

Plot

1 overview

`Plot` is a package of programs written in Shang language for creating scientific graphs and mathematical illustrations. These graphs and drawings can be 2D or 3D, black and white or colored. The graphs are saved as postscript files which can be easily viewed or converted to other image formats.

The original purpose of `plot` is to test the OOP related features of Shang. Currently it has a number of limitations to overcome. These include problems related to text alignment, non-ascii text printing, legend, hidden surface removal, and better treatment of intersection of surfaces, etc.

2 Postscript viewer

`plot` is not part of the core of the language — it is a program written in Shang. Shang does not have built-in graphical capabilities. The figures produced by the `plot` program are postscript files and need a viewer to be displayed and printed.

1. Install postscript and ghostview on your computer so that postscript files can be viewed, printed, and converted to other formats. For MS Windows, the programs can be obtained from

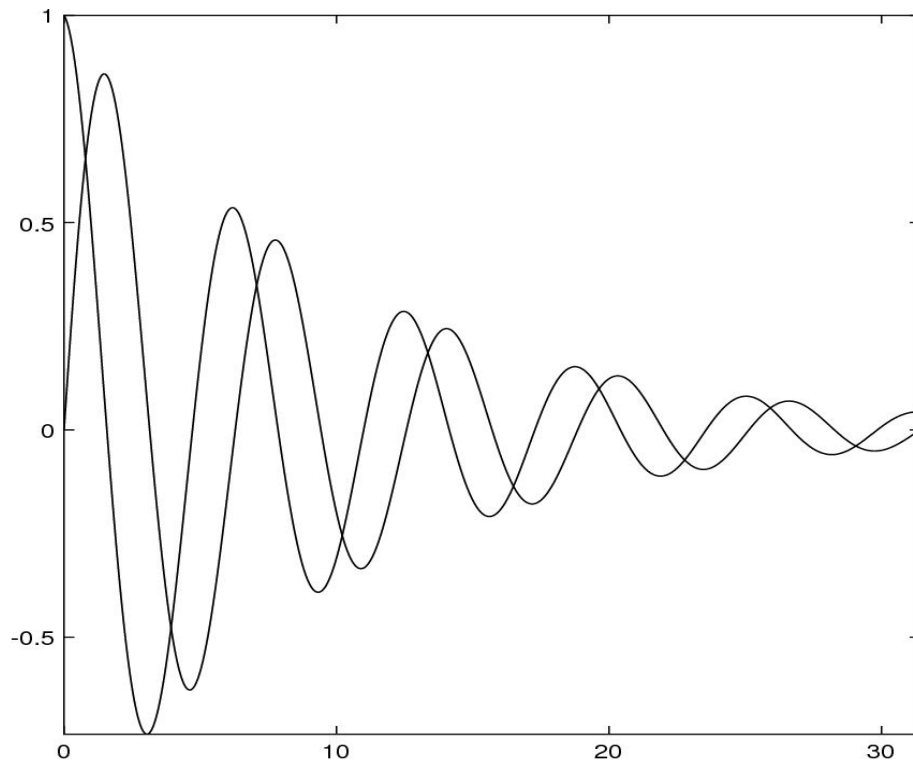
<http://pages.cs.wisc.edu/~ghost/>

2. Run `plot.x` before making any plot. This can be done manually or putting `with("plot.x")` in your program.

3 A simple example

After running the following commands, the graphs of the two functions $y = \cos x e^{-0.01x}$ and $y = \sin x e^{-0.01x}$ will be plotted and saved in the file `test.eps`.

```
with("plot.x");
x = linspace(0, 10 * pi, 500);
y1 = cos(x) .* exp(-.1 * x);
y2 = sin(x) .* exp(-.1 * x);
fig = figure.new();
fig.plot(x, y1);
fig.plot(x, y2);
fig.save("test.eps");
```



4 Structure of plot

The whole program resides in the file `plot.x`. It consists of the following classes, and a few global variable definitions.

`epspainter`

a postscript driver with many plotting commands. It is possible to work with these low level routines directly if you're familiar with the postscript language. This class is not documented and you need to look into the source file in order to use it.

`figure`

2d figure class for creating 2D graphs. There are several attributes corresponding to the the building blocks of figures. All are modifiable. If you want to improve them you can look through the source file.

`figure3d`

3d figure class. Draw 2d surfaces and 1d curves in space.

`histogram`

creating bar graphs given a set of data.

`piechart`

creating pie charts given a set of percentages.

5 2D plot

`figure` is a *class*. To make a 2D plot, you first create a member of the this class. It is like a blank canvas and you can add graphical elements such as curves, lines, symbols, etc, to it using functions defined for `figure` class. When everything is added to the figure, it can be saved in a postscript file, which can then be displayed or printed.

1. Create a figure.

Use the following command to create a figure and assign it to a variable named "fig":

```
fig = figure.new();
```

2. Plot data.

`plot` is an attribute function of `figure` and can treat two vectors `x` and `y` as coordinates of the locations of a sequence of points in the 2d plane. Marks can be drawn at these locations, or lines and curves drawn through them. The command for plotting `x` and `y` data on figure `fig` is

```
fig.plot(x, y, linestyle, linewidth, color, gray);
```

where `x` and `y` are two vectors of the same length. The plot can be straight line segments joining the points, marks placed at the locations defined by `x` and `y`, or a smooth curve (a piece-wise cubic polynomial) through the dots. The type of the plot is specified by the argument `linestyle`.

| | | | |
|----------|---------|-----------|----------------|
| solid | — | dotty | |
| dash | - - - - | dashdot | — . — . — . |
| dot | | circle | o o o |
| oval | ◡ ◡ ◡ ◡ | square | □ □ □ |
| diamond | ◇ ◇ ◇ | cross | × × × |
| flake | * * * | asterisk | * * * |
| triangle | △ △ △ | dtriangle | ▽ ▽ ▽ |
| plus | + + + | curve | (smooth curve) |

`linewidth` is a number. The line to be drawn will be `linewidth` times as wide as the default linewidth. For example, to make the line twice as wide as the normal, use value 2.

`color` is a vector of three numbers between 0 and 1, with each component representing the intensity of red, green, or blue. `gray` is a number between 0 and 1.

It's not necessary to provide all the arguments to `plot`. The default values of `linestyle`, `linewidth`, `color`, and `gray` are "solid", 1, [0, 0, 0], and 1. Therefore a simple call

```
fig.plot(x, y);
```

will draw solid straight line segments through the (x, y) points; the width of the lines is 1 unit, and the color is black. This is because that when calling a function, you may provide only the first few arguments, the others will receive default values. For example,

```
xx = [0, 1, 2, 3, 4, 5];  
yy = [0, 1, 0.5, 0.75, 0.625, 0.6875];  
fig.plot(x, y);
```

To change the line type,

```
fig.plot(xx, yy, "oval");
```

To change the line width as well

```
fig.plot(xx, yy, "oval", 2);
```

If you just want to specify the line width, you still have to provide at least the first four arguments, but you can use default value for the third argument `linetype`

```
fig.plot(xx, yy, *, 2);
```

Named argument By the previous way of calling `fig.plot`, the order of arguments have to match the signature of the function. Alternatively, you can use *named arguments*. For example

```
fig.plot{x = xx, y = yy, linewidth = 2};
```

