`, an integer: Plot `N` contours (therefore, `N+1` colored components of the surface) `CVALS`, a vector of floats: draw the contours at the specified levels.

`scale`

can be `"lin"`, `"log"`, or `"normal"` specifying the contour scale. (Only applicable if `contours = N`, of course).

`clear`

If `CLEAR == 1`, clear the display list first. Otherwise the current contour plot will be added to the display list.

`edges`

If `EDGES == 1`, plot the edges.

`color`

If `color == None`, then `bytscl` the palette into `N + 1` colors and send each of the slices to `pl3tree` with the appropriate color. If `color == "bg"`, will plot only the edges. See also `split` (below).

`cmin, cmax`

If `CMIN` is given, use it instead of the minimum `c` actually being plotted in the computation of contour levels. If `CMAX` is given, use it instead of the maximum `c` actually being plotted in the computation of contour levels. This is done so that a component of a larger graph will have the same colors at the same levels as every other component, rather than its levels being based on its own maximum and minimum, which may lie inside or outside those of the rest of the graph.

`zaxis_min, zaxis_max`

`ZAXIS_MIN` and `ZAXIS_MAX` represent axis limits on `z` as expressed by the user. If present, `ZAXIS_MIN` will inhibit plotting of all lesser `z` values, and `ZAXIS_MAX` will inhibit the plotting of all greater `z` values.

`caxis_min, caxis_max`

`CAXIS_MIN` and `CAXIS_MAX` represent axis limits on `c` as expressed by the user. If present, `CAXIS_MIN` will inhibit plotting of all lesser `c` values, and `CAXIS_MAX` will inhibit the plotting of all greater `c` values.

`split`

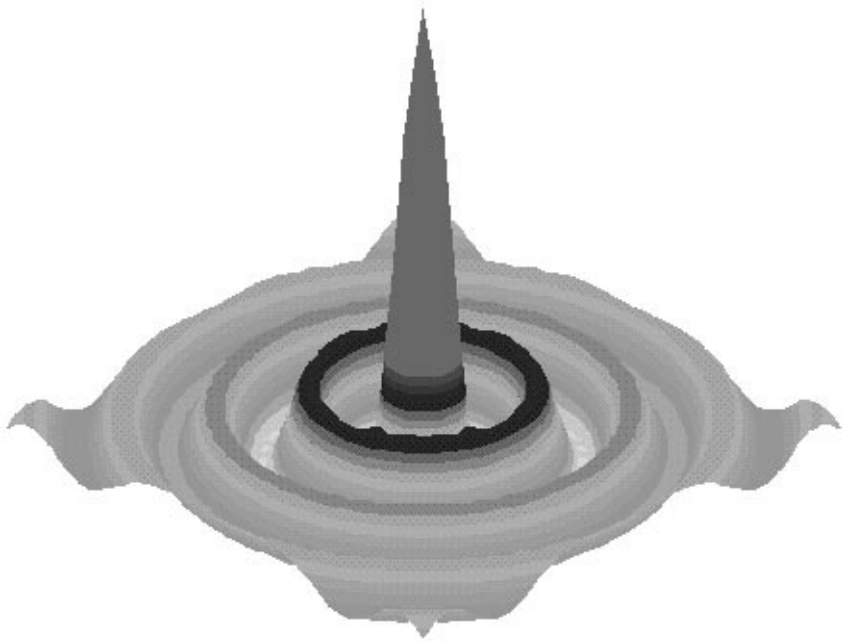
If `split == 1`, then it is intended to plot this portion of the graph as if the palette has been split, so only colors 0-99 will be used to color the contours. If `split == 0`, then all colors from 0 to 199 will be used.

Example

In the following example, we compute the sombrero function and then use plzcont to draw it with contours in `"normal"` scale. In `"normal"` scale, the top and bottom contours are two standard deviations away from the mean. Thus the peak of the sombrero is all the same color because its few points contribute very little to the standard deviation.

```
# compute sombrero function
x = arange (-20, 21, typecode = Float)
y = arange (-20, 21, typecode = Float)
z = zeros ( (41, 41), Float)
r = sqrt (add.outer ( x ** 2, y **2)) + 1e-6
z = sin (r) / r
fma ()
clear3 ()
gnomon (0)
# Make sure we don't draw till ready
```

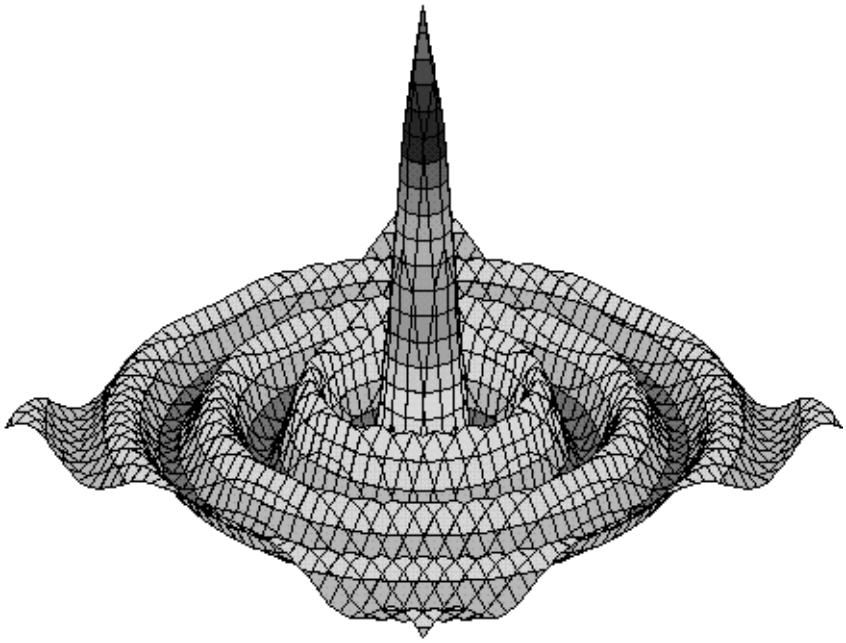
```
set_draw3_ (0)
palette ("rainbow.gp")
[nv, xyzv, dum] = slice3mesh (x, y, z)
plzcont (nv, xyzv, contours = 20, scale = "normal")
[xmin, xmax, ymin, ymax] = draw3 (1)
limits (xmin, xmax, ymin, ymax)
```



To draw the same function in "lin" scale, with edges visible, enter the following code:

```
plzcont (nv, xyzv, contours = 20, scale = "lin", edges=1)
[xmin, xmax, ymin, ymax] = draw3 (1)
limits (xmin, xmax, ymin, ymax)
```

The resulting graph is shown on the next page.



7.7 Animation: `movie` and `spin3`

7.7.1 The `movie` module and function

Calling Sequence

```
movie (draw_frame [, time_limit = 120.]
       [, min_interframe = 0.0]
       [, bracket_time = array ([2., 2.], Float )]
       [, lims = None]
       [, timing = 0])
```

Description

Note: All but the first argument are keyword arguments, with defaults as shown.

This function runs a movie based on the given `draw_frame` function. The movie stops after a total elapsed time of `time_limit` seconds, which defaults to 60 (one minute), or when the `draw_frame` function returns zero. (N. B. Currently the timing option described here and in a subsequent paragraph is not completely implemented.)

`draw_frame` is a function described as follows:

```
def draw_frame (i) :
```

```
    # Input argument i is the frame number.
    # draw_frame should return non-zero if there are more
    # frames in this movie.  A zero return will stop the
    # movie.
    # draw_frame must NOT include any fma command if the
    # making_movie variable is set (movie sets this variable
    # before calling draw_frame)
```

If `min_interframe` is specified, a pause will be added as necessary to slow down the movie. `min_interframe` is a time in seconds (default 0). The keyword `bracket_time` (again a time in seconds) can be used to adjust the duration of the pauses after the first and last frames. It may also be a two element array `[beg, end]`. If the pause at the end is greater than five seconds, you will be prompted to explain that hitting `<RETURN>` will abort the final pause. (Well, the Python version does not currently have this capability due to the difficulty of implementing it consistently over various platforms.)

`timing = 1` enables a timing printout for your movie.

If every frame of your movie has the same limits, use the `lims` keyword argument to fix the limits during the movie.

Example

In the following example, the movie demonstrates the effect of a moving light source on the currently drawn surface. (The plot functions creating the surface have not been shown; it is assumed that the data for the surface is on the current display list.)

