A Brief **Shang** Tutorial

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1 Using Shang as a calculator

1.1 Doing Arithemetic

If an arithmetic expression is entered at command prompt the interpreter will evaluate it and display the answer.

```
>> (75.00 + 89.50 + 97.50) / 3 * 0.7 + 92.00 * 0.3
    88.73333333
```

The expression may contain numbers and operators +, -, *, and / that represent addition, subtraction, multiplication, and division, and parentheses can be used for grouping.

`+`	addition
`-`	subtraction
`*`	multiplication
`/`	division
`^`	`a^b` is equal to a^b
`()`	grouping

Finding the square root of $6^2 + 8^2$

```
>> (6^2 + 8^2)^(1/2)
    10
```

Numbers can also be enter using *exponential format*. For example, `-1.1e-3` is the same as `-0.0011`, and `1e+6` or `1e6` is another way of writing `1000000`, a million.

1.2 Common Functions

Many common elementary functions such as `sqrt, exp, log, sin, cos, tan, asin, acos`, and `atan` are built in the interpreter can be used in the expressions directly. For example, `sqrt` is the name of square root function. To find the square root of $6^2 + 8^2$

```
>> sqrt(6^2 + 8^2)
    10
```

The built-in name for *exponential function* e^x is `exp`. To evaluate $e^{-0.5}$ we should write `exp(-0.5)` instead of `e^(-0.5)`. Although `e^(-0.5)` would in theory give the same answer, it's computed differently and might be less accurate. `log` is the name of the *natural logarithm* function $\ln x$.

1.3 Common Constants

The mathematical constants e, π and imaginary unit i are represented by `e`, `pi`, and `i` respectively, and can be used directly. For example:

```
>> cos(pi)
    -1
>> sin( pi)
   1.224606354e-16
```

Note that the exact answer to $\sin(\pi)$ is 0 and what we are given here is only an approximate answer since π is just an approximate representation of π, and the sin function uses numerical method.

1.4 Arbitrary Precision Computation

If a number has the suffix `M` it is treated as an arbitrary precision floating point number, which by default has about 38 significant decimal digits. For example

```
>> sqrt(3M)
   1.7320508075688772935274463415058723E0
>> x = 3.141592653589793238462643383279502M
     3.141592653589793238462643383279502E0
>> sqrt(x)
     1.7724538509055160272981674833411452E0
```

The precision of MPF can be rest by assigning a multiple to global variable `global.mpf_ndigits`. The default value of `mpf_ndigits` is 128, therefore an `mpf` may have 128 significant binary digits as opposed to 52 for `double`. The value of `mpf_ndigits`. can be set to a multiple (at least 2) of 32.
If a number has the suffix `L` it is treated as a long integer, which can be as big as the computer memory allows. For example

```
>> 128L ^ 20L
     1393796574908163946345982392040522594123776
```

1.5 Complex Numbers

Complex numbers are supported interally. A complex number of real and imaginary parts `a` and `b` is displayed as `a+bi`, and can be entered as either `a+bi, a+bI, a+bj`, or `a+bJ`. For example

```
>> sqrt(-5)
    0 + 2.236067977i
>> (3+5i) / (2-3j)
    -0.6923076923 + 1.461538462i
```

1.6 Define Variables

Variables can be defined using the assignment operator `=`. For example

```
>> h = 1.25
```

creates a variable named "`h`" and assign value 1.25 to it. If there is already a variable named "`h`", then its value will be updated to 1.25.
The interpreter remembers the values of the variables, so that you can recall the names of the variables to use their values. For example:

```
>> c = 10;
>> b = 8;
>> sqrt(c^2 - b^2)
    6
```

A variable name can be a string of letters and digits, and underscore `_`, but cannot begin with a digit. For example, `x1`, `value_1`, and `_val03` are all valid variable names.

1.7 Unwanted Printing

Usually the result of a command is displayed after `Enter` is hit.

```
>> h = 1.25
   1.25
```

To prevent this, a semicolon can be appended. By suppressing unwanted displays, the command window can be kept cleaner and the program may run more efficiently.

```
>> h = 1.25;
>> // nothing is displayed here
```

1.8 Command Editing and History

By using the up and down arrow keys on the keypad, the previously entered commands can be brought up for editing and entered again.

1.9 Two ways to enter commands

(a) Type in

You can always type the commands directly in the command window and see the answers right away.

(b) Edit and paste

Alternatively, you can edit all the commands using a text editor and when you are done, copy the commands to clipboard and then paste it to the Shang interpreter window. This can be more efficient since whenever anything goes wrong, you just need to correct the commands in the text editor and paste them again and don't have to retype everything.

1.10 Submit a Command and Abondon a Command

If the cursor position is at the end of the command, pressing enter will submit the command for execution.
When you press enter, if the interpreter doesn't show answer, but keep opening new lines, it thinks the input commands are not complete. It is expecting some closing brackets or quotes. If you want to start over and abondon the current commands, use the `ctrl-a` command.

1.11 Run a script

A script file is a text file that contains a sequence of Shang commands. For example, a file with name "testscript.txt" may contain the following lines

```
 f = (h, r, theta) -> r^2 + h * (1 + cos(theta));
 h = 3.5;
 r = 5;
 theta = pi / 2;
 f(h, r, theta)
```

In the interactive mode, if the following command is issued

```
>> run("testscript.txt");
   28.5
>>
```

All the commands in the script file will be executed.

1.12 Commenting

It's always a good idea to use comments to annotate your commands and programs.

1.12.1 Single line comment

All the characters in a line following the symbol // are ignored, and therefore can act as comments. For example

```
>> // this is a comment
>> sqrt(-3)   // this is a comment as well
```

1.12.2 Multi-line comment

Comments can run multilines as well. Any characters between a pair of `/*` and `*/` are ignored.

```
>> /* this is a comment
      this is still a comment
this is  still a comment
      ...
      we're done commenting (finally) */
```

Shang interpreter can recognize five levels of nested comments.