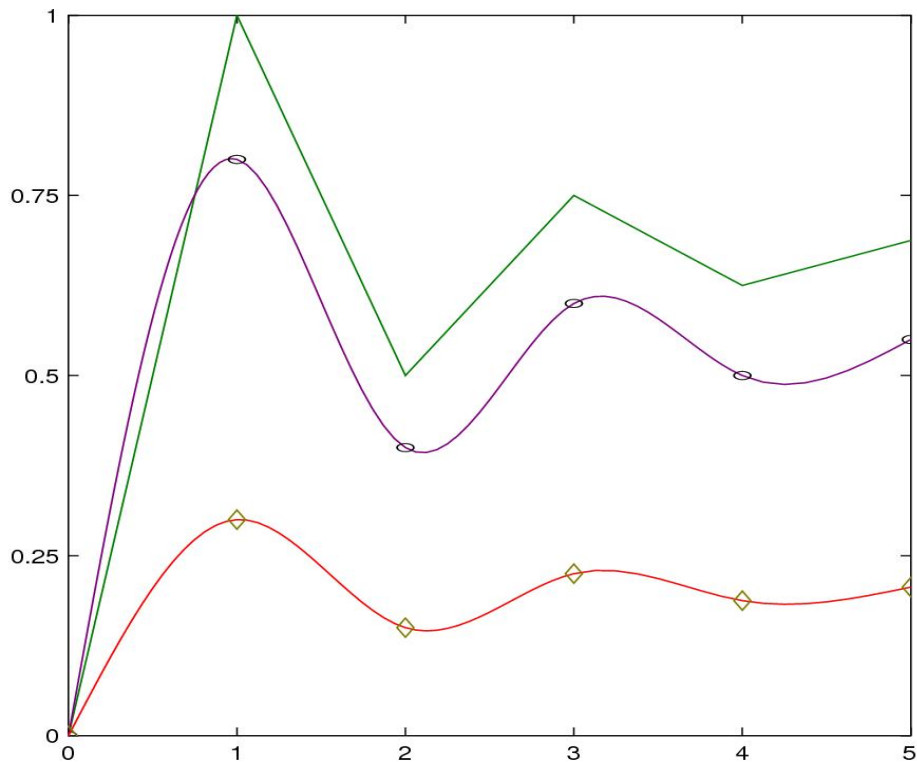
Note that you can not only skip certain arguments, but don't have to follow any specific order of argument either. For example

```
fig.plot{y = yy, linewidth = 2, x = xx};
```

However you still need to provide the correct names of the arguments, namely, `x`, `y`, `linewidth`, etc.

Example

```
xx = [0, 1, 2, 3, 4, 5];  
yy = [0, 1, 0.5, 0.75, 0.625, 0.6875];  
fig = figure.new();  
fig.plot(xx, yy, *, *, colors.green);  
fig.plot(xx, yy*0.8, "curve", *, colors.purple);  
fig.plot(xx, yy*0.8, "oval");  
fig.plot{x = xx, y = yy*0.3, linetype = "curve", color = colors.red};  
fig.plot{x = xx, y = yy*0.3, linetype = "diamond", linewidth = 2, color = colors.olive};  
fig.save("symbols.eps");
```



3. Draw objects

Some simple shapes can be drawn on the canvas without first defining data.

- line

To draw a line segment you need to specify the starting and the end points.

```
fig.line(P0, P1, style, linestyle, linewidth, color);
```

where P0 and P1 are the starting and end points of the line segment. **style** is one of "-", "->", "<-", or "<->" which specifies whether one end or both ends of the line has an arrow. **linestyle** is either "solid" or "dotted".

- polygon

The command

```
fig.polygon(x, y, type, color);
```

will draw a polygon given the x and y coordinates of the vertices. **type** can be "contour" or "solid", which specifies whether the polygon is hollow or solid.

- rectangle

The command

```
fig.rectangle(x, y, width, height, style, cornersize, type, color);
```

will draw a rectangle given the x and y coordinates of the center, the width, and the height. **style** can be "plain", "rounded", or "beveled", which specifies the shape of the four corners of the rectangle. **type** can be either "contour" or "solid".

- ellipse

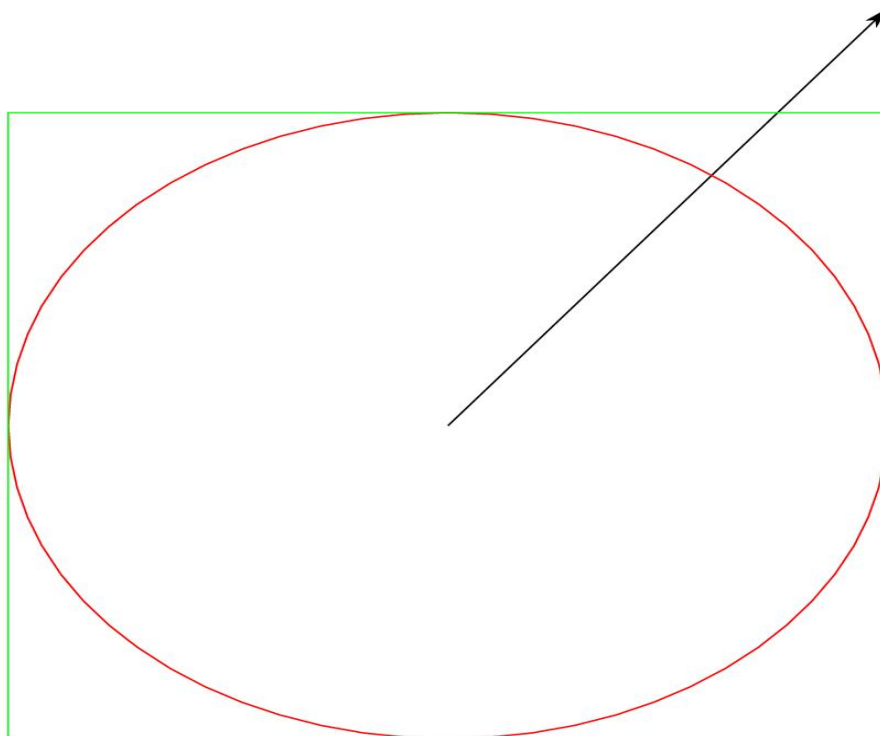
The command

```
fig.ellipse(ox, oy, a, b, theta, type, color);
```

draws an ellipse. It place the center of the ellipse at the location whose coordinates are `ox` and `oy`. `a` and `b` are the long and short axes, `theta` is the angle between the long axis of the ellipse and the horizontal direction of the canvas, `type` is either "contour" or "solid".

Example

```
fig = figure.new();  
fig.line([0, 0], [2, 2], "->");  
fig.ellipse{ox = 0, oy = 0, a = 2, b = 1.5, theta = 0, color = colors.red};  
fig.rectangle{x = 0, y = 0, width = 4, height = 3, color = colors.lime};  
fig.style = "empty";  
fig.save("objects.eps");
```



4. modify figure attributes

A **figure** has the following attributes that can be modified.

- style

This is the setting surrounding the figure. It can be put in a nice box, can come the horizontal and vertical axes, or coordinate grids. This feature is called the “style” of the figure and the value is one of "boxed", "grid", "center", or "empty". To change the style of a figure to "center"

```
fig.style = "center";
```

- title

It's the title of the figure, which is displayed on the top. The value should be a string. For example, to set the title of the figure to “The cosmos”

```
fig.title = "The cosmos";
```

- xlabel

The label of the horizontal axis. The value should be a string. To set the xlabel to “Time”

```
fig.title = "Time";
```

- ylabel

The label of the vertical axis. Works the same way as the horizontal axis.

- getXrange

This attribute is a function. It returns the width of the clipping area of the plot. The clipping area is a rectangular box. Anything out of the box is not shown on the actual image. The default values of `xrange` and `yrange` would try not to clipp off anything.

To check the `xrange` of the figure

```
r = fig.getXrange();
```

- getYrange

`fig.getYrange.()` returns the `yrange` of the clipping box of the plot.

- setXrange

A function attribute. To set the `xrange` to `[-5, 5]`

```
fig.setXrange([-5, 5]);
```

- setYrange

Similarly to `setXrange`, `fig.setYrange(yr)` sets the height of the clipping box to `yr`, which is vector of 2 numbers.