The `draw_frame` function is as follows:

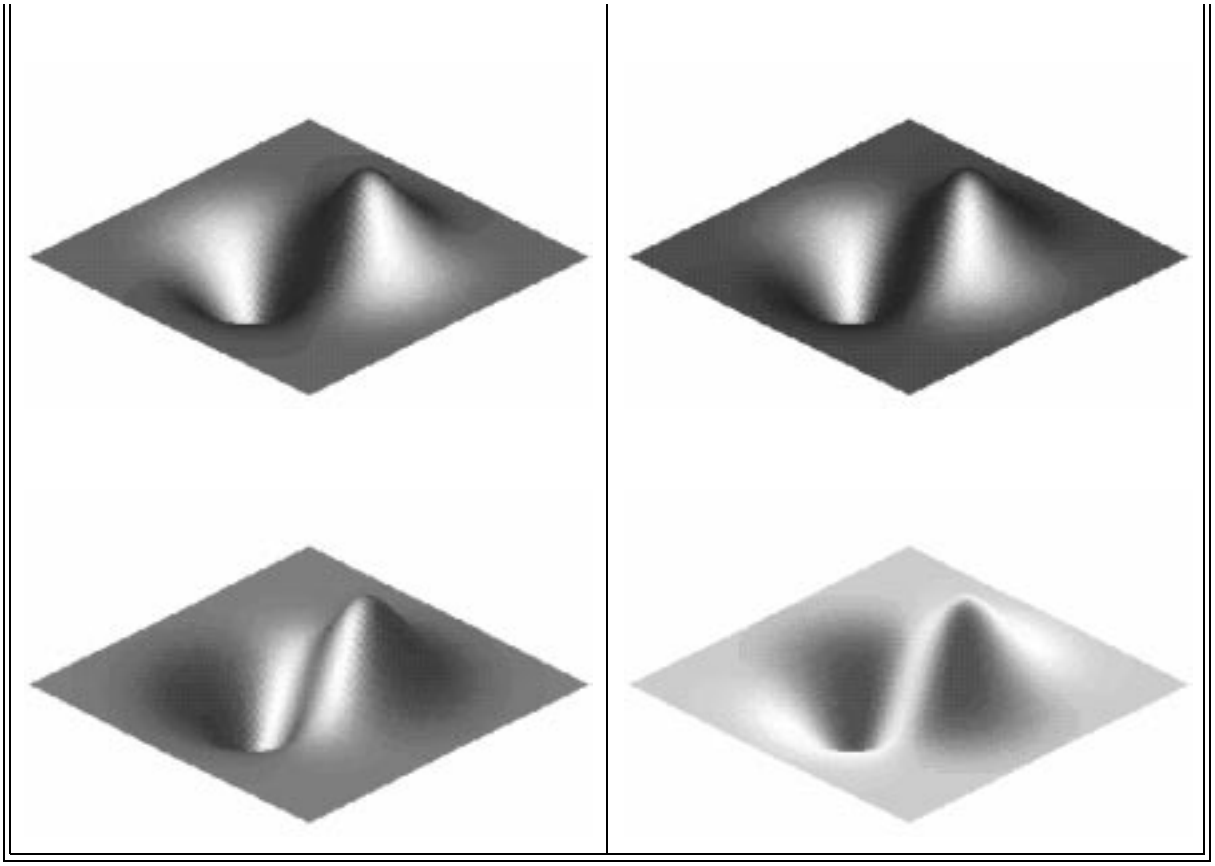
```
def demo5_light (i) :
   global making_movie
   if i >= 30 : return 0
   theta = pi / 4 + (i - 1) * 2 * pi/29
   light3 (sdir =
      array ( [cos(theta), .25, sin(theta)], Float))
   # without an explicit call to draw3, the light3
   # function would cause no changes until Python
   # paused for input from the keyboard, since
   # unlike the primitive plotting functions (plg, plf,
   # plfp, ...) the fma call made by the movie function
   # will not trigger the 3-D display list. any movie
   # frame display function which uses the 3-D drawing
   # functions in pl3d.py will need to do this. the
   # !making_movie flag supresses the fma in draw3 if
   # this function is called by movie (which issues
   # its own fma), but allows it otherwise

   draw3 ( not making_movie )
```

```
    return 1
```

Here is the Python code necessary to run a movie. This particular animation shows the surface with a peak and valley which we saw earlier in this chapter(See “Examples” on page 68), with a moving light source. A few frames of the movie are shown on the next page.

```
set_draw3_ (0)
x = span (-1, 1, 64, 64)
y = transpose (x)
z = (x + y) * exp (-6.*(x*x+y*y))
orient3 ( )
light3 (diffuse=.2,specular=1 )
limits_(square = 1)
plwf (z,y,x,shade=1,edges=0)
[xmin, xmax, ymin, ymax] = draw3 (1)
limits (xmin, xmax, ymin, ymax)
making_movie = 1
movie(demo5_light, lims = [xmin, xmax, ymin, ymax])
making_movie = 0
```

TABLE 1. **Selected Frames Showing Moving Light Source**



7.7.2 The `spin3` function

`spin3` is a function which takes an existing 3-D plot and spins it about an axis. It actually calls `movie` for you, with a `draw_frame` function which is internal to the `pl3d` module and not available outside this module, because its name begins with an underscore.

Calling Sequence

```
spin3 (nframes = 30,
   axis = array ([-1, 1, 0],  Float),
   tlimit = 60.,
   dtmin = 0.0,
   bracket_time = array ([2., 2.],  Float),
   lims = None,
   timing = 0,
   angle = 2. * pi)
```

Description

Spin the current 3-D display list about `axis` (default `[-1, 1, 0]`) over `nframes` (default 30). Note that all arguments are keywords. Also note that the timing keywords are allowed but are not currently implemented. Their meanings are:

`tlimit`: the total time allowed for the movie in seconds (default 60).

`dtmin`: the minimum allowed interframe time in seconds (default 0.0).

`bracket_time`: (as for `movie` function in `movie.py`).

`lims`: the axis limits, if you wish to specify them.

`timing` = `1` if you want timing measured and printed out, 0 if not.

`angle`: the total angle about the axis through which the object will be rotated. During each step of the rotation, the object will rotate `angle / (nframes - 1)`.

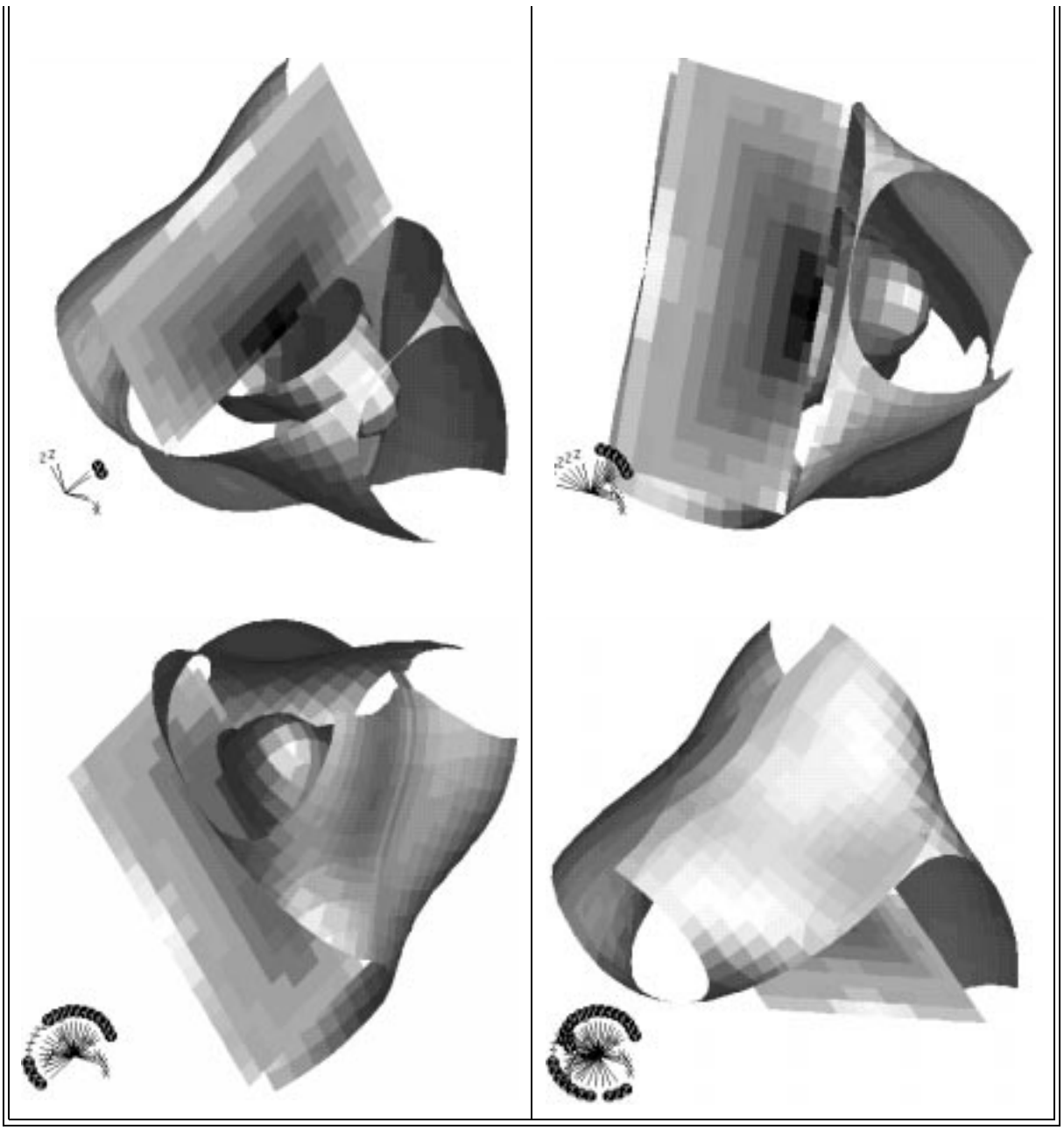
Example

In this example, we take the surface discussed previously (see “Example” on page 75) and rotate it about an axis. Assume that the sequence of code given there has been executed, giving the figure shown there. Then we do the following to run the movie:

```
spin3 () # (lims = [l0, l1, l2, l3])
```

Four frames from the resulting movie are shown on the next page.

TABLE 2. **Frames from Movie of Rotating Isosurfaces**



7.8 Syntactic Sugar: Some Helpful Functions

7.8.1 Specifying the palette to be split: `split_palette`

Calling Sequence

```
split_palette ( [palette_name])
```

Description

Split the current palette (if `palette_name` is not present) or the specified palette (if `palette_name` is present) into two parts; colors 0 to 99 will be a compressed version of the original, while colors 100 to 199 will be a gray scale. For details on the available palettes, see “palette: Set or Retrieve Palette” on page 21.