2 Flow Control

2.1 Conditionals

If we want to assign `c` to `b` when the condition `f(a) * f(c) < 0` is true:

```
if f(a) * f(c) < 0
       b = c;
end
```

If we want to assign `c` to `b` when the condition `f(a) * f(c) < 0` is true, and assign `c` to `a` when the condition is false:

```
if f(a) * f(c) < 0
       b = c;
else
       a = c;
end
```

To test the condition "`n` equals to `1`", we need to use two equal signs, like `n == 1`, not `n = 1`. Note that a single `=` is the assignment operator. The statement `n = 1` would assign `1` to `n` instead of testing the condition. The following assigns `c` to `b` when `n` equals 1, and assigns `c` to `a` when `n` equals to 2:

```
if n == 1
       b = c;
elseif n == 2
       a = c;
end
```

2.2 Loops

If we want to repeatedly execute a bunch of commands for a million times, we can use the `for` loop

```
s = 0;  // initialize s
for k = 1 : 1000000
    s += k;      // add k to s --- equivalent to "s = s + k"
end
```

The above loop compute the sum

$$\sum_{k=1}^{1000000} k$$

The `while` loop enables us to repeatedly execute a bunch of commands as long as a condtion is satisfied

```
s = 0;
k = 1;
while k <= 1000000   // do the following as long k is less than a million
    if k % 2 != 0    // k % 2 is the remainder of k/2
       s += k;
    end
    ++k;   // increment k, same as k = k + 1;
           // without the increment, k will stays as 1 and loop runs forever
end
```

The above `while` loop sums up all the odd numbers between 1 and a million; it is equivalent to the following `for` loop

```
s = 0;
for k = 1 : 2 : 1000000
    s += k;
end
```

A loop can be stopped by using `break` statement. For example

```
f = fopen("shopping-list.txt", "r");
while 1
    line = f.readline();   // read line from the file
    if line == ()          // line is empty --- file end reached
         break;
    end
    // process each line of the file
    // ...
end
```

Note that since the logical value of `1` is true, `while 1` starts an infinite loop (so it has to be stopped by a `break` somewhere).
Besides `for ... end` and `while ... end` loops, in the Shang reference manual you can also find details about the following different types of loops

```
until ... end
do ... while
do ... until
```

3 Define Functions

3.1 One Liner Functions

To define a simple one-liner function, one can use the arrow to join the input argument and the output value. For example, function $f(x) = \frac{1-x}{1+x+x^2}$ can be defined by

```
f = x -> (1 - x) / (1 + x + x^2)
```

A defined function can be called in the obvious way

```
f = x -> (1 - x) / (1 + x + x^2)  // define a function
f(-1)  // call the function
```

A function can have several input arguments. For example

$$f(r, \theta) = r(1 + \cos(\theta))$$

can be defined by

```
 f = (r, theta) -> r * (1 + cos(theta));  // define
```

3.2 More Complicated Functions

If a function definition has more than one line of statements, the keyword `function` should be used. The syntax is

```
function_name = function (input_arguments) -> (output arguments)
                        ... // a bunch of statements
                    end
```

Note that in the body of the function, the input arguments can be used as if they are variables (but they are not visible outside the function), and the output arguments should be given values before the end of the function. The following function evaluates the Taylor expansion of $\cos(x)$ function for a small x value

$$\cos x \approx \sum_{n=0}^{N} (-1)^n \frac{x^{2n}}{(2n)!}$$

```
cos_taylor = function (x, N) -> v
       v = 1;
       vk = 1;
       xsq = x * x;
       for k = 1 : N
           vk = - vk * xsq / (2 * k) / (2 * k - 1);
           v += vk;
       end
end
```

4 Matrices

A matrix is a rectangular array of numbers. it can be created with elements included in a pair of square brackets. The rows are separated by semicolons, while elements in the same row are separated by commas.

```
>> A = [1,4, 9; 2, 3, 5; -2, 5, 10]
   1   4    9
   2   3    5
  -2   5   10
```

To refer to the element of matrix `A` at second row and third column, use `A[2,3]`

```
>> A[2,3]
   5
```

Create Matrices
Alternatively, a matrix of a required size can be created and initialized using built-in functions `zeros`, `ones`, or `rand`. The command

```
A = zeros(3, 5)
```

will return a matrix of three rows and five columns, with each element being zero. Similar usage of `ones` and `rand` will create matrices of 1's and random numbers (between 0 and 1) respectively.
These three functions can also be called with a single parameter, in which case the second parameter is assumed to be 1, and thus a column vector is created.

```
>> B = rand(5)
    0.289
    0.353
    0.154
    0.566
    0.821
```

By the `dimension` of a matrix we refer to the number of rows and the number of columns. For example, the dimension of the scalar `-5` is `1` × `1`, while the dimension of the matrix

```
-2    3    9
 10   1    -2
```

is 2 × 3.

Create Even Spaced Vectors Using the Colon Operator

The symbol : can be used to create a row matrix whose elements are evenly spaced. The default step-size of the vector is 1, which is assumed when one colon is used.

```
>> A = -1 : 5
   -1  0  1  2  3   4   5
```

To specify a step-size other than 1, two colons are needed.

```
>> A = 3 : 0.5 : 5
   3  3.5  4  4.5  5
```

When you use `A : B` to create a vector, the value `B` is not always included in the vector. Alternatively, the built-in function `linspace` can be used to created even spaced vector with the specified end points included. `linspacea, b, n` will create a column vector of length `n`, with `a` and `b` being the two end points.