5. Print text

A character string can be printed anywhere in the graph. The location, size, and other attributes of the text can be specified, but it usually would take some trial and error to get it right or satisfactory. The following is the command for printing text

```
fig.print(x, y, contents, orientation, alignment, color, font, fontstyle,
fontscale);
```

where `x` and `y` are the coordinates of the location of the text, `contents` is the text to be printed (a string of characters). The other values are as follows:

| argument | allowed values |
|--------------------------|---|
| <code>orientation</code> | "portrait", "landscape" |
| <code>alignment</code> | "left", "right", "center", "top", "bottom", |
| <code>font</code> | "Helvetica", "Times", "Courier", "Symbol" |
| <code>fontstyle</code> | "Regular", "Bold", "Italic", "BoldItalic" |
| <code>fontscale</code> | positive number |
| <code>color</code> | vector of three number between 0 and 1 |

6. Save a figure.

You won't see any picture until you save the `figure` in a file. To save the figure as an encapsulated postscript file, do `fig.save(filename)`. For example

```
fig.save("flowering-times.eps");
```

Note that most of the processing occurs when the figure is being saved, therefore if there's something wrong with the plotting commands, error messages usually are not produced until at this stage.

After a figure is saved, it still exists and more contents can be added to it and then it can be saved again.

7. Reset a figure

If you're not satisfied with how a figure looks, you can erase everything in it by using `clear`. To delete all elements in a figure and leave it empty

```
fig.clear();
```

Or you could simply redo `fig = figure.new()` — the previous value of `fig` is destroyed.

8. Working with color

A color a vector of length three with each element (a number between 0 and 1) representing the intensity of red, green, or blue. Sixteen colors are predefined in the global variable `colors`.

```
global.colors = {
    black = [0, 0, 0],
    gray = [0.5, 0.5, 0.5],
    silver = [0.75, 0.75, 0.75],
```



```

white = [1, 1, 1],
yellow = [1, 1, 0],
lime = [0, 1, 0],
aqua = [0, 1, 1],
fuchsia = [1, 0, 1],
red = [1, 0, 0],
green = [0, 0.5, 0],
blue = [0, 0, 1],
purple = [0.5, 0, 0.5],
maroon = [0.5, 0, 0],
olive = [0.5, 0.5, 0],
navy = [0, 0, 0.5],
teal = [0, 0.5, 0.5]
};

```

To specify a color, one can give the rgb vector like

```
fig.plot{x = xx, y = yy, color = [0.5, 0.7, 0.2]};
```

or use one of the predefined colors like

```
fig.plot{x = xx, y = yy, color = colors.olive};
```

New color definition can be easily added to the global variable `colors`. For example:

```
global.colors.lavender = [0.6, 0.35, 0.73];
```

6 3D plot

The 3D figure class can draw surfaces defined by parametric functions, and space curves or meshes according to the given data. If only one object is plotted, the result is usually satisfactory. If several surfaces in the space are shown at the same time, the correction depiction of the intersections cannot be achieved efficiently.

6.1 Plot objects in 3D space

To make a 3D plot, you first create a member of the the class `figure3d`.

1. To create a 3D figure

```
fig = figure3d.new();
```

2. Plot a surface

```
plot(xf, yf, zf, urange, vrange, meshsize, frontcolor, bgcolor, type);
```

where `xf`, `yf`, and `zf` are the three parameteric equations that define the surface to be drawn. Each of them is a function of two parameters. For example, the unit sphere can be represented by the following three equations

$$x = \cos u \cos v$$

$$y = \cos u \sin v$$

$$z = \sin u$$

`urange` is the range of the first parameter. `vrange` is the range of the second parameter.

`meshsize` is a vector of two numbers, which specifies how many points are sampled on `urange` and `vrange`. If these numbers are big, the surface will be finer and smoother; otherwise it be more like a polyhedron rather than a smooth surface.

`frontcolor` and `bgcolor` are the colors of the front side and the back side of the surface respectively. Here we suppose that the surface is orientable, i.e., it has two sides.

`type` is either `solid` or `contour`. If `type` is `solid`, the interior of the polygon is painted with the specified color, otherwise only the boundary is painted.

A semisphere can be drawn using this command

```
fig = figure3d.new();
xf = (u, v) -> cos(u) * cos(v);
yf = (u, v) -> cos(u) * sin(v);
zf = (u, v) -> sin(u);
fig.plot(xf, yf, zf, [-pi/2, 0 ], [0, 2 * pi]);
fig.save("semisphere.eps");
```

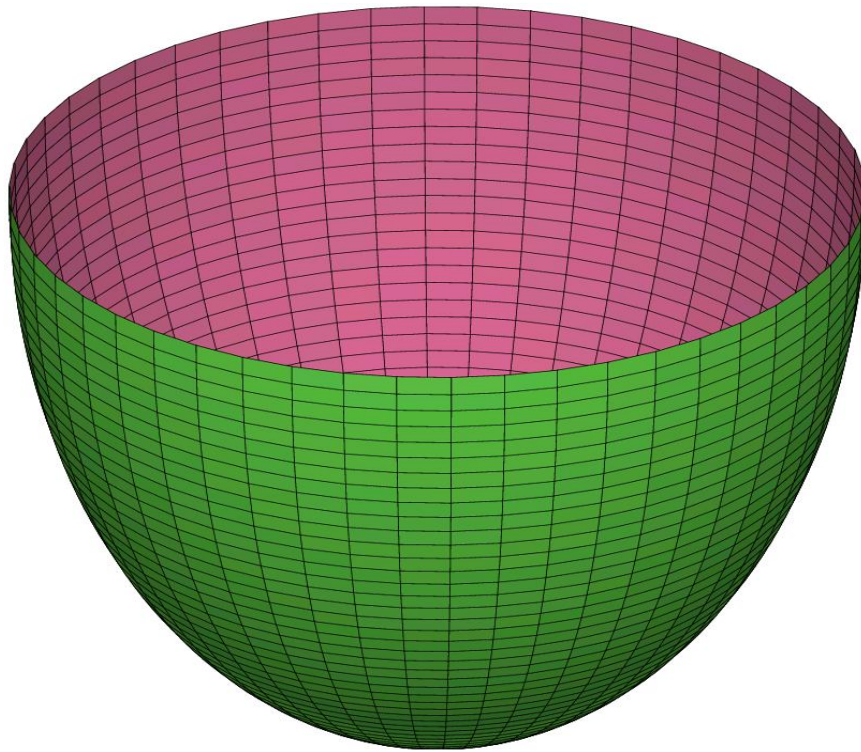
In the above `meshsize`, `frontcolor`, `bgcolor`, and `type` are not specified — the default values are used.

3. Plot 1D data in space

Draws a smooth curve through a set of points in the space.

```
fig.curve(x, y, z, color, lw);
```

`x`, `y`, and `z` are three vectors of the same length which are treated as the coordinates of dots in the space; a smooth curve with width `lw` through the dots will be drawn. Without some background, it is very hard to tell if a curve is in 3D space. So in the following example, we plot three orthogonal planes to reveal the dimension



```

fig = figure3d.new();
fig.light_direction = [2/3, 1/3, 3/5];
gx = (y, z) -> 0;
gy = (x, z) -> 0;
gz = (x, y) -> 0;
fig.plot(gx, (y,z)->y, (y,z)->z, [0, 30], [0, 30], [4, 4], rand(3), rand(3));
fig.plot((x,y)->x, (x,y)->y, gz, [0, 30], [0, 30], [4, 4], rand(3), rand(3));
fig.plot((x,z)->x, gy, (x,z)->z, [0, 30], [0, 30], [4, 4], rand(3), rand(3));
t = linspace(0, 10 * pi);
x = 6 * cos(t) + 10;
y = 6 * sin(t) + 10;
fig.curve(x, y, t, colors.red, 3);
fig.save("spiral.eps");