If you use `split_palette` to split the palette yourself, then be sure to call `pl3tree` with keyword `split = 0`, because otherwise `pl3tree` will split it again, with bizarre results. Alternatively, you can use the `palette` function referenced above to set the palette to your choice, then call `pl3tree` with `split = 1`.

7.8.2 Saving and restoring the view and lighting: `save3`, `restore3`

Calling Sequences and Example

```
view = save3 ()
movie (_spin3, ... <other arguments>)
restore3 (view)
```

Description

In the above, the `save3` function returns a copy of the current 3-D viewing transformation and lighting, so that the user can put it aside in the variable `view`. The `_spin3` function does actually change the viewing transformation and lighting; the call to `restore3` with argument `view` sets it back to its previous configuration.

CHAPTER 8: Useful Functions for Developers

In this chapter we describe more of the available functions in detail, for those who are really interested in plumbing the depths of the low-level 3D graphics.

8.1 Find 3D Lighting: `get3_light`

Calling Sequence

```
get3_light(xyz [, nxyz])
```

Description

Return 3D lighting for polygons with vertices `XYZ`. If `NXYZ` is specified, `XYZ` should be `sum(nxyz)`-by-3, with `NXYZ` being the list of numbers of vertices for each polygon (as for the `plfp` function; see page 39). If `NXYZ` is not specified, `XYZ` should be a quadrilateral mesh, `ni`-by-`nj`-by-3 (as for the `plf` function; see page 35). In the first case, the return value is `len (NXYZ)` long; in the second case, the return value is `(ni-1)`-by-`(nj-1)`.

The parameters of the lighting calculation are set by the `light3` function (see "Lighting Parameters" on page 57).

8.2 Get Normals to Polygon Set: `get3_normal`

Calling Sequence

```
get3_normal(xyz [, nxyz])
```

Description

Return 3D normals for polygons with vertices `XYZ`. If `NXYZ` is specified, `XYZ` should be `sum(nxyz)`-by-3, with `NXYZ` being the list of numbers of vertices for each polygon (as for the `plfp` function; see page 39). If `NXYZ` is not specified, `XYZ` should be a quadrilateral mesh, `ni`-by-`nj`-by-3 (as for the `plf` function; see page 35). In the first case, the return value is `len(NXYZ)`-by-3; in the second case, the return value is `(ni-1)`-by-`(nj-1)`-by-3.

The normals are constructed from the cross product of the lines joining the midpoints of two edges which as nearly quarter the polygon as possible (the medians for a quadrilateral). No check is made

that these not be parallel; the returned ‘‘normal’’ is [0,0,0] in that case. Also, if the polygon vertices are not coplanar, the ‘‘normal’’ has no precisely definable meaning.

8.3 Get Centroids of Polygon Set: `get3_centroid`

Calling Sequence

```
get3_centroid(xyz [, nxyz])
```

Description

Return 3D centroids for polygons with vertices `XYZ`. If `NXYZ` is specified, `XYZ` should be `sum(nxyz)`-by-3, with `NXYZ` being the list of numbers of vertices for each polygon (as for the `plfp` function; see page 39). If `NXYZ` is not specified, `XYZ` should be a quadrilateral mesh, `ni`-by-`nj`-by-3 (as for the `plf` function; see page 35). In the first case, the return value is `len(NXYZ)` in length; in the second case, the return value is `(ni-1)`-by-`(nj-1)`-by-3.

The centroids are constructed as the mean value of all vertices of each polygon.

8.4 Get Viewer’s Coordinates: `get3_xy`

Calling Sequence

```
get3_xy(xyz [, 1])
```

Description

Given 3-by-anything coordinates `XYZ`, return `X` and `Y` in viewer's coordinate system (set by `rot3`, `mov3`, `orient3`, etc.; see “Functions For Setting Viewing Parameters” on page 56). If the second argument is present and non-zero, also return `Z` (for use in `sort3d` or `get3_light`, for example; see “Sort z Coordinates: sort3d” on page 89 and “Find 3D Lighting: get3_light” on page 87.). If the camera position has been set to a finite distance with `setz3` (see “Physical orientation” on page 57), the returned coordinates will be tangents of angles for a perspective drawing (and `Z` will be scaled by `1/zc`). `x`, `y`, and z can be either 1D or 2D, so this routine is written in two cases.

8.5 Add object to drawing list: `set3_object`

Calling Sequence

```
set3_object(drawing_function, [arg1,arg2,...])
```

Description

Set up to trigger a call to `draw3`, adding a call to the3D display list of the form:

```
DRAWING_FUNCTION ( [ARG1, ARG2, ...]))
```

When `draw3` calls `DRAWING_FUNCTION`, the external variable `draw3_` will be non-zero, so `DRAWING_FUNCTION` can be written like this:

```
def drawing_function(arg) :       if (draw3_) :
     arg1= arg [0]
     arg1= arg [1]
     ...
     ...<calls to get3_xy, sort3d, get3_light, etc.>...
     ...<calls to graphics functions plfp, plf, etc.>...
     return

  ...<verify args>...
  ...<do orientation and lighting independent calcs>...
  set3_object (drawing_function, [arg1,arg2,...])
```

8.6 Sort z Coordinates: `sort3d`

Calling Sequence

```
sort3d(z, npolys)
```

Description

Given `Z` and `NPOLYS`, with `len(Z)==sum(npolys)`, return a 2-element list `[LIST, VLIST]` such that `take(Z, VLIST)` and `take (NPOLYS, LIST)` are sorted from smallest average `Z` to largest average `Z`, where the averages are taken over the clusters of length `NPOLYS`. Within each cluster (polygon), the cyclic order of `take (Z, VLIST)` remains unchanged, but the absolute order may change.

This sorting order produces correct or nearly correct order for a `plfp` call to make a plot involving hidden or partially hidden surfaces in three dimensions. It works best when the polygons form a set of disjoint closed, convex surfaces, and when the surface normal changes only very little between neighboring polygons. (If the latter condition holds, then even if `sort3d` mis-orders two neighboring polygons, their colors will be very nearly the same, and the mistake won't be noticeable.) A truly correct 3D sorting routine is impossible, since there may be no rendering order which produces correct surface hiding (some polygons may need to be split into pieces in order to do that). There are more nearly correct algorithms than this, but they are much slower.

8.7 Set the `cmax` parameter: `lightwf`

Calling Sequence

```
lightwf (cmax)
```

Description

Sets the `cmax` parameter interactively, assuming the current 3D display list contains the result of a previous `plwf` call. This changes the color of the brightest surface in the picture. The darkest surface color can be controlled using the `ambient` keyword to `light3` (see “Lighting:” on page 56).

8.8 Return a Wire Frame Specification: `xyz_wf`

Calling Sequence

```
xyz_wf (z, [y, x] [,scale = 1.0])
```

Description

Returns a 3-by-`ni`-by-`nj` array whose 0^{th} entry is `x`, 1^{th} entry is `y`, and 2^{th} entry is `z`. `z` is `ni`-by-`nj`. `x` and `y`, if present, must be the same shape. If not present, integer ranges will be used to create an equally spaced coordinate grid in `x` and `y`. The function which scales the ‘‘topography’’ of `z(x,y)` is potentially useful apart from `plwf`.

For example, the `xyz` array used by `plwf` can be converted from a quadrilateral mesh plotted using `plf` to a polygon list plotted using `plfp` like this:

```
xyz= xyz_wf(z,y,x,scale=scale)
ni= z.shape[1]
nj= z.shape[2]
list = ravel (add.outer (
   ravel(add.outer (adders,zeros(nj-1, Int))) +
   arange((ni-1)*(nj-1), typecode = Int),
   array ( [[0, 1], [nj + 1, nj]])))
xyz=array([take(ravel(xyz[0]),list),
   take(ravel(xyz[1]),list),
   take(ravel(xyz[2]),list)])
nxyz= ones((ni-1)*(nj-1)) * 4;
```

The resulting array `xyz` is 3-by-`(4*(nj-1)*(ni-1))`. `xyz[0:3,4*i:4*(i+1)]` are the clockwise coordinates of the vertices of cell number `i`.

8.9 Calculate Chunks of Mesh: `iterator3`

Calling Sequences

```
iterator3 (m3)
iterator3 (m3, chunk, clist)
iterator3_rect (m3)
iterator3_rect (m3, chunk, clist)
iterator3_irreg (m3)
iterator3_irreg (m3, chunk, clist)
```

Description

The iterator3 functions combine three distinct operations:

1. If only the `M3` argument is given, return the initial chunk of the mesh. The chunk will be no more than `chunk3_limit` cells of the mesh.
2. If only `M3` and `CHUNK` are given, return the next `CHUNK`, or `None` if there are no more chunks.
3. If `M3`, `CHUNK`, and `CLIST` are all specified, return the absolute cell index list corresponding to the index list `CLIST` of the cells in the `CHUNK`. Do not increment the chunk in this case.

The form of the `CHUNK` argument and return value for cases (1) and (2) is not specified, but it must be recognized by the `xyz3` and `getv3` functions (see "Return Vertex Coordinates for a Chunk: xyz3" on page 93 and "Get Vertex Values of Function: getv3" on page 91) which go along with this `iterator3`. (For case (3), `CLIST` and the return value are both ordinary index lists.) In the irregular case, it is guaranteed that the returned chunk consists of only one type of cell (tetrahedra, hexahedra, pyramids, or prisms).