5 Matrix Indexing

5.1 Single Index

If a matrix `A` is a row vector or a column vector, then `A[k]` refers to the kth element of `A`. The index `k` is a number between 1 and the length of the vector. Note that 0 is not a valid index value.

```
>>  A = [3, 5, -2, 7, 0.9];
>>  A[3]
    -2
```

The index itself can be vector such that a bunch of the elements of `A` are referenced.

```
>>  A = [3, 5, -2, 7, 0.9];
>>  A[[1, 3, 5]]
    3  -2   0.9
>> A[1:3]
    3   5    -2
>> A[1 : 2 : 5]   // 1 : 2 : 5 is the same as [1, 3, 5]
    3  -2   0.9
```

The dollar sign `$` when used as an index, is the largest value of the index, therefore `A[$]` is the last element of `A`.

```
>>  A = [3, 5, -2, 7, 0.9];
>>  A[$]
    0.9
>>  A[3:$]
    -2  7  0.9
```

If matrix `A` is not a vector, then the element referred to by `A[k]` is the `k`-th element of the row vector obtained by horizontally joining all the rows of `A`.

```
>> A = [1,4, 9; 2, 3, 5; -2, 5, 10]
   1   4    9
   2   3    5
  -2   5   10
>> A[5]
   3
>> A[9]
   10
```

5.2 Two Indices Separated by a Comma

`A[i, j]` is the element of `A` at `i`-th row and `j`-th column. Both `i` and `j` (or their elements) must be positive integers. Note that both indices can be vectors

```
>> A = [8, 1, 6; 3, 5, 7; 4, 9, 2]
   8    1    6
   3    5    7
   4    9    2
>> A[2,3]
   7
>> A[1, 1 : 3]   // the first row
   8    1    6
>> A[1 : 3, 2]   // the second column
   1
   5
   9
>> A[[2, 3], [2, 3]]  // the 2x2 submatrix on the lower right corner
   5    7
   9    2
```

5.3 The colon : alone as an index

If an index consists of a single colon, then it is equivalent to `1 : $`. For example, `A[1, :]` returns the first row, `A[:, 3]` returns the third column.

```
>> A = [8, 1, 6; 3, 5, 7; 4, 9, 2]
   8    1    6
   3    5    7
   4    9    2
>> A[1, :]   // the first row
   8    1    6
>> A[:, 2]   // the second column
   1
   5
   9
>> A[1 : 2, :]  // the first two rows
   8    1    6
   3    5    7
```

5.4 The colon : alone as an index

If an index consists of a single colon, then it is equivalent to `1 : $`. For example, `A[1, :]` returns the first row, `A[:, 3]` returns the third column.

```
>> A = [8, 1, 6; 3, 5, 7; 4, 9, 2]
   8    1    6
   3    5    7
   4    9    2
>> A[1, :]   // the first row
   8    1    6
>> A[:, 2]   // the second column
   1
   5
   9
>> A[1 : 2, :]  // the first two rows
   8    1    6
   3    5    7
```

5.5 Change the Elements of a Matrix

Any of the indexing expression can be used to modify part of the elements of a matrix. For example, `A[2, 3]=-1` would change the element at row `2` and column `3` to -1.

```
>> A = zeros(3,5)
   0   0   0   0   0
   0   0   0   0   0
>> A[2,3]=2.3
   0   0    0    0   0
   0   0  2.3    0   0
>> A[:, 1] = [5; 10]
    5   0    0    0   0
   10   0  2.3    0   0
>> A[:, 3] = A[:, 3}  + A[:, 1]
    5   0     5    0   0
   10   0  12.3    0   0
>> A[2, :] = 9
    5   0     5    0   0
    9   9     9    9   9
```

Usually when an indexing expression is used as an lvalue, the dimension and size of the right hand side of the assignment should match that of the indexing expression to make the assignment possible. The only exception is when the right hand side is a scalar, then all the indexed elements of the matrix will be set to the same value.

```
>> A = zeros(3,3)
   0   0   0
   0   0   0
   0   0   0
>> A[\] = 1;
   1   0   0
   0   1   0
   0   0   1
```

When updating the contents of a matrix, the indices don't have to be within the upper bounds, which makes it possible to make the size of the matrix grow. As the size of a matrix is being extended, the new entries are set to zero, except for those being specified by the assignment statement. For example,

```
>> X = [1,4,9]
   1   4   9
>> X[4] = 16
   1   4   9   16
>> x[8]=36
   1   4   9    16    0    0   0   36
```

6 Matrix Operation

6.1 Arithmetic

If `A` and `B` are two matrices, then `A+B`, `A-B`, and `A * B` are the sum, difference, and product of `A` and `B`.
`A+B`, `A-B` are possible only when `A` and `B` have the same dimensions, or one of them is a scalar.
`A*B` is possible only when the number of columns of `A` equals the number of rows of `B`, or one of them is a scalar.

6.2 Solving Linear System: \

If both `A` and `B` are matrices, then `A \ B` is the (numerical) solution of matrix equation `A X = B`. The matrix `A` must be an `n` $\times$ `n` non-singular square matrix and `B` must have `n` rows. For example

```
>>  A = [1, 2, -3; 2, 1, 5; 0, -1, 5];
>>  b = [3; 1; -2];
>>  x = A \ b
     0.75
     0.75
    -0.25

>>  A * x - b
    0
    0
    0
```

7 Numerical Computation

7.1 Solving linear system

If A is a square matrix and b is a column vector (with the same rows as A), then A b gives the solution to the linear system $Ax = b$. For example, let

$$A = \begin{bmatrix} 2 & 2 & 0 & 6 \\ 2 & 1 & -1 & 1 \\ 3 & -1 & -1 & 2 \\ -1 & 2 & 6 & -1 \end{bmatrix}, b = \begin{bmatrix} 8 \\ 1 \\ -3 \\ 4 \end{bmatrix},$$

Then

```
>> A = [2, 2, 0, 6; 2, 1, -1, 1; 3, -1, -1, 2; -1, 2, 6, -1];
>> b = [8; 1; -3; 4];
>> x = A \ b
   -1
    2
    0
    1
>> // verify x is the solution
>> A * x - b
   0
   0
   0
   0
>> norm(A * x - b)
   0
```

The solution obtained by `A`
`b` is numerical, so usually expect `A * x - b` to be nonzero.
If `A` is not a square matrix, and `b` has the same number of rows as `A`, then `A`
`b` gives the least square solution to $Ax = b$.