```

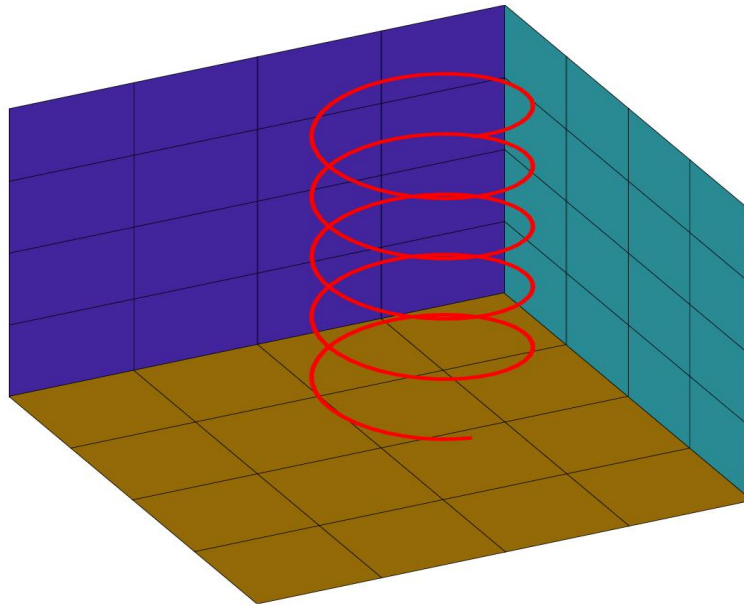
4. Plot a polygon in space

```
fig.polygon(x, y, z, nv, frontcolor, bgcolor);
```

Draws a polygon whose vertices are x , y , and z , normal direction is nv (a 3d vector), colors of front and back are `frontcolor` and `bgcolor`.

5. Plot 2D data in space

This is like a uniform discretization of a surface $z = f(x, y)$ over the rectangle $[0, m] \times [0, n]$. You only need to provide the z coordinates of the points on the surface.



```
fig.mesh(v, frontcolor, bgcolor);
```

v is a $m \times n$ matrix whose elements are treated as the z coordinates of a set of points. The x and y coordinates are the $0, 1, \dots, m - 1$ and $0, 1, \dots, n - 1$.

6.2 Customize the plot

A member of the `figure3d` class has the following attributes:

1. `light_direction`

It's a 3d vector at which the the 3d objects are projected. For example, `fig.light_direction = [1, 1, 0.5]`.

2. `type`

It specifies if the axes are plotted. Choose "boxed" or "empty". For example, `fig.type = "empty"` will make a graph without axes.

3. `hsr`

`hsr` specifies how hidden surface removal is done.

Choose from "auto", "bsp", or "painter". "painter" is more efficient and results in a smaller image size, while "bsp" (binary spatial partitioning) is supposed to render the intersection of the surfaces more accurately. Use `fig.hsr = "auto"` to let algorithm be automatically selected.

7 Bar graph

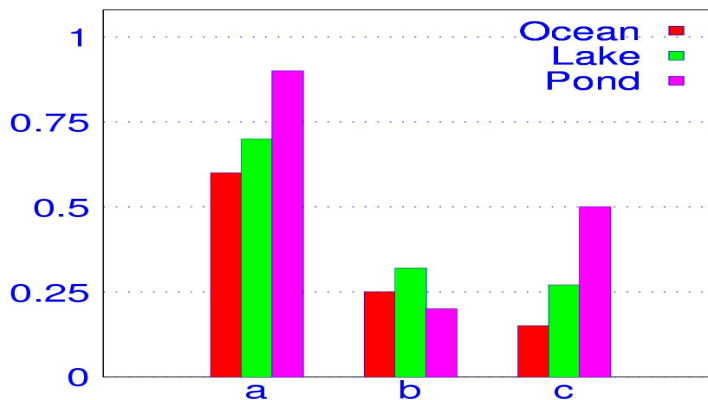
This is a class for creating bar graphs. It draw bars whose lengths are proportional to a small set of data values and hence visually display and compare the data values.

The class is called `histogram`. To create a memeber of this class

```
h = histogram.new(xlabels, yvalues, grouplabels);
```

where `xlabels` is the labels displayed on the horizontal axis used to identify each value. `yvalues` are the values to be compared. `grouplabels` is the labels used to identify each group of data. It can be left out if there's only one group.

```
hist = histogram.new(("a", "b", "c"), ((0.6, 0.25, 0.15), (0.7, 0.32, 0.27), ...  
                                     (0.9, 0.2, 0.5)), ("Ocean", "Lake", "Pond"));  
hist.save("hist.eps");
```



8 Pie chart

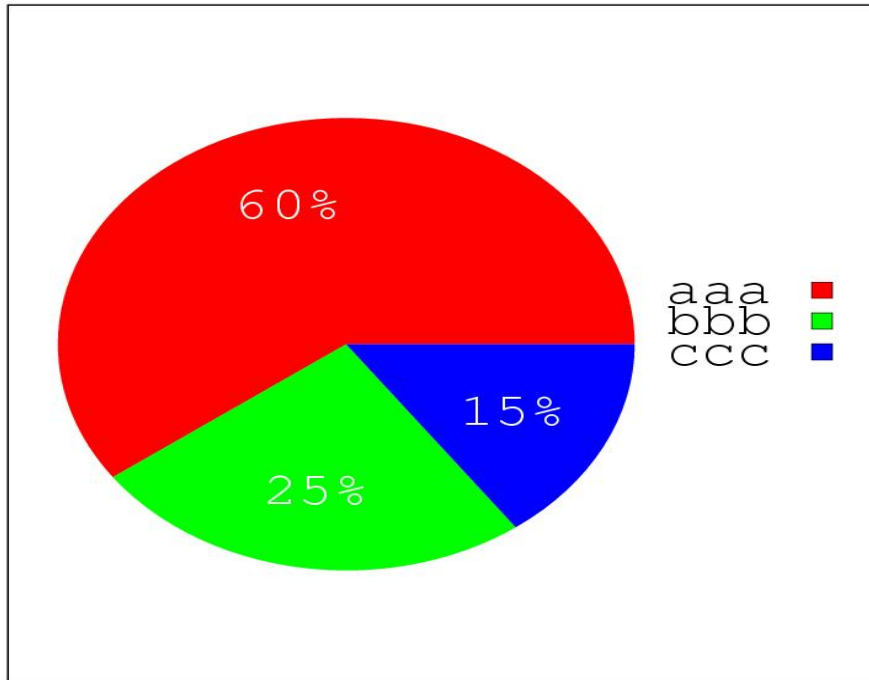
A pie chart is a circular disk divided into sectors with the angles proportional to a set of frequencies. This is how a pie chart is created.

```
chart = piechart.new(percentages, labels);
```

where `percentages` is the vector of percentages (must add up to 1), and `labels` is a list of strings used to identify each percentage.

```
chart = piechart.new((0.6, 0.25, 0.15), ("aaa", "bbb", "ccc"));  
chart.font = "Courier";  
chart.save("pie.eps");
```

test pie chart



9 Tips

- The `plot` program can function like a normal drawing tool — the only difference is that you have to type commands instead of using mouse. While it may seem not as convenient as using a normal painter program, the advantage of using commands is that it is very easy to modify and improve them. With Shang `plot`, a graph is very portable, — it is no more than a few commands saved in a file. Besides, `plot` has all the numerical computing capabilities of Shang at its disposal.
- There's no need to plot everything before you save the figure. You can save the figure every time you add something to the figure or make a change to it. After saving, the postscript viewer will refresh the image, so that your command takes effect right away.
- Put all the plotting commands in a file. Keep editing it and then running it until the figure is satisfactory.