8.10 Get Vertex Values of Function: `getv3`

Calling Sequence

```
getv3(i, m3, chunk)
getv3_rect(i, m3, chunk)
getv3_irreg (i, m3, chunk)
```

Description

`getv3` returns vertex values of the `I`th function attached to 3D mesh `M3` for cells in the specified `CHUNK`. The `CHUNK` may be a list of cell indices, in which case `getv3` returns a 2x2x2x(`CHUNK.shape`) list of vertex coordinates. `CHUNK` may also be a mesh-specific data structure used in the `slice3` routine (see "slice3: Plane and Isosurface Slices of a 3-D mesh" on page 65), in which case `getv3` may return a `(ni)x(nj)x(nk)` array of vertex values. For meshes which are logically rectangular or consist of several rectangular patches, this is up to 8 times less data, with a concomitant performance advantage. Use `getv3` when writing slicing functions for `slice3`.

`getv3_rect` does the job for a regular rectangular mesh.

`getv3_irreg`, for an irregular mesh, returns a 3-list whose elements are:

1. the function values for the `I`th function on the vertices of the given `CHUNK`. (The function values must have the same dimension as the coordinates; there is no attempt to convert zone-centered values to vertex-centered values.)
2. an array of relative cell numbers within the list of cells of this type.
3. a number that can be added to these relative numbers to give the absolute cell numbers for correct access to their coordinates and function values

8.11 Get Cell Values of Function: `getc3`

Calling Sequence

```
getc3(i, m3, chunk)
getc3(i, m3, clist , l, u, fsl, fsu, cells)
```

Description

Returns cell values of the `I`th function attached to 3D mesh `M3` for cells in the specified `CHUNK`. The `CHUNK` may be a list of cell indices, in which case `getc3` returns a (`CHUNK.shape`) array of vertex coordinates. `CHUNK` may also be a mesh-specific data structure used in the `slice3` routine (see "slice3: Plane and Isosurface Slices of a 3-D mesh" on page 65), in which case `getc3` may return a `(ni)x(nj)x(nk)` array of vertex values. There is no savings in the amount of data for such a `CHUNK`, but the gather operation is cheaper than a general list of cell indices. Use `getc3` when writing coloring functions for `slice3`.

If `CHUNK` is a `CLIST`, the additional arguments `L`, `U`, `FSL`, and `FSU` are vertex index lists which override the `CLIST` if the `I`th attached function is defined on mesh vertices. `L` and `U` are index arrays into the (`CLIST.shape`)x2x2x2 vertex value array, say `vva`, and `FSL` and `FSU` are corresponding interpolation coefficients; the zone centered value is computed as a weighted average of involving these coefficients. The `CELLS` argument is required by `histogram` to do the averaging. See the source code for details. By default, this conversion (if necessary) is done by averaging the eight vertex-centered values.

`getc3_rect` does the job for a regular rectangular mesh.

`getc3_irreg`: Same thing as `getc3_rect`, i. e., returns the same type of data structure, but from an irregular mesh. `m3 [1]` is a 2-list; `m3[1] [0]` is an array whose `i`th element is an array of coordinate indices for the `i`th cell, or a list of up to four such arrays. `m3 [1] [1]` is the 3 by `nverts` array of coordinates. `m3 [2]` is a list of arrays of vertex-centered or cell-centered data. `chunk` may be a list, in which case `chunk [0]` is a 2-sequence representing a range of cell indices; or it may be a one-dimensional array, in which case it is a nonconsecutive set of cell indices. It is guaranteed that all cells indexed by the `chunk` are the same type.

8.12 Controlling Points Close to the Slicing Plane: `_slice2_precision`

Calling Sequences

```
precision = get_slice2_precision ()
set_slice2_precision (precision)
```

Description

Internal variable `_slice2_precision` controls how `slice2` (or `slice2x`) handles points very close to the slicing plane or surface. `PRECISION` should be a positive number or zero. Zero `PRECISION` means to clip exactly to the plane, with points exactly on the plane acting as if they were slightly on the side the normal points toward. Positive `PRECISION` means that edges are clipped to parallel planes a distance `PRECISION` on either side of the given plane. (Polygons lying entirely between these planes are completely discarded.)

Default value is 0.0.

8.13 Scale variables to a palette: `bytscl`, `split_bytscl`

Calling Sequence

```
bytscl(z, top=max_byte, cmin=lower_cutoff,
  cmax=upper_cutoff)
split_bytscl (x, upper, cmin = None, cmax = None)
```

Description

`bytscl` returns an unsigned char array (Python typecode `"b"`)of the same shape as `Z`, with values linearly scaled to the range 0 to one less than the current palette size. If `MAX_BYTE` is specified, then the scaled values will run from 0 to `MAX_BYTE` instead. If `LOWER_CUTOFF` and/or `UPPER_CUTOFF` are specified, `Z` values outside this range are mapped to the cutoff value; otherwise the linear scaling maps the extreme values of `Z` to 0 and `MAX_BYTE`.

`split_bytscl` is as the `bytscl` function, but scales to the lower half of a split palette (0-99, normally the color scale) if the second parameter is zero or nil, or the upper half (100-199, normally the gray scale) if the second parameter is non-zero.

8.14 Return Vertex Coordinates for a Chunk: `xyz3`

Calling Sequence

```
xyz3 (m3, chunk)
```

Description

Return vertex coordinates for `CHUNK` of 3D mesh `M3`. The `CHUNK` may be a list of cell indices, in which case `xyz3` returns a (`CHUNK.shape`))x3x2x2x2 list of vertex coordinates. `CHUNK` may also be a mesh-specific data structure used in the `slice3` routine (see “slice3: Plane and Isosurface Slices of a 3-D mesh” on page 65), in which case `xyz3` may return a 3x`(ni)`x`(nj)`x`(nk)` array of vertex coordinates. For meshes which are logically rectangular or consist of several rectangular patches, this is up to 8 times less data, with a concomitant performance advantage. Use `xyz3` when writing slicing functions or coloring functions for `slice3`.

8.15 Find Corner Indices of List of Cells: `to_corners3`

Calling Sequence

```
to_corners3(list, nj, nk)
```

Description

Convert an array of cell indices in an `(ni-1)`-by-`(NJ-1)`-by-`(NK-1)` logically rectangular grid of cells into the array of `len(LIST)`-by-2-by-2-by-2 cell corner indices in the corresponding `ni`-by-`NJ`-by-`NK` array of vertices. The algorithm used is described in section 9.4 “More slice3 details”. Note that this computation in Yorick gives an absolute offset for each cell quantity in the grid. In Yorick it is legal to index a multidimensional array with an absolute offset. In Python it is not. However, an array can be flattened if necessary.

Other changes from Yorick were necessitated by row-major order and 0-origin indices, and of course the lack of Yorick array facilities.

8.16 Timing: `timer`, `timer_print`

Calling Sequences

```
timer (elapsed)
timer (elapsed, split)
timer_print (label1, split1 [,label2, split2, ...])
```

Description

`timer` returns a triple consisting of the times `[cpu, system, wall]`. If argument `split` is present, a sequence is returned whose first element is `[cpu, system, wall]` and whose second element is the sum of `split` and the difference between the new and old values of ‘`elapsed`.' `timer_print` prints out a timing summary for splits accumulated by `timer`.

CHAPTER 9: Maintenance: Things You Really Didn't Want to Know

In this chapter we discuss in even more gory detail how the PyGist graphics are put together.

9.1 The Workhorse: `gistCmodule`

The reader should be familiar with many of the functions in `gistCmodule` from CHAPTER 5: "Two-Dimensional Plotting Functions", page 27. Most of the `gistCmodule` functions discussed there, and many of the helper functions, are pretty close to literal translations of the equivalent functions in Gist, the main difference geing the superstructure built on top of them in order to handle `PyObject`s.. In addition to the plotting functions, a number of functions in `gistCmodule` are essential for maintenance of that module, and are discussed here. We also discuss briefly a few other functions which are not literal translations of Gist functions.

9.1.1 Memory Maintenance: `PyObject`s

One of the primary challenges facing the developer of Python extensions is correct management of the reference counting for Python objects. Memory leaks will result if the programmer fails to decrement the reference count in temporary objects. On the other hand, decrementing the reference count too early can cause an object to go away that is referred to later, which can cause a segmentation fault when it is referenced. We have semi-automated the process in gistCmodule by maintaining a list of all PyObjects created in the process of running one of the module's functions. This list is declared as follows:

```
#define ARRAY_LIST_SIZE 30

static PyObject * PyArrayList [ARRAY_LIST_SIZE];
static int array_list_length = 0;
```

There is a suite of functions for manipulating `PyArrayList`.

Function Prototypes

```
static int addToArrayList (PyObject * obj)
static void clearArrayList ()
```

```
static void removeFromArrayList (PyObject * obj)
static void takeOffArrayList (PyObject * obj)
```

Description

`addToArrayList` places `obj` on `PyArrayList` and returns 1 if successful. If `obj` is `NULL` or the list is full, returns 0. `clearArrayList` `DECREF`'s everything on the list, and sets `array_list_length` to 0. This needs to be done prior to any error return. `removeFromArrayList` `DECREF`'s `obj` (if it is on the list), removes it from the list, and compresses the list. `takeOffArrayList` removes `obj` from the list and compresses the list, but does not `DECREF` `obj`. This is done, for example, when `obj` is to be returned to the caller.

`addToArrayList` occurs throughout `gistCmodule` primarily in macros which create arrays. All of these macros use the `TRY` macro, which is defined as follows:

```
#define TRY(e, m) do{if(!(e)){clearArrayList(); \
   clearFreeList(0);clearMemList();return m;}} while(0)
```

The idea behind `TRY` is that generally Python functions return 0 or `NULL` if an error occurred. In this case it is necessary to get rid of all temporary objects and memory which was allocated up to this point. `clearArrayList` was discussed above, `clearFreeList` and `clearMemList` are discussed later in the chapter.