7.2 Polynomials and interpolation

To create a polynomial $p(x) = 1 - 2x + 5x^2 - 0.2x^3$, do

```
p = poly[[1, -2, 5, -0.2]];
```

or make a copy of poly and then modify the coeff attribute

```
p = poly;
p.coeff = [1, -2, 5, -0.2];
```

If `p` is a polynomial, `p(x)` gives the value. Here `x` can be a scalar, vector, or matrix.
To find the polynomial interpolation through a set of points, do

```
p = interp(x, y)
```

The result is a polynomial of Newton form and can be called directly.
To create a spline, use `splinefit` function. For example

```
>> x = [-1, 0, 1];
>> y = [1.5, 0, 2.5];
>> s = splinefit(x, y);
>> s(x)
    1.5
    0
    2.5
```

As the result shows, the spline `s` can be called directly. `s.coeff` and `s.xnodes` give the coefficient matrix and the nodes of the spline. Note that the following examples give natural spline, periodic spline, not-a-knot spline, and clampled spline respectively

```
s = splinefit(x, y);
s = splinefit(x, y, "cyclic");
s = splinefit(x, y, "not-a-knot");
s = splinefit(x, y, ypl, ypr);
// ypl and ypr are the specified derivative values
//at the left and right end points
```

7.3 Integration

One dimensional integral:

```
int(f, a, b)
```

Multi-dimensional integral: `f` has to be a function of one variable, e.g.,

```
f = x -> exp(-(x[1]^2 + x[2]^2);

int(f, [0, 0], [1, 2])
```

7.4 Differential equation

You need to have an ODE function, which takes `t` and `y` as input arguments and returns the derivative `dy/dt` as output values, e.g.,

```
lorenz = function [sigma = 10, b=8/3, r=28] (t, y) -> yp
                    d1 = sigma * (y[2] - y[1]);
                    d2 = r*y[1] - y[2] - y[1] * y[3];
                    d3 = y[1] * y[2] - b * y[3];
                    yp = [d1; d2; d3];
         end;

// solve the ivp on t=[0, 1]
(t, y) = dsolve(lorenz, [0, 1], [8; 9; 10]);
```

`t` is the vector of time values, and `y` is the matrix whose each column is the numerical solution at the corresponding `t` value.
The complete signature of the `dsolve` program is

```
dsolve(ode, tspan, yini, reltol, abstol, ode_type, output_type)
```

To specify the relative tolerance (default value is 10^{-5}) as 10^{-7}

```
(t, y) = dsolve(lorenz, [0, 1], [8; 9; 10], 1e-7);
```

To specify both the relative and the absolute tolerances

```
(t, y) = dsolve(lorenz, [0, 1], [8; 9; 10], 1e-7, 1e-9);
```

If you know the IVP is stiff or non-stiff problem, you can specify the type as ”stiff” or ”nonstiff”. The default value is ”auto”.

```
(t, y) = dsolve(lorenz, [0, 1], [8; 9; 10], 1e-7, 1e-9, "nonstiff");
```

By default, the solver will output all the time steps and the y values at these steps. You may require the solver by specifying the final option to report only the y value at the final t point, or just return a function (which is an Hermite polynomial interpolation of the discrete solution). The last option can have values ”recording” (the default), ”final”, or ”interp”.

```
(t, y) = dsolve(lorenz, [0, 1], [8; 9; 10], 1e-7, 1e-9, "nonstiff", "final");
```

or

```
y = dsolve(lorenz, [0, 1], [8; 9; 10], 1e-7, 1e-9, "nonstiff", "interp");
```

7.5 Use random number generator

A distribution is a function which when called return random numbers. The built-in distributions include: `rand,randz, normal, gauss, gammarv, betarv, binomal, chi, exprv,poisson, frv, student, hypergeom, and multinomial`.
Each function is a random number generator. For example, `normal(3)` returns 3 random numbers of normal distribution. The `normal` function has two public parameters `mu` and `sigma`. To create a new normal distribution, you can reset the parameter values

```
rv = normal;
rv.mu = 100;
rv.sigma = 15;
```

The `normal` function also has `common` parameters `mean,stddev,variance,pdf, cdf, prob, quantile`. If you want to calculate the probability that a random variable of distribution `rv` is between `70` and `130`, do

```
>> rv.prob(70, 130)
   0.9544997361
```

8 Graphics

Shang has no built-in functionalities for handling graphics. However there is a package of programs written in the Shang language which can create 2D and 3D plots. The package saves pictures as encapuslated postscript files. In order to print or display the images created by plot.x, you need to download and install the Ghostscript and GSview programs at

`http://pages.cs.wisc.edu/~ghost/`

To use this package, you need to run the file `plot.x`, which is located in the `programs` directory. Or just run the following command before you plot

```
include("plot.x");
```

The package `plot.x` defines a class named `figure`. To make a plot, first create a `figure` object using

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

If `X` and `Y` are the coordinates of a sequence of points, then

```
fig.plot(X, Y);
```

will plot `Y` against `X`. The result is the points joined by straight line segments.
To plot `(X,Y)` as dots, use

```
fig.plot(x=X, y=Y,  linetype = "dot");
```

To plot `(X,Y)` as circles, use

```
fig.plot(x=X, y=Y,  linetype = "circle");
```

To plot a smooth curve through the `(x,y)` points, use

```
fig.plot(x=X, y=Y,  linetype = "curve");
```