10 Examples

1. Lines and curves

```
with("plot.x");  
  
x = linspace(-5, 5, 10);  
fig = figure.new();
```

```

/* draw small circles at (x,y) locations */
/* color is vector of 3 numbers between 0 and 1, in rgb format */
fig.plot{x=x, y=cos(x), linetype="circle", color=[1, 0, 0]};

/* connect the dots with solid lines,
   linetype is the default value "solid" */
fig.plot{x=x, y=cos(x), color=[0,1,0.5]};

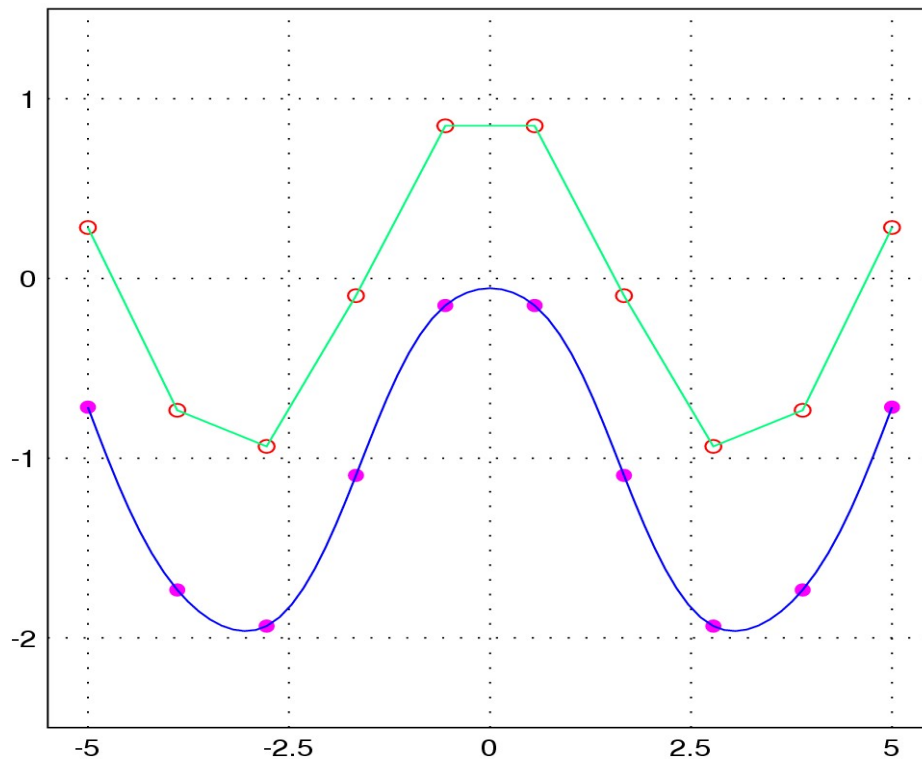
/* draw circular dots at location underneath the previous curve */
fig.plot{x=x, y=cos(x) -1, linetype="dot", color=[1, 0, 1]};

/* connect the dots with smooth curve */
fig.plot{x=x, y=cos(x) -1, linetype="curve", color = [0, 0, 1]};

/* set the xrange and yrange of the picture */
fig.setXrange([-5.5, 5.5]);
fig.setYrange([-2.5, 1.5]);

fig.save("curves.eps");

```



2. Butterfly curves

```

with("plot.x");

fig = figure.new();

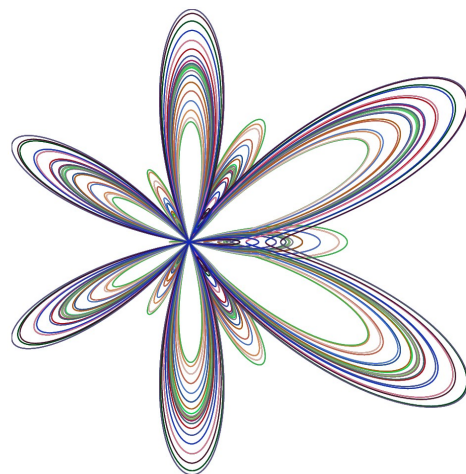
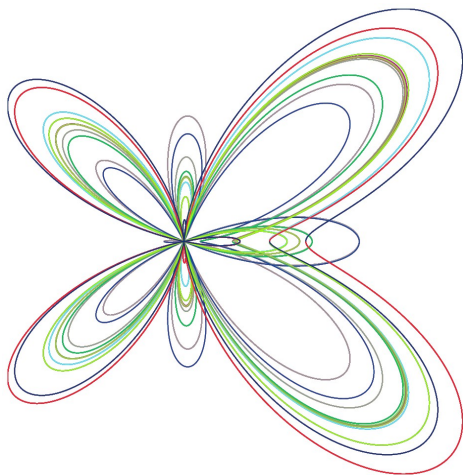
for k = 0 : 99
    theta = linspace(k * 2 * pi, (k + 1) * 2 * pi, 500);
    rho = exp(cos(theta)) - 2 * cos(4*theta)+sin(theta/12).^5;
    x = rho .* cos(theta);
    y = rho .* sin(theta);
    fig.plot{x=x, y=y, linetype="curve", color=rand(3)};
end

fig.style = "empty";
fig.save("butterfly.eps");

fig = figure.new();
for k = 0 : 99
    theta = linspace(k * 2 * pi, (k + 1) * 2 * pi, 500);
    rho = exp(cos(theta)) - 2.1 * cos(6*theta)+sin(theta/30).^7;
    x = rho .* cos(theta);
    y = rho .* sin(theta);
    fig.plot{x=x, y=y, linetype="curve", color=rand(3)};
end

fig.style = "empty";
fig.save("butterfly2.eps");

```



3. Sierpinsky Gasket

```
fig = figure.new();
```



```

h = 10 * sin(pi/3);
x = [-5, 5, 0];
y = [-h/3, -h/3, h*2/3];

/* the big solid triangle */
fig.polygon(x, y, "solid", [0.2, 1, 0.2]);

/* recursively remove the center of triangle whose vertices are x and y */
/* figp is pointer to fig object. It needs to be a pointer since function
   remove_triangle_center will modify the figure object
*/
remove_triangle_center = function (figp, x, y) -> ()
    L = norm([x[2] - x[1], y[2] - y[1]]);
    xo = x.mean;
    yo = y.mean;

    /* midpoints of the sides */
    xm = [x[1] + x[2], x[2] + x[3], x[3] + x[1]] / 2;
    ym = [y[1] + y[2], y[2] + y[3], y[3] + y[1]] / 2;

    /* [1, 1, 1] is color white -- to remove the center */
    figp >>. polygon(xm, ym, "solid", [1, 1, 1]);

    theta = pi/5;
    for k = 1 : 10
        cx = xo + L * 0.08*cos(k * theta);
        cy = yo + L * 0.08*sin(k * theta);

        /* draw an ellipse; x and y are center coordinates
           0.5 and 0.4 are long and short axis
           0 is angle between long axis and horizontal
           "contour" is the style -- other option is "solid"
           [1, 0, 1] is the color -- r=1, g=0, b=1
        */
        figp >>. ellipse(cx, cy, 0.04 * L, 0.03 * L, 0, "contour", [1, 0, 1]);
    end

    if L >= 1
        this(figp, [xm[1], x[2], xm[2]], [ym[1], y[2], ym[2]]);
        this(figp, [xm[2], x[3], xm[3]], [ym[2], y[3], ym[3]]);
    end