The array creation macros are as follows:

```
#define GET_ARR(ap,op,type,dim,cast) \
  TRY(addToArrayList((PyObject *)(ap=(PyArrayObject *)\
    PyArray_ContiguousFromObject(op,type,dim,dim))), \
    (cast)PyErr_NoMemory ())
```

This macro is the usual protocol for creating a contiguous array from a `PyObject` which has been sent as an argument to a function.

```
#define NEW_ARR(ap,n,dims,type,cast) \
  TRY(addToArrayList((PyObject *)(ap=\
  (PyArrayObject *)PyArray_FromDims(n,dims,type))), \
  (cast)PyErr_NoMemory ())
```

This macro is used usually when creating an array whose dimensions are known and which is to be filled with computed data.

```
#define RET_ARR(op,ndim,dim,type,data,cast)\
  TRY(addToArrayList(op=\
  PyArray_FromDimsAndData(ndim,dim,type,data)), \
  (cast)PyErr_NoMemory ())
```

This final macro is used when we have a block of data and we wish to create an array containing this data, usually as a return value from a function. In order to keep this object from being permanent, use the following macro:

```
#define SET_OWN(op) \
```

```
( (PyArrayObject *) op)->flags |= OWN_DATA
```

This macro sets a flag in the `PyObject` which tells Python that it can be `DECREF`'ed.

9.1.2 Memory Management: `ArrayObjects`

ArrayObjects are defined as follows:

```
typedef struct arrayobject {
   void * data ;
   int size ;
   char typecode ;
   } ArrayObject;
```

These objects are used primarily in the `slice2` routines to store temporary results during the calculation. The final results are passed back in `PyArrayObject`s created by `RET_ARR`. Two lists of `ArrayObject`s are maintained by the `slice2` suite: list 0 by `slice2` itself, and list 1, which is used by `_slice2_part`, which is called by `slice2`. These lists are declared as follows:

```
#define MAX_NO_LISTS 2
#define MAX_LIST_SIZE 30

static ArrayObject * freeList [MAX_NO_LISTS] [MAX_LIST_SIZE];
static int freeListLen [MAX_NO_LISTS] = {0, 0};
```

Function Prototypes

```
static ArrayObject * allocateArray (int size, char tc,
   int nlist)
static ArrayObject * copyArray (ArrayObject * a)
static ArrayObject * arrayFromPointer (int size, char tc,
   void * data, int nlist)
static void freeArray (ArrayObject * a, int n)
static void clearFreeList (int n)
static int addToFreeList (ArrayObject * x, int n)
static void removeArrayOnly (ArrayObject * x, int n)
static void removeFromFreeList (ArrayObject * x, int n)
```

Description

`allocateArray` allocates an appropriate amount of space for `size` items of type `tc`. It then creates an `ArrayObject` containing this data and puts it on `freeList [nlist]`. `copyArray` makes and returns a copy of `a`. It does not add `a` to any `freeList`. `arrayFromPointer` creates an `arrayObject` whose data pointer points to `data`; it is assumed that the caller has supplied correct `size` and `tc` arguments. The resulting object is placed on `freeList [nlist]`. `freeArray` frees `a`'s data and then `a` itself, and removes it from `freeList [n]` if it is there. `clearFreeList` frees everything on `freeList [n]` and sets the list length to 0. `addToFreeList` adds `x` to `freeList [n]`, if it can. `removeArrayOnly` removes the array from `freeList [n]`, then

frees x without freeing its data. This would most likely be done when RET_ARR creates a PyArrayObject which points to x's data. removeFromFreeList frees x's data, then x itself, and removes x from freeList [n].

9.1.3 Memory Management: naked memory

Occasionally in gistCmodule it is necessary to malloc a block of memory which is not contained inside some type of object. MemList is used to keep track of such memory:

```
#define MEM_LIST_SIZE 15

static void * PyMemList [MEM_LIST_SIZE];
static int mem_list_length = 0;
```

MemList is maintained by its own suite of functions.

Function Prototypes

```
static int addToMemList (void * addr)
static void clearMemList ()
```

Description

The first function adds an address to MemList; the second frees everything on MemList and sets its length back to 0.

9.1.4 Computing contour curves: contour

Calling Sequence

```
# Set mesh first
plmesh (y, x, ireg, triangle = triangle)
[nc, yc, xc] = contour (level, z)
```

Description

The calling sequence given above emphasizes that mesh parameters should be set by a call to plmesh prior to calling contour. plmesh arguments are explained in section "plmesh: Set Default Mesh" on page 29. If level is a scalar floating point number, then the the returned values are the points at that contour level. All such points lie on edges of the mesh. If a contour curve closes, the final point is the same as the initial point (i.e., that point is included twice in the returned list). If level is a sequence of two reals, then contour returns the points of a set of polygons which outline the regions between the two contour levels. The returned values are in the form required for arguments of plfp (see Section 5.1.8 "plfp: Plot a List of Filled Polygons" on page 39).These will include points on the mesh boundary which lie between the levels, in addition to the edge points for both levels. The polygons are closed, simply connected, and will not contain more than about 4000 points (larger polygons are split into pieces with a few points repeated where the pieces join).

The 2D filled contour plot routine `plfc` (see Section 5.1.7 "plfc: Plot filled contours" on page 37) operates by calling `contour` with pairs of adjacent contour levels, and then calling `plfp` with the output and a single color, inside a loop. `contour` needed to be programmed in C because it can be called many times to do a single filled contour plot, and the calculations take too long to be performed in interpreted code. `contour` calls lower level Gist routines that do most of the work.

9.1.5 Computing slices: `slice2`, `slice2x`, `_slice2_part`

The 3D graphics in Gist itself is still experimental, and virtually all the computational functions are written in Yorick, an interpreted language. Many of the PyGist 3D computations were translated into Python from Yorick, originally including the `slice2` and `slice2x` functions, and their auxiliary, `_slice2_part`. When we impleoemnted contours and filled contours on surfaces (which is currently not implemented in Gist itself), we used `slice2` and `slice2x` to compute the contours and the polygon lists enclosed within them. These computations were much too slow, so we rewrote `slice2` in C (`slice2x` remains in Python; it just calls `slice2` with a parameter set) and put them into the `gistCmodule`. The user interface to these functions has been discussed in a previous section (7.4.3 “slice2 and slice2x: Slicing Surfaces with planes”), but we discuss them here from the viewpoint of implementation. We also discuss the ‘‘hidden’’ function `_slice2_part` here for the first time.

Calling Sequences

```
[nverts, xyzverts, values] = slice2 (plane, nv,
     xyzv, vals = None, _slice2x = 0)
[nverts, xyzverts, values, nvertb, xyzvertb, valueb] =
     slice2x (plane, nv, xyzv, vals)
static int _slice2_part (ArrayObject * xyzc,
   ArrayObject * keep, ArrayObject * next, ArrayObject * dp,
   ArrayObject * prev, ArrayObject * last,
   ArrayObject * valc, ArrayObject ** xyzc_new,
   ArrayObject ** nvertc, ArrayObject ** valc_new,
   int freexyzc, int freevalc)
```

Description

The argument plane can be either a scalar or a `plane3` (see “Creating a Plane” on page 61); `nv` is an array of integers, the i^{th} entry of which gives the number of vertices of the i^{th} polygonal cell; `xyzv` are the vertices of the coordinatesof the cells, with each consecutive `nv [i]` entries representing the vertices of the i^{th} cell; and `vals` being a set of values, one for each cell. These arguments are the same format as returned by `slice3` and `slice3mesh`.

If `plane` is a `plane3`, then `vals` (if not `None`) is a cell-centered set of values expressing the color of each cell, and the outputs `nverts`, `xyzverts`, and `values` represent the polygons and their colors (if any) describing the portion of the sliced surface that is on the positive side of the plane. That’s all you get with `slice2`. With `slice2x`, you get in addition `nvertb`, `xyzvertb`, and `valueb`, which describe the part of the surface on the negative side of the slicing plane. Warning: one

of these specifications could be `None`, `None`, `None` if the entire surface lies on one side of the plane.

If `plane` is a scalar value, then `vals` must be present and must be node-centered. In this case, the outputs `nverts`, `xyzverts`, and `values` represent the polygons and their colors (if any) describing the portion of the sliced surface where `vals` on the vertices are greater than or equal to the scalar value `plane`. (This actually allows you to form an arbitrary two-dimensional slice of a surface.) With `slice2x`, you get in addition `nvertb`, `xyzvertb`, and `valueb`, which describe the part of the surface where `vals` on the vertices are less than the scalar value `plane`.

The optional parameter `_slice2x`, if 1, tells `slice2` to return slices on both sides of the slicing surface or plane; if not present, or 0, then the slice on ''top'' is returned. `slice2` works by deciding which polygons lie entirely ''above'' the slicing surface, which ones lie entirely ''below'' the slicing surface, and which ones are cut by the surface. If `_slice2x` is 0, then the ones ''below'' the surface are discarded. `slice2` then calls `_slice2_part` with the polygons to be cut by the plane; once to get the cut polygons ''above'' the surface, then, if `_slice2x` is 1, a second time to get the cut polygons ''below'' the surface. The list of uncut and cut polygons ''above'' the surface is concatenated and returned (`_slice2x == 0`); the list of uncut and cut polygons ''below'' the surface is concatenated and returned also if `_slice2x` is 1.