To plot a smooth curve through the `(x,y)` points, using red color, and making the line thicker

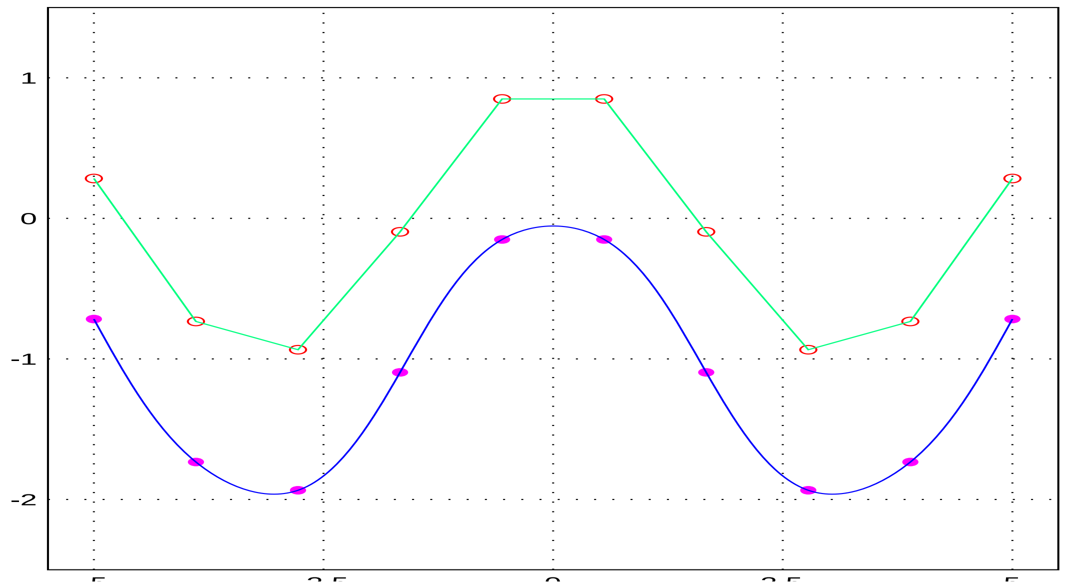
```
fig.plot(x=X, y=Y,  linetype = "curve", linewidth = 2, color=[1,0,0]);
```

When the plotting is done, pick a file name (extension eps) and save the picture

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

For example, the following commands will plot some curves and dots

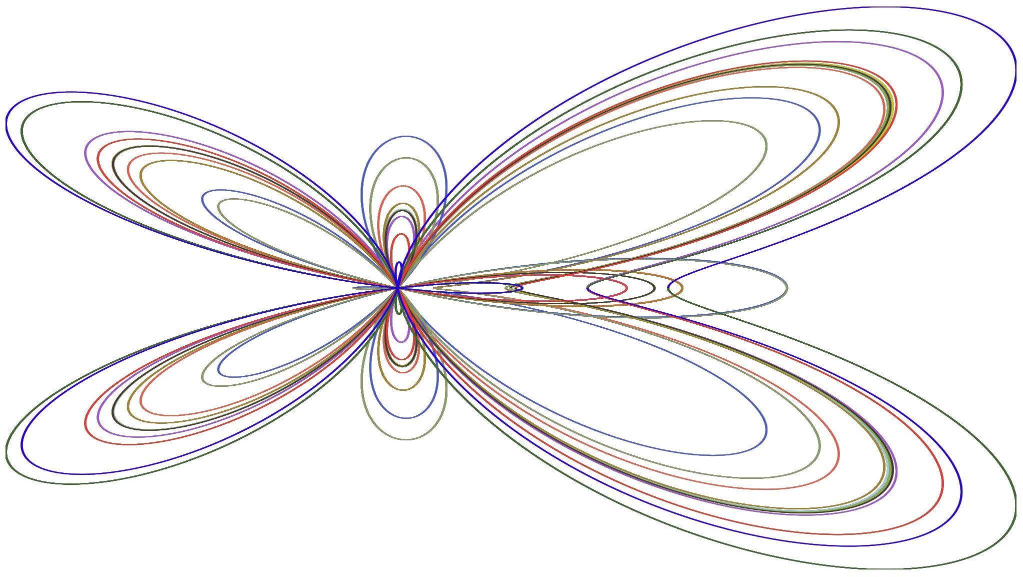
```
     with("plot.x");
     x = linspace(-5, 5, 10);
     fig = figure.new();
     /* draw small circles at (x,y) locations */
     /* color is vector of 3 numbers between 0 and 1, in rgb format */
     fig.plot{x=x, y=cos(x), linetype="circle", color=[1, 0, 0]};
     /* connect the dots with solid 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 picutre */
     fig.setXrange([-5.5, 5.5]);
     fig.setYrange([-2.5, 1.5]);
     fig.save("curves.eps");
```



The following commands will draw a butterfly

```
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");
```



For more examples, check out Shang website.

9 File

To open a file named "Ragu.txt" for reading, do

```
f = fopen("Ragu.txt", "r");
```

Here the file is supposed to located in the current directory. If it's not, the file name can be an absolute path, or you can use `pwd` and `cd` to change the current working directory. To read a line of text from an opened fle `f`.

```
line = f.readline();
```

The return value `line` is a character string. When all the lines have been read, `f.readline()` will return empty list `()`.
To open a file for writing

```
fo = fopen("Ragu.txt", "w");
```

To write a string to file `fo`

```
fo.write("abcde");
```

`f.writeline(str)` will write a line and append a new newline. `f.printf(format, ...)` will print to the file according to a format. After all operations are done, the file should be closed using `f.close()`.
Example: the following makes a copy of a file.

```
f1 = fopen("Ragu.txt", "r");
f2 = fopen("Ragu-1.txt", "w");
if f1 && f2
     line = f1.readline();
     while line != null
          f2.writeline(line);
          line = f1.readline();
     end
end
f1.close();
f2.close();
```