```

```

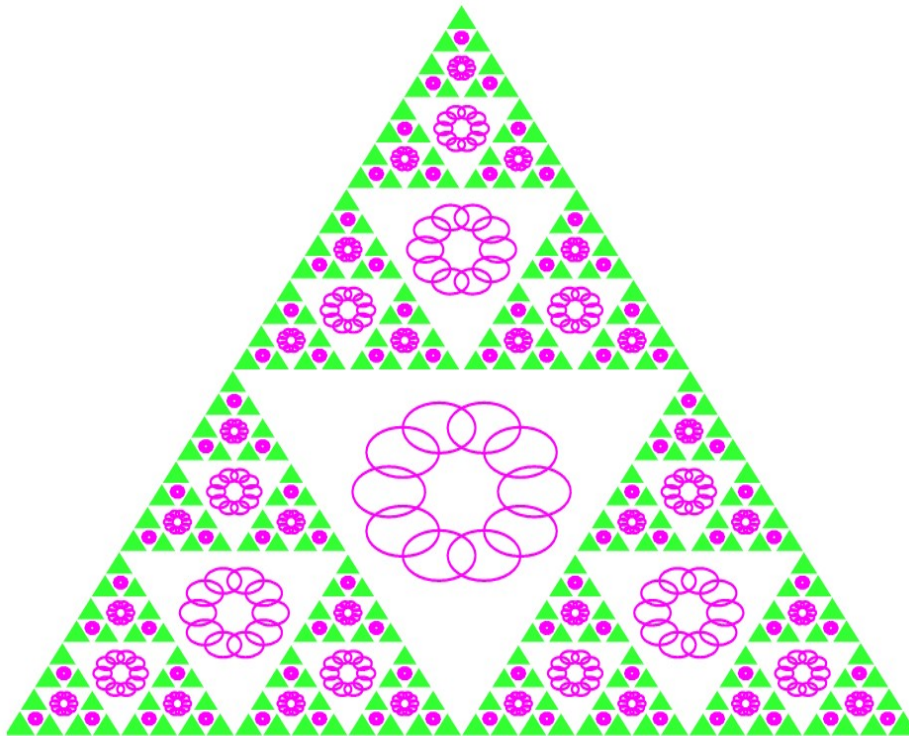
        this(fig, [xm[3], x[1], xm[1]], [ym[3], y[1], ym[1]]);
    end
end

remove_triangle_center(>>fig, x, y);

fig.setXrange([-5, 5]);
fig.setYrange([-5, 9]);

fig.title = "Sierpinsky Gasket with flower pattern";
fig.style = "empty";
fig.save("gasket.eps")

```



4. Fractal Fern

```

with("plot.x");
N = 50000;

x = zeros(N);
y = zeros(N);
x[1] = 0.5;
y[1] = 0.5;

```

```

z = [0.5; 0.5];
p = [0.85, 0.92, 0.99, 1.00];
A1 = [0.85, 0.04; -0.04, 0.85];
b1 = [0; 1.6];
A2 = [0.20, -0.26; 0.23, 0.22];
b2 = [0; 1.6];
A3 = [-0.15, 0.28; 0.26, 0.24];
b3 = [0; 0.44];
A4 = [0, 0; 0, 0.16];

for k = 2 : N
    r = rand(1);
    if r < p[1]
        z = A1 * z + b1;
    elseif r < p[2]
        z = A2 * z + b2;
    elseif r < p[3]
        z = A3 * z + b3;
    else
        z = A4 * z;
    end
    x[k] = z[1];
    y[k] = z[2];
end

fig = figure.new();
fig.plot{x=x, y=y, linetype="dot", linewidth=0.2, color=[0.0, 0.9, 0.3]};
//fig.plot{x=x, y=y};
fig.style="empty";
fig.save("fern.eps");

```

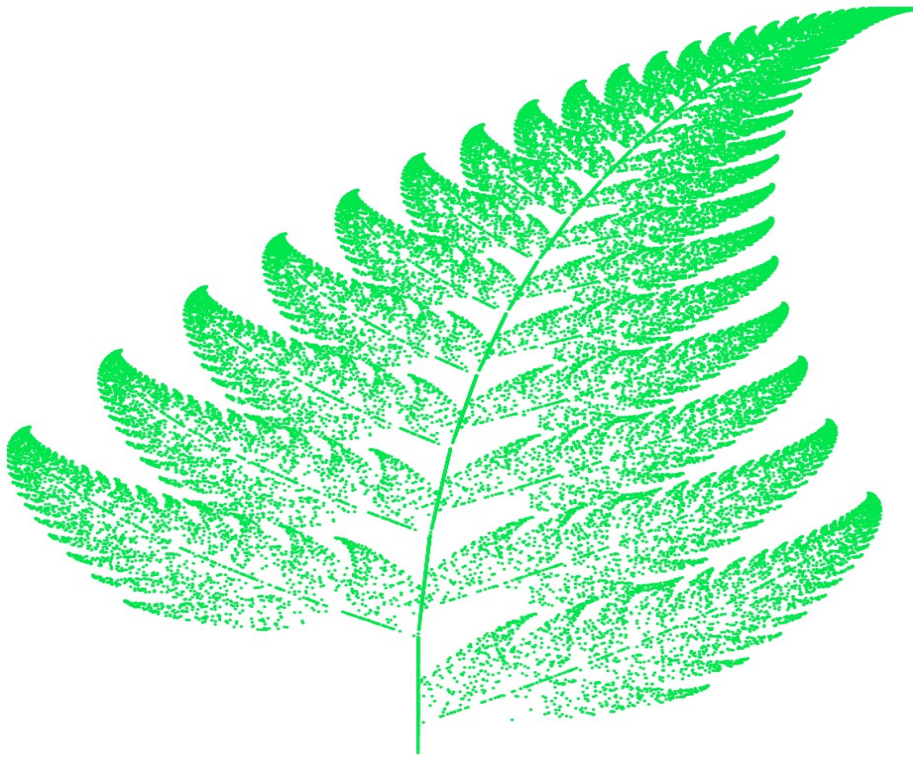
5. Bushes

```

with("plot.x");

/* generate a tree of n generations */
generate_tree = function (T0, fatom, xatom, n) -> T
    T = T0;
    for j = 1 : n
        t = T;
        T = "";
    end
end

```



```
for k = 1 : t.length
    if t[k] == "F"
        T = T + fatom;
    elseif t[k] == "X"
        T = T + xatom;
    else
        T = T + t[k];
    end
end
end
end

/*
fatom = "FF-[-F+F+F]+[+F-F-F]";
xatom = "";
T0 = "F";
turning_angle = 22;
*/

/* draw the tree according to commands given in a string
   this function is recursive
```

figp: pointer to the figure object. It needs to be a pointer since
the function will modify the figure object
x, y: the current position
direction: the angle of the current direction
angle: the angle in degree of turning when commands + and - are executed
command: the string of commands
kp: the pointer to the current position in the command string
*/

```
draw_tree = function (figp, x, y, direction, angle, command, kp, color) -> ()
  k = kp>>; /* take the index of the first command code */
  while k <= command.length
    c = command[k];
    if c == "]"
      kp >>= k + 1; /* let kp point to the next command code */
      return;
    elseif c == "["
      kp >>= k + 1;
      /* call itself to execute the commands up to the matching ] */
      this(figp, x, y, direction, angle, command, kp, color);
      k = kp>>;
      continue;
    elseif c == "+"
      direction += angle/180*pi;
    elseif c == "-"
      direction -= angle/180*pi;
    elseif c == "F"
      nx = x + cos(direction);
      ny = y + sin(direction);
figp >>. line([x, y], [nx, ny], *, *, *, color);
      x = nx;
      y = ny;
    end
    ++k;
  end
end

/* ----- bush 1 ----- */

fatom = "FF-[-F+F+F]+[+F-F-F]";
xatom = "";
```

```

T0 = "F";
turning_angle = 22;

bush = generate_tree (T0, fatom, xatom, 4);

/* let command pointer point to the beging of command code sequence */
k = 1;
kp = >>k;

fig = figure.new();

/* pass the pointer to fig to draw_tree */
draw_tree(>>fig, 0, 0, pi/2, turning_angle, bush, kp, colors.lime);
fig.style="empty";
fig.save("bush1.eps");

/* ----- bush 2 ----- */

fatom = "FF";
xatom = "F[+X]F[-X]+X";
turning_angle=20;
T0 = "X";
bush = generate_tree (T0, fatom, xatom, 6);

k = 1;
kp = >>k;

fig = figure.new();

draw_tree(>>fig, 0, 0, pi/2, turning_angle, bush, kp, colors.blue);
fig.style="empty";
fig.save("bush2.eps");

/* ----- bush 3 ----- */

fatom = "FF";
xatom = "F-[[X]+X]+F[+FX]-X";
turning_angle = 22.5;

T0 = "X";
bush = generate_tree (T0, fatom, xatom, 6);