In the case of a plane slice, suppose that the equation of the slicing plane is

$$ax + by + cz = d$$

Then a point (x_1, y_1, z_1) is considered to be on the positive side of the plane if

$$ax_1 + by_1 + cz_1 - d >= \_slice2\_precision$$

and on the negative side if

$$ax_1 + by_1 + cz_1 - d < \_slice2\_precision$$

For a discussion of `_slice2_precision`, and how to get and set its value, see Section 8.12 "Controlling Points Close to the Slicing Plane: _slice2_precision" on page 92.

In the case of a slicing surface, vertex `i` is considered to be above the surface if

$$vals[i] - plane >= \_slice2\_precision$$

and below it if

$$vals[i] - plane < \_slice2\_precision$$

For all intents and purposes, the user may assume that `_slice2_precision` is 0.0, as this is the default. However, we allow you to change this if you think you have good reason.

There is a conceptual difficulty for the case of a quad face all four of whose edges are cut by the slicing plane or surface. This can only happen when two opposite corners are above and the other two below the slicing plane. There are three possible ways to connect the four intersection points in two pairs: (1) `//` (2) `\\` and (3) `X`. There is a severe problem with (1) and (2) in that a consistent decision must be made when connecting the points on the two cells which share the face - that is, each face must carry information on which way it is triangulated. For a regular 3D mesh, it is relatively easy to come up with a consistent scheme for triangulating faces, but for a general unstructured mesh, each face itself must carry this information. This presents a huge challenge for data flow, which we don't believe is

worthwhile, because the X choice is unique, and we don't see why we shouldn't use it here. For contouring routines, we reject the X choice on aesthetic grounds, and perhaps that will prove to be the case here as well - but we believe we should try the simple way out first. In this case, we are going to be filling these polygons with a color representing a function value in the cell. Since the adjacent cells should have nearly the same values, the X-traced polygons will have nearly the same color, and we doubt there will be an aesthetic problem. Anyway, our implementation of `slice3`, `slice2`, and `_slice2_part` produces the unique X (bowtied) polygons, rather than attempting to choose between // or \\ (non-bowtied) alternatives. Besides, in the case of contours, the trivial alternating triangulation scheme is just as bad aesthetically as every zone triangulated the same way!

9.2 Some Yorick-like Functions: `yorick.py`

The module `yorick.py` contains a few functions similar to ones in Yorick, which perform array manipulations necessary in doing 3D graphics. Those array manipulations which were too slow to do in interpreted code have been put into a Python extension module `arrayfnsmodule` (see Section 9.3 "Additional Array Operations: arrayfnsmodule" on page 102). We shall depart from our usual format here, and just give the calling sequences followed by a short explanation for each of the functions.

`zcen_ (x, i = 0)`

Returns an array whose i^{th} dimension is one smaller than the i^{th} dimension of x, with the elements along the i^{th} being the averages of two adjacent elements in the original `x`. `i` cannot be larger than 5.

`dif_ (x, i = 0)`

Returns an array whose i^{th} dimension is one smaller than the i^{th} dimension of x, with the elements along the i^{th} being the differences of two adjacent elements in the original `x`. `i` cannot be larger than 5.

`maxelt_ (*x)`

`maxelt_` accepts a sequence of one or more possible multi-dimensional numerical objects and computes their maximum. In principle these can be of arbitrary complexity, since the routine recurses.

`minelt_ (*x)`

`minelt_` accepts a sequence of one or more possible multi-dimensional numerical objects and computes their minimum. In principle these can be of arbitrary complexity, since the routine recurses.

`rem_0_ (z)`

`rem_0_(z)` returns a copy of array `z` after having replaced any zero elements with `1.e-35`. Assumes `z` has one or two dimensions.

`avg_ (z)`

`avg_(z)` returns the average of all elements of its array argument.

`sign_ (x)`

Returns 1 if `x >= 0`, `-1` otherwise.

`timer_ (elapsed, *split)`

`timer_print (label, split, *other_args)`

see Section 8.16 "Timing: timer, timer_print" on page 94.

9.3 Additional Array Operations: `arrayfnsmodule`

A number of functions which emulate Yorick functions are used frequently by the 3D graphics, and in interpreted code simply run too slowly. These functions have been moved to arrayfnsmocule and written in C. Their diescriptions form this section of the manual.

9.3.1 Counting Occurrences of a Value: `histogram`

Calling Sequence

```
histogram (list [, weight])
```

Description

`histogram` accepts one or two arguments. The first is an array of non-negative integers and the second, if present, is an array of weights, which must be promotable to double. Call these arguments `list` and `weight`. Both must be one-dimensional with `len(weight) >= max(list) + 1`. If `weight` is not present:

`histogram(list)[i]` is the number of occurrences of `i` in `list`.

If `weight` is present:

`histogram(list, weight)[i]` is the sum of all `weight[j]` where `list[j] == i`.

9.3.2 Assigning to an Arbitrary Subset of an Array: `array_set`

Calling Sequence

```
array_set (vals1, indices, vals2)
```

Description

`array_set` accepts three arguments. The first is an array of numerics (Python characters, integers, or floats), and the third is of the same type. The second is an array of integers which are valid subscripts into the first. The third array must be at least long enough to supply all the elements called for by the subscript array. (It can also be a scalar, in which case its value will be broadcast.) The result is that elements of the third array are assigned in order to elements of the first whose subscripts are elements of the second.

```
arr_array_set (vals1, indices, vals2)
```

is equivalent to the Yorick assignment

```
vals1 (indices) = vals2
```

We have generalized this so that the source and target arrays may be two dimensional; the second dimensions must match. Then the array of subscripts is assumed to apply to the first subscript only of the target. The target had better be contiguous.

9.3.3 Sorting an array: `index_sort`

Calling Sequence

```
index_sort (x)
```

Description

`index_sort` accepts a one-dimensional array `x` of some numerical type and returns an integer array of the same length whose entries are the subscripts of the elements of the original array arranged in increasing order. We chose to use heap sort because its worst behavior is `n*log(n)`, unlike quicksort, whose worst behavior is `n**2`.

9.3.4 Interpolating Values: `interp`

Calling Sequence

```
interp (x, y, z)
```

Description

`interp (y, x, z)` treats `(x, y)` as a piecewise linear function whose value is `y [0]` for `x < x [0]` and `y [len (y) - 1]` for `x > x [len (y) - 1]`. An array of floats the same length as `z` is returned, whose values are ordinates for the corresponding `z` abscissae interpolated into the piecewise linear function.

9.3.5 Digitizing an array: `digitize`

Calling Sequence

```
digitize (x, bins)
```

Description

`bins` is a one-dimensional array of integers which is either monotonically increasing or monotonically decreasing. `digitize (x, bins)` returns an array of python integers the same length as `x` (if `x` is a one-dimensional array), or just an integer (if `x` is a scalar). The values `i` returned are such that `bins [i - 1] <= x < bins [i]` if `bins` is monotonically increasing, or `bins [i - 1] > x >= bins [i]` if `bins` is monotonically decreasing. Beyond the bounds of `bins`, returns either `i = 0` or `i = len (bins)` as appropriate.

9.3.6 Reversing a Two-Dimensional array: `reverse`

Calling Sequence

```
reverse (x, n)
```

Description

`reverse (x, n)` returns a `PyFloat` matrix the same size and shape as `x`, but with the elements along the n^{th} dimension reversed. `x` must be two-dimensional.

9.3.7 Obtaining an Equally-Spaced Array of Floats: `span`

Calling Sequence

```
span (lo, hi, num, d2 = 0)
```

Description

`span (lo, hi, num, d2 = 0)` returns an array of num equally spaced `PyFloat`s starting with `lo` and ending with `hi`. if `d2` is not zero, it will return a two-dimensional array, each of the `d2` rows of which is the array of equally spaced numbers.

9.3.8 Effective Length of an Array: `nz`

Calling Sequence

```
nz (x)
```

Description

`nz (x)`: `x` is an array of unsigned bytes (Python typecode `"b"`). If `x` ends with a bunch of zeros, this returns with the index of the first zero element after the last nonzero element. It returns the length of the array if its last element is nonzero. This is essentially the ‘‘effective length’’ of the array.

9.3.9 Finding Edges Cut by Isosurfaces: `find_mask`

Calling Sequence

```
find_mask (fs, node_edges)
```

Description

This function is used to calculate a mask of integers whose corresponding entry is 1 precisely if an edge of a cell is cut by an isosurface or plane, i. e., if the function `fs` is one on one of the two vertices of an edge and zero on the other (`fs = 1` represents where some function on the mesh was found to be negative by the calling routine). `fs` is `ntotal` by `nv`, where `nv` is the number of vertices of a cell (4 for a tetrahedron, 5 for a pyramid, 6 for a prism, 8 for a hexahedron). `node_edges` is a `nv` by `ne` array, where `ne` is the number of edges on a cell (6 for a tet, 8 for a pyramid, 9 for a prism, 12 for a hexahedron). The entries in each row are 1 precisely if the corresponding edge is incident on the vertex. The exclusive or of the rows which correspond to nonzero entries in `fs` contains 1 in entries corresponding to edges where `fs` has opposite values on the vertices. (The vertices and edges of a cell have a standard ordering which is discussed in “Standard ordering for the four types of mesh cells” on page 107.)

The mask returned by this function will be a one dimensional array `ntotal * ne` long. An entry `[i * ne + j]` in this mask will be `1` precisely if edge `j` of cell `i` is cut by the isosurface or plane.