10 String and Regular Expression

10.1 Character String

A string literal is entered this way

```
>> s = "Jerry Gallo."
   Jerry Gallo
```

You can extract a character or a substring by using operator `[]` as if it were a vector of characters. For example

```
>> s = "Jerry Gallo"
   Jerry Gallo
>> s[7]
      G
>> s[7 : 11]
      Gallo
>> s[7] = "C"
   Jerry Callo
```

Strings can be added

```
>> s = "The fair breeze blew, " + "the white foam flew."
     The fair breeze blew, the white foam flew.
```

10.2 Regular Expression

If you want to test if a string contains a sequence of `z`'s, you can create a regular expression by

```
r = ~/zz*/
```

A regular expression can be used as a function or a set. For example

```
>> r = ~/zz*/;
>> s = "Jazz";
>> r(s)
   3 4
>> s in r
   1
```

If the regular expression doesn't match the string, the return value is an empty matrix, otherwise, the starting and ending indices of the match are returned. Or you can use the regular expression as a set. `s in r` returns either true or false.

10.3 Regular Expression Substitution

A regular expression substitution is another special text function. Suppose that you want to replace every instance of "mate" in a string with "dude", you can create a regular expression substitution with

```
>> r = ~s/mate/dude/g;
>> text = "Hey mate, you ...;
>> r(text)
   "Hey dude, you ...?"
```

Note that the g at the end of the expression stands for "global", meaning substituting every occurence of the match. Without the g option, only the first occurence is substituted.
If you want to substutute "mate" with "dude" and "Mate" with "Dude", you can do it twice, like

```
>> r1 = ~s/mate/dude/g;
>> r1 = ~s/Mate/Dude/g;
>> text = r2(r1(text))
```

Regular expressions can be complicated and powerful. Now suppose that you want to replace every occurence of \code{some text} with
`<font face="Courier New">some text</font>`, where `some text` can be any text, you can do it by

```
>> r = ~s/\\code{(.*?)}/<font face="Courier New">\1<\/font>/g;
>> text = r(text)
```

11 List and Hash Table

11.1 List

If you want to store a bunch of non-numerical value in a variable, you can use a list. A list is like an arry, but each element can be any type of value. For example

```
mylist = ("fishhook", "gum", "earplug", "lighter");
```

To access an element of a list, use the operator #, for example

```
>> mylist = ("fishhook", "gum", "earplug", "lighter");
>> mylist # 3
   earplug
```

The index can be vector also

```
>> mylist = ("fishhook", "gum", "earplug", "lighter");
>> mylist # [2, 3]
   (gum, earplug)
```

Modify or add an element

```
>> mylist # 2 = "slingshot";
   (fishhook, slingshot, earplug, lighter);
```

The length of a list `s` can be checked by the expression `#s`.
A list entered this way has a fixed length, meaning you cannot add new elements. For example

```
>> mylist = ("fishhook", "gum", "earplug", "lighter");
>> mylist # 5 = "tobacco";
   Error: index value 5 out of bound 1-3
```

If you want the length of the list extendable, you need to append a tilde at the end of the list

```
>> mylist = ("fishhook", "gum", "earplug", "lighter");
>> mylist # 6 = "glue";
   (
      fishhook
      gum
      earplug
      lighter
      []
      glue
   )
```

Note that the fifth element of the list was not given a value, so it got an empty matrix.

11.2 Hash table

A hash table is another type of collective data. Like list, it contains a collection of values, but each value is not referenced by an index but by a key. For example

```
anagrams = {"mother in law"       => "woman Hitler",
            "domitory"            => "dirt room",
            "desperation"         => "a rope ends it",
            "election results"    => "lies, let’s recount"}
```

Each element of the table can be extracted and reset using the operator `@`.

```
>> anagrams @ "election results"
   lies, let’s recount
>> anagrams @ "astronomer" = "moon starer";
```

Note that a hash table can have a `default` key and associated value, whenever `k` is not a key of the table, `t@k` returns the value associated with `default`. For example

```
>> anagrams @ "default" = "blah";
>> anagrams @ "punishment"
   blah.
```

12 Class

A class is a custom defined data type. For example, you want to define a `circle` class so that all the interested information and attributes of a circle is stored in a variable as a member of the `circle` class. Suppose that you want to store the center location and the radius of the circle, then you need to specify two attributes. You can define the class like this

```
circle = class
             public center = [0, 0];
             public radius = 1;
         end;
```

Here `public` is the access control type of attribute `center`, meaning it can be access inside and outside the class. The two values `[0, 0]` and `1` are the default values of the two attributes.
Now, to create a new member of the class

```
c = circle.new();
```

`c` will be a member of the class `circle` and we can check the values of attributes and also reset them

```
>> c.center
   0  0
>> c. radius
   1
>> c.radius = 10;
>> c.radius
   10
```

Then function `new` is the constructor of the class. Note that we didn't write a constructor so the sysem automatically generates a default constructor for us, which assigns the default value to each attribute. If we want to write the constructor by ourself, it's very simple. Just write a function named `new` which has no output value. The `new` function returns a class member, whose each attribute obtains the value of the local variable of the `new` function that has the same name. Any attribute not mentioned in the constructor gets the default value. For example

```
>> circle = class
             public center = [0, 0];
             public radius = 1;
             new = function (a, b) - ()
                      center = a;
                      radius = b;
                   end
         end;
>> c = circle.new([2, 3], 15);
>> c.center
   2   3
>> c.radius
   15
```

Note that the constructor `new` should have no access control type like `public`, since it is not a member attribute.
A member attribute can be a function also. Suppose we want to use `c.area()` and `c.perimeter(`
to find the area and perimeter of the circle, we can do it like this

```
circle = class
             public center = [0, 0];
             public radius = 1;
             common area = () -> pi * (parent.radius)^2;
         end;
```

Here `common` is another access control type. A `common` attribute has to be a function and is going to be shared by all members of the class, can be called but cannot be modified.