```

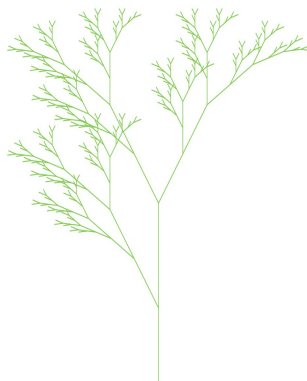
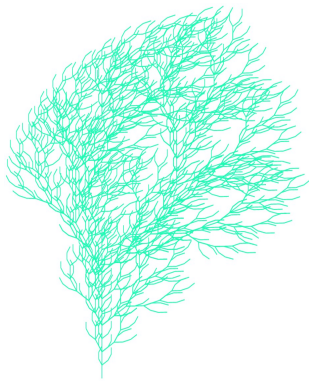
```

k = 1;
kp = >>k;

fig = figure.new();

draw_tree(>>fig, 0, 0, pi/2, turning_angle, bush, kp, colors.purple);
fig.style="empty";
fig.save("bush3.eps");

```



6. Lorenz Attractor

```

with("plot.x");

/* the lorenz differential equation */

lorenz = function [a = 10, b=28, c=8/3] (t, y) -> dydt
  d1 = a * (y[2] - y[1]);
  d2 = b*y[1] - y[2] - y[1] * y[3];
  d3 = y[1] * y[2] - c * y[3];
  dydt = [d1; d2; d3];
end

/* solve the ivp on t=[0,50] */
(x, y) = dsolve(lorenz, [0, 50], [8; 9; 10]);

/* 2d plot */
fig = figure.new();
fig.plot{x = y[:,2], y = y[:,1], linetype = "curve", color = [0.2, 1, 0.1]};
fig.save("lorenz21.eps");

```

```

fig = figure.new();
fig.plot{x = y[:,2], y = y[:,3], linestyle = "curve", color = [0.7, 0.2, 0.1]};
fig.save("lorenz23.eps");

fig = figure.new();
fig.plot{x = y[:,1], y = y[:,3], linestyle = "curve", color = [0.2, 0.2, 0.7]};
fig.save("lorenz13.eps");

/* for 3d view plot */

cr = y.columnrange;

fig = figure3d.new();
fig.light_direction = [2/3, 1/3, 3/5];

gx = [xv=cr[1,1]] (y, z) -> xv;
gy = [yv=cr[1,2]] (x, z) -> yv;
gz = [zv=cr[1,3]] (x, y) -> zv;

fig.plot(gx, (y,z)->y, (y,z)->z, cr[:, 2], cr[:, 3], [4, 4], rand(3), rand(3));
fig.plot((x,y)->x, (x,y)->y, gz, cr[:, 1], cr[:, 2], [4, 4], rand(3), rand(3));
fig.plot((x,z)->x, gy, (x,z)->z, cr[:, 1], cr[:, 3], [4, 4], rand(3), rand(3));

fig.curve(y[:,1], y[:,2], y[:,3], rand(3));
fig.save("lorenz3d.eps");

```

7. Mesh

```

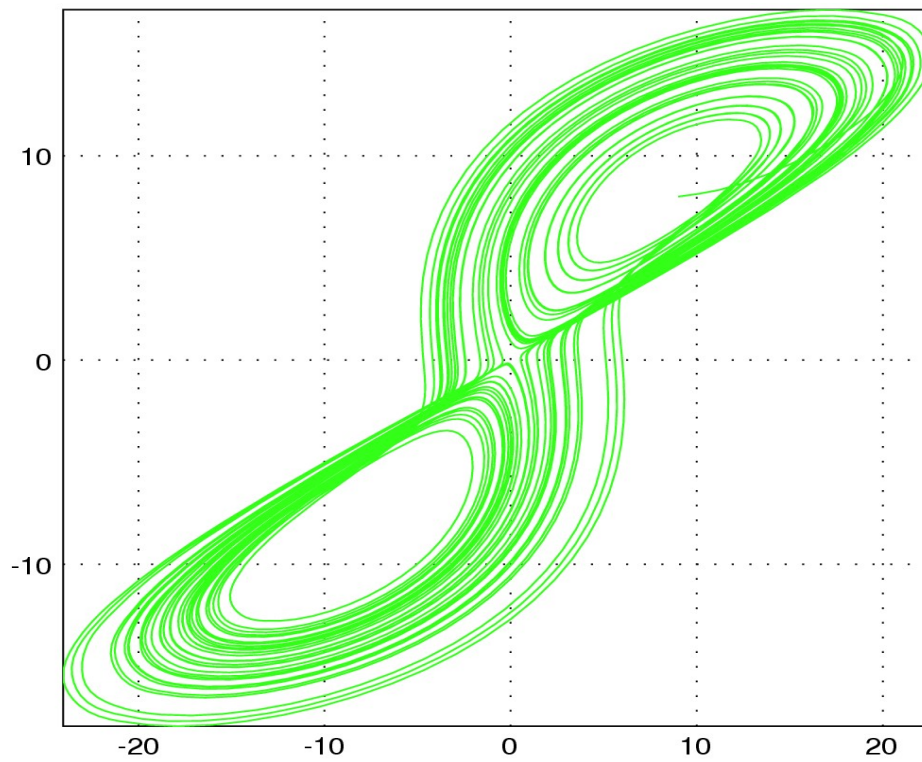
with("plot.x");

// Solve Laplace's equation with Jacob's relaxation method
// Usage: lpc(w,h,bv_up,bv_down,bv_left,bv_right,minchange)
// w: width, h: height, bv_up...bv_down: boundary values, min_change: precision

lpc = function (w, h, bv_up, bv_down, bv_left, bv_right, min_change = 1e-5) -> v

    % a crude guess initial value
    v=(bv_up+bv_down+bv_left+bv_right)*0.25*ones(w,h);

```

```

vave=zeros(w-2,h-2);
//boundary conditions
v[1,:]=bv_left*ones(1,h);
v[w,:]=bv_right*ones(1,h);
v[:,1]=bv_down*ones(w,1);
v[:,h]=bv_up*ones(w,1);

change=10;

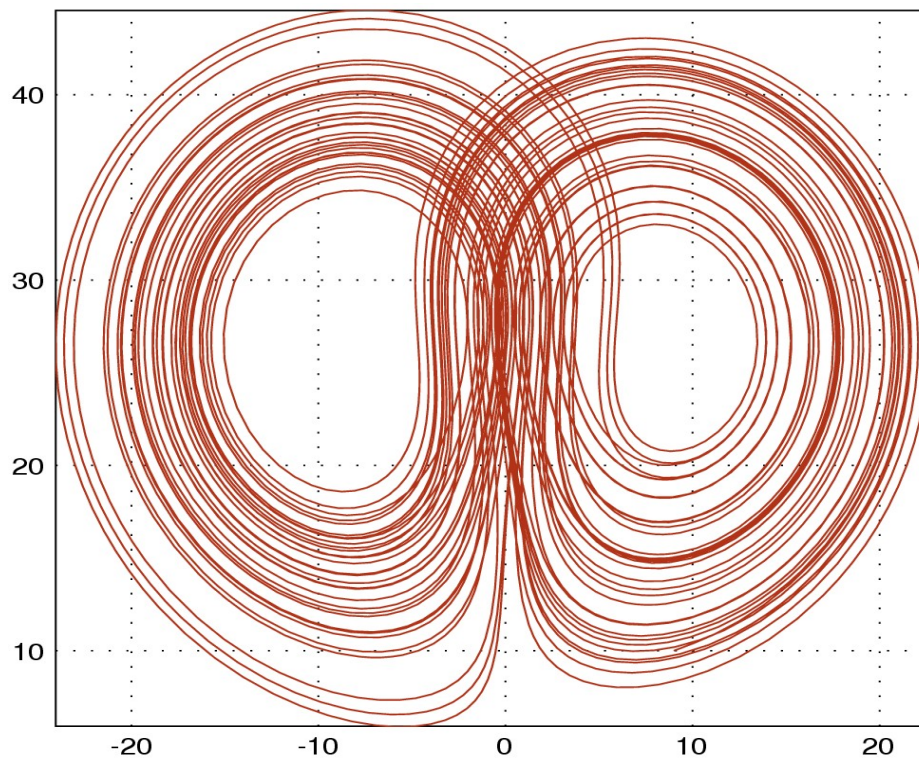
while change>min_change
    vave=(v[2:w-1,1:h-2]+v[1:w-2,2:h-1]+v[2:w-1,3:h]+v[3:w,2:h-1])*0.25;

    change=max(max(abs(vave-v[2:w-1,2:h-1])));

    v[2:w-1,2:h-1]=vave;
end
end

v = lpc(30,30,5, 5, 9, 25,*);
fig = figure3d.new();
fig.light_direction = [1/3, 2/3, 1/3];