9.3.10 Order Cut Edges of a cell: `construct3`

Calling Sequence

```
construct3 (mask, itype)
```

Description

Computes how the cut edges of a particular type of cell must be ordered so that the polygon of intersection can be drawn correctly. `itype` = 0 for tetrahedra; 1 for pyramids; 2 for prisms; 3 for hexahedra. Suppose `nv` is the number of vertices of the cell type, and `ne` is the number of edges. `mask` has

been `ravel`led so that it is flat; originally it had `2**nv-2` rows, each with `ne` entries. Each row is `ne` long, and has an entry of 1 corresponding to each edge that is cut when the set of vertices corresponding to the row index has negative values. (The binary number for the row index `+ 1` has a one in position `i` if vertex `i` has a negative value.) The return array `permute` is `ne` by `2**nv-2`, and the columns of permute tell how the edges should be ordered to draw the polygon properly.

9.3.11 Expand cell-centered values to node-centered values: `to_corners`

Calling Sequence

```
to_corners (values, nv, sumnv)
```

Description

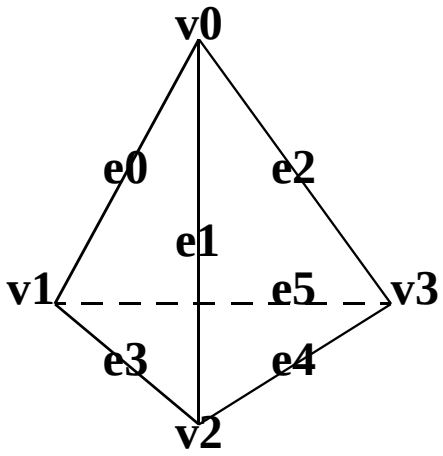
`values` is a one-dimensional array of floating point values defined on a set of polygons. `nv` is an integer array of the same size telling how many vertices each of the polygons has. `sumnv` is the sum of all the values in `nv`. This routine takes an array of floats describing cell-centered values and returns an array of node-centered values. It is very unsophisticated, merely creating an array of floats `sumnv` long, whose first `nv [0]` entries are all `values [0]`, next `nv [1]` entries are all `values [1]`, etc.

9.4 More `slice3` details

The way `slice3` works depends strongly on a standard ordering of the nodes, edges, and faces of mesh cells. In this section we shall delineate the standard ordering used. This ordering is encapsulated in various tables contained in `slice3.py` and `arrayfnsmodule.c`. The maintainer of this code must have an understanding of this order.

9.4.1 Standard ordering for the four types of mesh cells

Tetrahedra



On the illustration at the left, the vertices are numbered v0 through v4, and the edges, e0 through e5. The faces are numbered as shown in the following table:

TABLE 3. **tet face numbering**

face number	edges on face
f0	e0, e1, e3
f1	e0, e2, e5
f2	e1, e2, e4
f3	e3, e4, e5

Pyramids

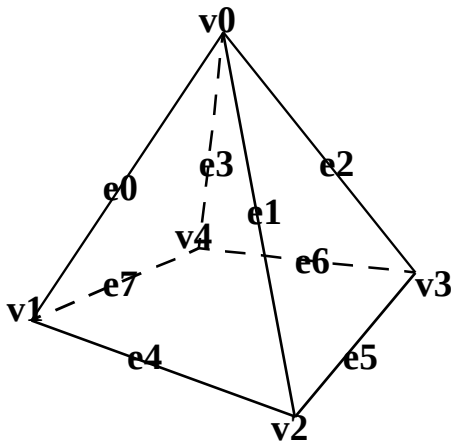


TABLE 4. **pyr face numbering**

face number	edges on face
f0	e0, e1, e4
f1	e1, e2, e5
f2	e2, e3, e6
f3	e0, e7, e3
f4	e4, e5, e6, e7

prisms

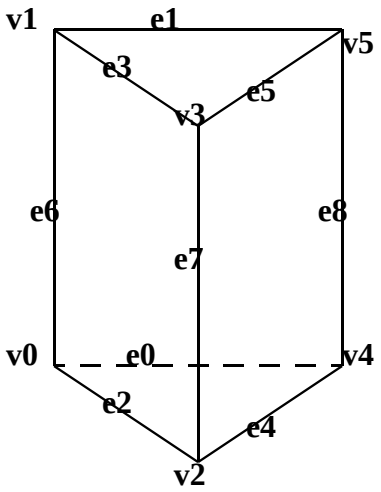


TABLE 5. **pri face numbering**

face number	edges
f0	e2, e7, e3, e6
f1	e0, e6, e1, e8
f2	e4, e8, e5, e7
f3	e0, e4, e2
f4	e1, e3, e5

hexahedra

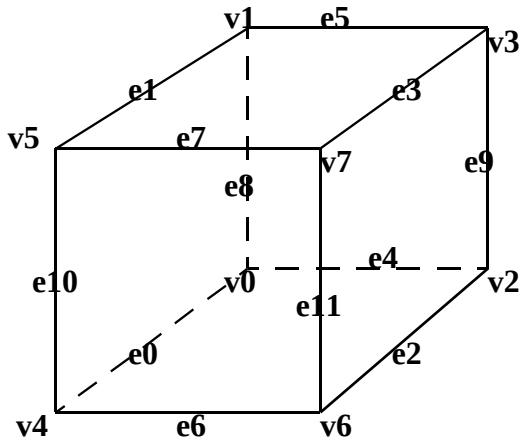


TABLE 6. **hex face numbering**

face number	edges
f0	e0, e6, e2, e4
f1	e1, e5, e3, e7
f2	e0, e8, e1, e10
f3	e2, e11, e3, e9
f4	e4, e9, e5, e8
f5	e6, e10, e7, e11

9.4.2 Standard numbering of cells in a regular rectangular mesh

Suppose we have a regular rectangular mesh whose cell dimensions are `ni - 1` by `nj - 1` by `nk - 1` (and thus the vertex array is `ni` by `nj` by `nk`). The total number of cells is

```
ncells = (ni - 1) * (nj - 1) * (nk - 1)
```

and the cells are numbered from `0` to `ncells - 1` according to the following scheme. Suppose that `(i, j, k)` are the maximum subscripts of the eight vertices of a cell numbered `N` in our scheme. Then the number of the cell with maximum vertex subscripts `(i, j, k + 1)` will be `N + 1`; the number of the cell with maximum vertex subscripts `(i, j + 1, k)` will be N + nk; and the number of the cell with maximum vertex subscripts `(i + 1, j, k)` will be `N + nj * nk`. Thus each triple of subscripts `(i, j, k)`, where none of the three is zero, uniquely determines a cell number, and cell numbers run consecutively as we increment the subscripts through their ranges (starting with `1`) in *row major* order. Similarly, we can number the vertices from 0 through `ni * nj * nk - 1` by numbering them consecutively as we increment the subscripts through their ranges (starting with `0`) in *row major* order.

This leads for the following scheme for computing the vertex numbers for all eight of the vertices of a cell, given the cell number. First, construct the scalar

```
N1 = N + N / (nk - 1) + nk * (N / ( (nk - 1) * (nj - 1)))
```

Then, add this scalar to each element of the 2 x 2 x 2 array

```
array ( [ [ [0, 1], [nk, nk + 1]],
          [ [njnk, njnk + 1], [nk + njnk, nk + njnk + 1]]])
```

The result is a 2 x 2 x 2 array of the vertex numbers of the vertices of the cell. Given that the arrays of vertex coordinates are stored in row major order, then if we `ravel` them (i. e., flatten them out), flatten the above array of vertex numbers, extract precisely those eight coordinates from each coordinate array, and then reshape them to 2 x 2 x 2, then we have the coordinates of the vertices of the cell under consideration.

The function `to_corners3` does this calculation for an arbitrary list of cell numbers (see 8.15 “Find Corner Indices of List of Cells: to_corners3”8.15 “Find Corner Indices of List of Cells: to_corners3”). The function `slice3` calls `to_corners3` with a list of cells which are cut by a plane or isosurface in a rectangular mesh in order to determine the coordinates of their vertices, the final goal being to find the points at which the edges are cut by the plane or isosurface. These edge points are then connected in a systematic way using (among other things) the numbering schemes described previously, in order to yield the polygonal sections through cells made by the plane or isosurface.

9.4.3 How `slice3` works

Recall the calling sequence of slice3 (see see Section 7.4.2 "slice3: Plane and Isosurface Slices of a 3-D mesh" on page 65):

```
[nverts, xyzverts, color] = \
   slice3 (m3, fslice, nv, xyzv [, fcolor [, flg1]]
   [, value = <val>] [, node = flg2])
```

The important arguments are `m3`, a mesh specification which was returned by an earlier call of `mesh3` (see 7.3.2 “Creating a mesh3 argument”); `fslice` (which specifies either the name of a slicing function, a slicing plane in `plane3` format (see Section 7.3.1 "Creating a Plane" on page 61), or the number of the function defined on the mesh with respect to which an isosurface is to be computed); `fcolor`, which (if `None`) specifies that the section is to be shaded, or (if a function) gives a

set of values on the the cells specified to it when `slice3` calls it; `value`, which in the case of an isosurface specifies the value of the function doing the slicing; and `node`, which if nonzero and color is calculated, says to return node-centered rather than cell-centered values.

One of the first things that `slice3` does is to call `iterator3` with `m3` as argument, which in turn calls the appropriate iterator for the particular type of mesh. (Recall that `m3` contains names of appropriate functions to call for this mesh.) The purpose of `iterator3` is to ''chunk'' up the mesh into manageable pieces; the main loop in `slice3` calls `iterator3` repeatedly until it finally returns `None`, signalling that the entire mesh has been processed. The details of both types of iterator are straightforward and can be had by inspecting the source code. One thing to bear in mind is that in the case of an unstructured mesh, `iterator3` is guaranteed to return a chunk which consists of only one type of cell.