Inside the attribute function `area`, to refer to another attribute of the class member, the keyword `parent` has to be used (meaning the class member owns the attribute function being defined). Here's how to use it

```
>> circle = class
             public center = [0, 0];
             public radius = 10;
             common area = () -> pi * (parent.radius)^2;
             common perimeter = () -> 2 * pi * (parent.radius);
         end;
>> c = circle.new();
>> c.area()
   314.1592654
>> c.perimeter()
   62.83185307
```

If `c` is a member of `circle` class, `c.radius` gives the value of the `radius` attribute and `c.radius = -2` modifies the attribute. This is possible due to the fact that `radius` is a `public` attribute. A `public` attribute is accessible and modifiable inside and outside the class. If you don't want to expose an attribute to the outside intrusion and tampering, you can declare it as a `private` attribute

```
>> circle = class
             public center = [0, 0];
             private radius = 10;
             common area = () -> pi * (parent.radius)^2;
             common perimeter = () -> 2 * pi * (parent.radius);
         end;
>> c = circle.new();
>> c.area()
   314.1592654
>> c.radius
   Error "c.radius": accessing private attribute 'radius' disallowed
>> c.radius = 25
   Error "c.radius=25":  trying to reset non-public field 'radius'
```

See, now the `radius` attribute is hidden and cannot be reset outside the class. However, it can be modified internally. For this purpose, we need to write an attribute function

```
>> circle = class
             private radius = 10;
             common get_radius = () -> parent.radius;
             common set_radius = function r -> res
                        if r in (0+ to inf)
                           parent.radius = r;
                           res = 1;
                        else
                           res = 0;
                        end
                     end
             common area = () -> pi * (parent.radius)^2;
             common perimeter = () -> 2 * pi * (parent.radius);
         end;
>> c = circle.new();
>> c.set_radius(25);
>> c.get_radius
   25
```

If you want to write `c.area` instead of `c.area()` to get the area, you can declare the access control type of `area` to be `auto` instead of `common`

```
>> circle = class
             private radius = 10;
             auto area = () -> pi * (parent.radius)^2;
         end;
>> c = circle.new();
>> c.area
   314.1592654
```

An `auto` attribute has to be a function that takes no input argument. The only advantage it has over `common` is calling it doesn't need `()`.
If you don't want to use `get_radius` and `set_radius`, but still want to prevent `radius` from receiving an invalid value like a negative number, you can use a domain

```
>> circle = class
             public radius = 10 in (0+ to inf);
             common area = () -> pi * (parent.radius)^2;
             common perimeter = () -> 2 * pi * (parent.radius);
         end;
>> c = circle.new();
>> c.radius
   10
>> c.radius = -5;
   Error "c.radius=-5":  reseting public field 'radius', value out of domain
>> c.radius = 5
   5
```

Here the domain of `radius` is `0+ to inf`, the interval $(0, \infty)$. Now you can access and modify the attribute directly, but cannot reset it to an invalid value.

13 Set and Domain

A set is a non-ordered collection of values. If `x` is a member of set `s`, the expression

```
x in s
```

evaluates to 1 (true), otherwise, the test value is 0.
There are several ways to implement a set. The first is finite set. Just list all the members of the set and put them in a pair of curly braces, like

```
>> s = {"Morse", pi, e, [3, 5], 7z};
>> 7z in s
   1
>> "Barber" in s
   0
```

You can also use the finite set as if it were a function

```
>> s = {"Morse", pi, e, [3, 5], 7z};
>> s("Morse")
   1
>> s("Barber")
   0
```

A finite set has several attributes: `add`, `remove`, and `size`, which are used to add element, remove element, and check the size of the set. For example

```
>> s = {"Morse", pi, e, [3, 5], 7z};
>> s.remove("Morse");
>> s.add("Barber")
>> s.size
   5
```

If your set cannot be represented by a finite set, that is, you can not list all the elements, you can use a function to represent the set. This function is called the characteristic function of the set. All it does is check a given value and find out if it is a member of the set. If it is, the function returns 1 otherwise 0. For example, the set of all real numbers x that satisfies $6 \leq x \leq 17$ or $x \geq 70$ can be defined like this

```
>> s = x -> (x >= 6 && x <= 17) || x >= 70;
>> 55 in s
   0
>> 81 in s
   1
```

Of course, since it is a function, you can use as a function: `s(55)` will return the same value as `55 in s`. Note here the logical operator `&&` means "and", and `||` means "or".
Intervals of real numbers are special sets that can be created directly. For example, the interval $[-1, 2]$ can be created like this

```
>> s = -1 to 2;
>> -0.5 in s
   1
>> 2.5 in s
   0
```

Open and half open intervals can be created also. See the following examples

```
>> s1 = (0 to 1);   // interval [0, 1]
>> s2 = (0+ to 1-);   // open interval (0, 1)
>> s3 = (0+ to 1);   // half open interval (0, 1]
>> s4 = (0 to 1-);   // half open interval [0, 1)
>> s5 = (0 to inf);   // interval [0, inf)
>> s6 = (-inf to 1);   // interval (-inf, 1]
>> s7 = (-inf to inf);   // interval (-inf, inf) equivalent to _R
```

Regular expressions can be used as sets of character strings. For example, a set of strings that contain one or more `z`'s can be created by

```
>> s = ~/zz*/;
>> x = "Jazz";
>> x in s
   1
```

Shang also has a number of built-in sets. For example, `_R` is the set of all real numbers, `_R2` is the set of all vectors of real numbers with length 2, etc. Check the manual for the complet list.