```



```

c = rand(3);
d = rand(3);
fig.mesh(v, c, d);
fig.save("laplace.eps");

```

8. Surfaces

```

with("plot.x");
fig = figure3d.new();

fx = (theta, phi)->(9 + 2 * cos(phi)) * cos(theta);
fy = (theta, phi) -> (9 + 2 * cos(phi)) * sin(theta);
fz = (theta, phi) -> 2 * sin(phi);

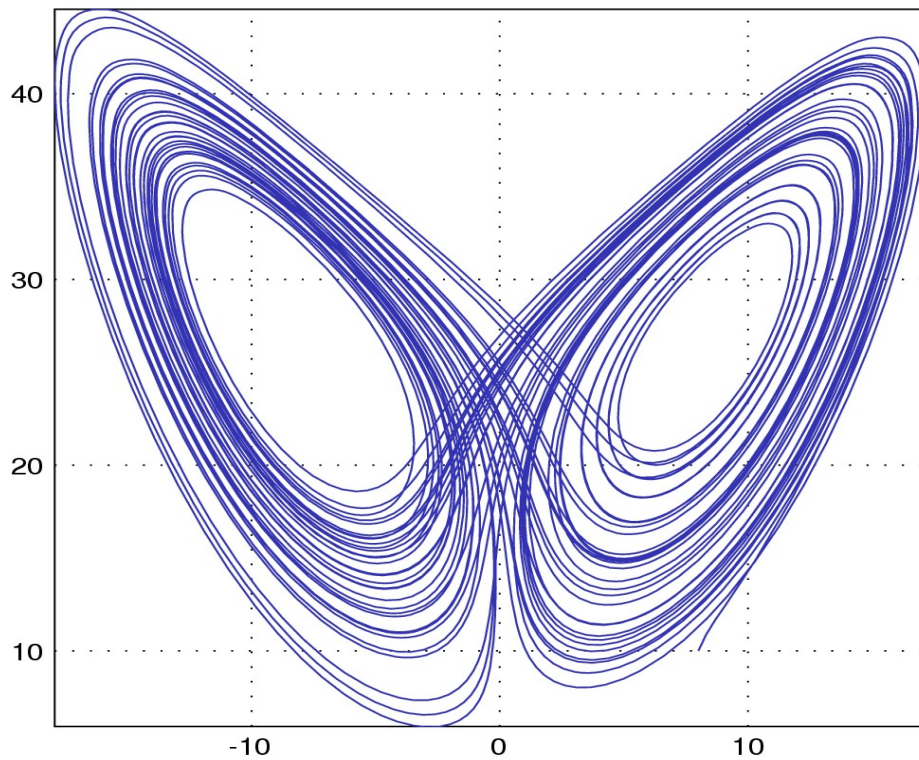
fig.plot(fx, fy, fz, [0,2*pi], [0,2*pi]);

fx = (theta, phi)->(4 + 1.2 * cos(phi)) * cos(theta);
fy = (theta, phi) -> (4 + 1.2* cos(phi)) * sin(theta);
fz = (theta, phi) -> 2+1.2 * sin(phi);

fig.plot(fx, fy, fz, [0,2*pi], [0,2*pi]);

fx = (theta, phi)->1+(9 + 3 * cos(phi)) * cos(theta);

```



```

fy = (theta, phi) -> 3 * sin(phi);
fz = (theta, phi) -> (9 + 3 * cos(phi)) * sin(theta);

fig.plot(fx, fy, fz, [0.7,1.2*pi], [0,2*pi]);

fx = (theta, phi)->7+(3 + 0.6 * cos(phi)) * cos(theta);
fy = (theta, phi) -> 0.6 * sin(phi);
fz = (theta, phi) -> (3 + 0.6 * cos(phi)) * sin(theta);

fig.plot(fx, fy, fz, [0,2*pi], [0,2*pi]);

fig.light_direction = [2/3, 2/3, 1/3];
fig.save("torus.eps");

```

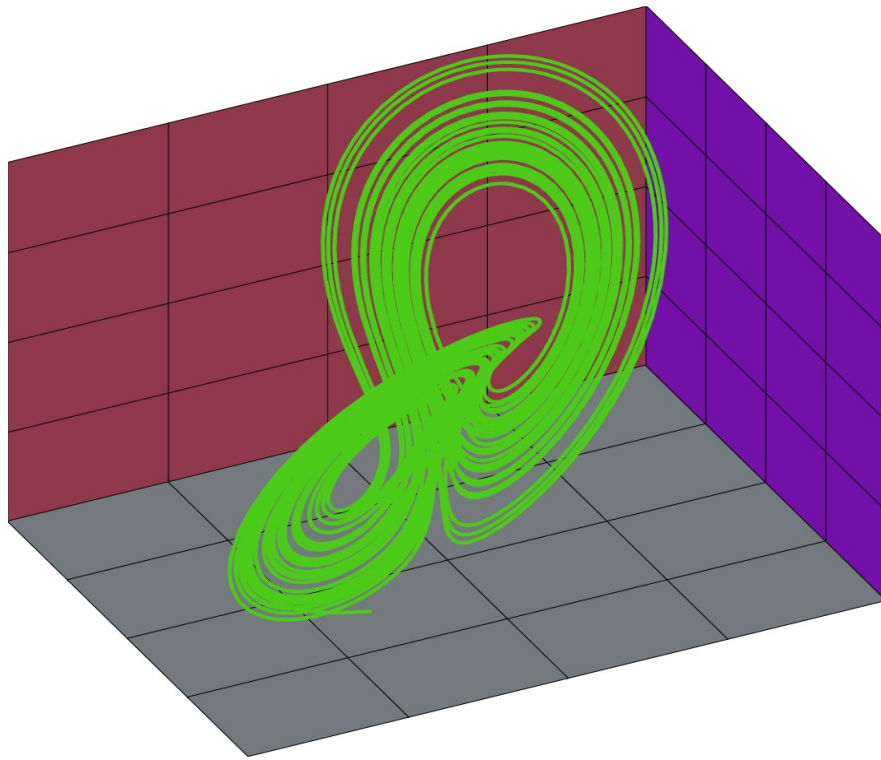
9. Seashell

```

with("plot.x");

/* it's not necessary to use global variable
   in order to use function parameter
   just to show it's possible
*/

```



```
global.n = 3;
global.a = 8;
global.b=35;
global.c=5;
fig = figure3d.new();
fig.light_direction = [2/3, -2/3, 1/4];

fx = (s, t)->a * (1-t/(2*pi))*cos(n*t) * (1+cos(s)) + c * cos(n*t);
fy = (s, t)->a * (1-t/(2*pi))*sin(n*t) * (1+cos(s)) + c * sin(n*t);
fz = (s, t)->b * t / (2*pi) + a *(1-t/(2*pi)) * sin(s);

fig.plot(fx, fy, fz, [0,2*pi], [0,6], [50, 50]);

fig.save("seashell.eps");
```