Why ''chunk'' up the mesh? The creators of the Yorick version of slice3, Langer and Munro, did so in order to avoid the possibility of creating very large temporaries and thus, perhaps, having memory problems. It seemed to us judicious to do the same thing.

The first thing done inside the `slice3` main loop is to call the appropriate slicing function. Two functions are supplied in `slice3.py`. Their calling sequences and descriptions are as follows:

`_isosurface_slicer (m3, chunk, iso_index, _value)`

> an isosurface slicer brings back a list `[vals, None]` where `vals` is simply an array of the values of the `iso_index`th mesh function on the vertices of the specified chunk, or (in the unstructured case) a triple, consisting of the array of values, an array of relative cell numbers in the chunk, and an offset to add to the preceding to get absolute cell numbers.

`_plane_slicer (m3, chunk, normal, projection)`

> In the case of a plane slice, this returns a list `[vals, _xyz3]` (or `[ [vals, clist, cell_offset], _xyz3]` in the irregular case) where `_xyz3` is the array of vertices of the chunk. `_xyz3` is `ncells` by `3` by something (in the irregular case), `ncells` by `3` by `2` by `2` by `2` in the regular case,and `3` by `ni` by `nj` by `nk` otherwise. `vals` will be the values of the projections of the corresponding vertex on the normal to the plane, positive if in front, and negative if in back.

In addition, the user may supply a slicing function; if so, its calling sequence must be of the form

`fslice (m3, chunk)`

and it must return something resembling the returned values above. If the `m3` mesh is totally unstructured, the chunk should be arranged so that `fslice` returns an `ncells`-by-`2`-by-`2`-by-`2` [hex case] (or `ncells`-by-`3`-by-`2` [prism] or `ncells`-by-`5` [pyramid] or `ncells`-by-`4` [tet]) array of vertex values of the slicing function. Note that a chunk of an irregular mesh always consists of just one kind of cell. On the other hand, if the mesh vertices are arranged in a rectangular grid (or a few patches of rectangular grids), the chunk should be the far less redundant rectangular patch.

Determination of the Critical Cells

The critical cells are those cells (if any) which are cut by the slicing plane or isosurface. There are precisely those cells on the vertices of which the `vals` returned by the slicing function changes sign. For cells of one of the four types present in an unstructured mesh, one adds up the number of vertices on which vals is negative. If this is a positive number and also less than the number of vertices for that cell type, then the cell is critical. In the structured case, `vals` is `ni` by `nj` by `nk`. To the array which is `1` where `vals` is negative and `0` elsewhere, we apply the `zcen_` (see page 101) function along each of its three dimensions. The result is an array `ni - 1` by `nj - 1` by `nk - 1` of values defined on each cell which can be one of the nine values 0., .125, .25, .375, .5, .625, .75, .875, 1.0. Those cells where the value is strictly between the two end values are critical. Thus we form `clist`, which is an array of absolute cell numbers of the critical cells.

If `clist` is not empty, then we extract the coordinates of the critical cells, the data values at these points, and (if appropriate) the colors of the cells. In the case of a structured mesh, we use the `to_corners3` function discussed earlier (see page 109) to convert cell numbers to node numbers, in order to get the node coordinates and data. We append a list of this to our list of results (appending `[None, None, None, None]` if `clist` is empty) and then continue iterating.

Determination of the Cut Edges and the Intersection Points

Once this loop completes, there is another `for` loop which loops through each type of cell (structured meshes are lumped under hex cells) present in the mesh, putting together the ‘‘chunks’’ of results if necessary. It then calls `find_mask` (page 105), which returns a mask array `ncells * ne` long (`ncells` is the total number of cells of this type, `ne` the number of edges on a cell) which contains `1`’s corresponding to edges which are cut by the plane or isosurface (in the standard ordering discussed earlier in this chapter; see page 107). It is now easy to get the coordinates of the endpoints of the cut edges using the standard numbering embodied in the tables; we then linearly interpolate along the cut edges, based on the values on their endpoints, to obtain a list of coordinates of the intersections of the plane or isosurface with the cells. This list of points now needs to be ordered so that the polygons of intersection can be drawn properly.

Ordering of the Intersection Points

We associate with each critical cell a pattern number between 0 and 255 (non-inclusive) which denotes in one number the pattern of its vertices where the function value is negative. The pattern number is arrived at by assigning the number 2^k to the k^{th} vertex in the cell, then adding together for each cell the numbers assigned to its vertices that have negative values. We now create a new `pattern` array which is `ncells * ne` long and in which the entry corresponding to each cut edge contains the same pattern number as its adjacent cell; i. e., if cell `j` has cut edge `i` and pattern number `n`, then `pattern[i * ne + j]` will contain `n`.

The `_poly_permutations` array. To each pattern, there corresponds a permutation of the edges so that they occur in the order in which the edges are to be connected. Let each such permutation be stored as a list of integers from `0` to `ne - 1` such that sorting the integers into increasing order rearranges the edges at the corresponding indices into the correct order. (The position of unsliced edges

in the list is arbitrary as long as the sliced edges are in the proper order relative to each other.) Let these permutations be stored in a `ne`-by-`254` array `_poly_permutations`.

`_poly_permutations` is computed (one time only) as follows. When `slice3.py` is imported, `_construct3` is called four times, once for each type of cell. `_construct3` first creates a mask array `below` dimensioned `(2^nv - 2)` by `nv`. The row `below [k]` has an entry for each vertex, marked 0 or 1 corresponding to the pattern number `k + 1`. `_construct3` now calls `find_mask` (see 9.3.9 "Finding Edges Cut by Isosurfaces: find_mask") with parameters `below` and the `_node_edges` array for that particular type of cell. `find_mask` returns an array (called `mask`) `(2^nv - 1)` by `ne` in size; each set of `ne` consecutive entries is filled with an edge mask, i. e., the entry corresponding to an edge in the standard order is 1 or 0 according as the corresponding edge is cut or not. `_construct3` now calls `construct3`, a function in `arrayfnsmodule` (see 9.3.10 "Order Cut Edges of a cell: construct3"), with `mask` and the cell type as parameters.

The purpose of `construct3` is to determine an order for the cut edges so that the polygons representing the plane or isosurface cut of the cell will be drawn properly. `construct3` does this by calling an auxiliary function `walk3` inside a loop, each call of `walk3` being with the next `ne` entries of mask. `walk3` not only decides the correct order of the points of intersection in order to draw the polygons, but also decides whether there are disjoint polygonal intersections with this cell. The `walk3` algorithm begins with the lowest numbered cut edge (and marks that edge as having been used) and examines the lowest numbered face incident upon this edge. There must be at least one other cut edge on this face. If the face is triangular, it looks first at the next edge counterclockwise (in the outwards normal direction), then (if necessary) the next one clockwise. On a square face it looks first at the opposite edge, then at the next one clockwise, then counterclockwise. When it has selected an edge, it goes to the other face incident upon that edge and repeats the process. If at some point no unused edge can be found, then that means a closed polygon has been found. The next unused edge with the lowest number is chosen (if there is one) and the process repeats. In the latter case, there is more than one disjoint polygonal intersection with the cell, and the number `ne *` (no. of disjoint polygons so far) is added to the edge permutations.

Thus, for each cut cell in the mesh, `_poly_permutations` tells the order that the cutting points must be connected, and how many polygonal intersections there are with the cell. In the function slice3, the following instructions compute subscripts into the array of points in the correct order for drawing:

```
pattern = take (ravel (transpose (_poly_permutations [i])),
   _no_edges [i] * (pattern - 1) + edges) \
   + 4 * _no_edges [i] * cells
order = argsort (pattern)
```

The `order` array is now used as a set of subscripts so that we can extract the coordinates of the cutting points in the proper order. Once this has been done, the array whose entries give the number of vertices in each polygon is calculated.

There remains only the question of splitting the points in a single cell into multiple disjoint polygons. To do this, recall that when computing `_poly_permutations`, we had added `ne` (the number of edges on this type of cell) to any second disjoint polygon's edge list, `2 * ne` to any third one, etc. The following will now give an array whose entries corresponding to the edge orderings for each cell will be 0 for the first disjoint polygon, 1 for the second, 2 for the third, and 3 for the fourth (if there

are that many).

```
pattern = pattern / _no_edges [i]
```

Now pattern jumps by 4 between cells, smaller jumps within cells get the list of places where a new value begins, and form a new pattern with values that increment by 1 between each plateau. Then the following relatively straightforward computation computes the `nverts` array. In order to fully appreciate how the algorithm works, we have indicated the results supposing that we began with the pattern [0, 0, 0, 1, 1, 1, 1, 2,2,2,4,4,4,4,4,5,5,5,8,8,8].

```
pattern = dif_ (pattern, 0)
#[0,0,1,0,0,0,1,0,0,1,0,0,0,0,1,0,0,1,0,0]
nz = nonzero (pattern)
#[2,6,9,14,17]
list = zeros (len (nz) + 1, Int)
#[0,0,0,0,0,0]
list [1:] = nz + 1
#[0,3,7,10,15,18]
newpat = zeros (len (pattern) + 1, Int)
#[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
newpat [0] = 1
newpat [1:] = cumsum (not_equal (pattern, 0)) + 1
#[1,1,1,2,2,2,2,3,3,3,4,4,4,4,4,5,5,5,6,6,6]
pattern = newpat
nverts = histogram (pattern) [1:]
#[3,4,3,5,3,3]
```

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