13.1 Domain

If you have a variable `a`, usually you can assign any value to it. But suppose that you only want it to hold numbers between 18 and 79. Of course, if you keep this in mind and always check the value assigned to it, you will be fine. But suppose that you want to prevent it from getting an illegal value accidentally, you can specify a domain for it. The domain is a set, and has to be given the first the time the variable is created. For example

```
>> a = 21 in (18 to 79);
>> a = 15;
   Error "a=15": assignment justification failed
```

Note that here the domain can be a set defined in any of ways discussed earlier (finite set, interval, characteristic function, built-in set, regular expressions, vectors, matrices, etc). Function arguments can have domains. For example

```
f = function [x = 1 in (0 to 1)] x in _R -> y
        ...
    end
```

Then if you call the function by `f(-0.2)`, the interpreter will find out the argument value is not in the domain and refuse to carry out the function call.
Class member attributes can have domains also. For example, here we have a "person" class. Each member has attributes `gender`, `age`, `fist`, and `last`. The `gender` attribute has to be either `F` or `M`, `age` has to be between 1 and 150, `fist` and `last` have to be strings of letters with the fist one capitalized.

```
person = class
              public gender = "M" in {"F", "M"};
              public age    = 38 in 1 : 150;
              public first  = "Jerry" in ~/[A-Za-z][A-Za-z]*/;
              public last   = "Gallo" in ~/[A-Za-z][A-Za-z]*/;
         end
```

This way, although all the attributes are public, no illegal values can be assigned to a member.

14 More about Functions

14.1 Default argument value

Suppose that you want to write an equation solver `fsolve` which takes arguments `f`, `x0`, and `reltol`. `reltol` is the relative tolerance. If you don't want to force the user to give the value of `reltol` every time, you can specify the default value of `reltol` in the function definition

```
fsolve = function (f, x0, reltol = 1e-5) -> x
            ...
         end
```

This way the function can be called by either `fsolve(f, x0)` (in which case the default `reltol` is used) or `fsolve(f, x0, reltol)`.

14.2 Function parameters

Suppose that you want to write an ODE function for Lorenz's equation

$$\begin{aligned}
y_1'(t) &= \sigma(y_2 - y_3) \\
y_2'(t) &= r * y_1 - y_2 - y_1 y_3 \\
y_3'(t) &= y_1 y_2 - y_2 - b y_3
\end{aligned}$$

The ODE depends on three parameters σ, r, b. If we write a function that takes these three, along with t and y vector, as arguments, the standard ODE solver may refuse to solve it because it expects a function of t and y only. Instead, we can set σ, r and b as function parameters

```
lorenz = function [sigma = 10, b=8/3, r=28] (t, y) -> yp
                      d1 = sigma * (y[2] - y[1]);
                      d2 = r*y[1] - y[2] - y[1] * y[3];
                      d3 = y[1] * y[2] - b * y[3];
                      yp = [d1; d2; d3];
         end;
```

This way, `lorenz` is still a function of two arguments `t` and `y`, just the way ODE solver wants. `sigma`, `r`, and `b` are now parameters and can be easily modified. Note that 10, 8/3, and 28 are just the default values of the parameters and can be reset like this

```
>> lorenz.sigma
   10
>> loranz.sigma = 15
   15
```

14.3 Partial substitution

Consider the previous problem, we can actually write the Lorenz function like this

```
lorenz = function (t, y, sigma, b, r) -> yp
                      d1 = sigma * (y[2] - y[1]);
                      d2 = r*y[1] - y[2] - y[1] * y[3];
                      d3 = y[1] * y[2] - b * y[3];
                      yp = [d1; d2; d3];
         end;
```

Now `sigma`, `b`, and `r` are also function arguments like `t` and `y`. But the ODE solver expects a function of only two arguments. We can use partial substitution to solve the problem

```
>> ode = lorenz(., ., 10, 8/3, 28);
>> (t, y) = dsolve(ode, [0, 10], [1, 1, 1]);
```

Note that the first two arguments are passed dots in the function call. The result of such a call is a new function (of the missing arguments).

14.4 Quit from a function

The `return` statement can be used to terminate a function immediately. For example

```
bisect = function (f, a, b) -> x
     if f(a) * f(b) > 0
         return;
     end
     ...
end
```

The function first check if the given arguments values are valid. If the test fails, the rest of the computation will be skiped and the function is terminated by the `return` statement. Of course, you may want to display some error message before `return`. Note that the `return` statement takes no argument. The return value of the function call is always the value of the output variable (the one on the RHS of the arrow in the function definition, in this example, `x`).

14.5 Returning multiple arguments

If you want a function to return more than one values, these values can be wraped in a list and returned. Or it can be done like this

```
f = function (x, y) -> (small, big, average)
         small = min(x, y);
         big   = max(x, y);
         average = (x + y) / 2;
    end
```

When this function is called, a list of the three output values will be returned.

```
>> f(9, 7)
   (7, 9, 8)
```

Or you can use a multiple assignment to receive the three values

```
>> f = function (x, y) -> (small, big, average)
         small = min(x, y);
         big   = max(x, y);
         average = (x + y) / 2;
    end;
>> f(9, 7)
   (7, 9, 8)
>> (sm, bg, ave) = f(9, 7);
>> sm
```

```
   7
>> bg
   9
>> ave
   8
```

14.6 Domain

Function arguments and parameters can have domains. For example

```
f = function (x in _R, v in _R2) -> z in _R
        ...
    end
```

Here the input argument `x` has domain `_R`, the set of all real numbers, and `v` has domain `_R2`, the set of all real vector of length 2. This way, inside the function you don't need to write code to check if the input arguments indeed satisfy these conditions, so the function will not operate on invalid input values, because the interpreter does this for you.

15 More Advanced Topics

There are other features of Shang not covered in this tutorial. If you're interested in more advanced topics on Shang programming, please take a look at the language reference manual and other documentations.