Human-Oriented Robotics

Octave/Matlab Tutorial

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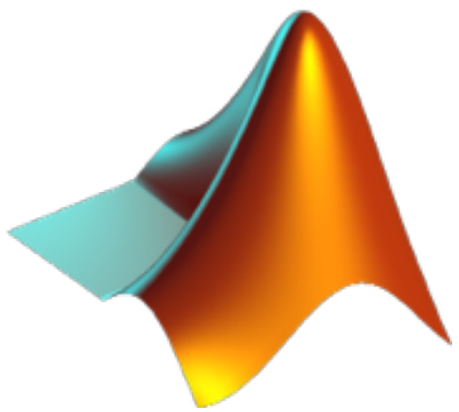
Contents

- Overview
- Start, quit, getting help
- Variables and data types
- Matrices
- Plotting
- Programming
- Functions and scripts
- Files I/O
- Misc
- Octave and Matlab in practice
- librobotics

GNU Octave



Matlab

Overview

- **Octave** is the "open-source **Matlab**"
- **Octave** is a great gnuplot wrapper
- www.octave.org
- www.mathworks.com

Octave and **Matlab** are both, high-level languages and mathematical programming environments for:

- Visualization
- Programming, algorithm development, prototyping
- Scientific computing: linear algebra, optimization, control, statistics, signal and image processing, etc.

Beware: Octave/Matlab programs can be **slow**

Overview

Comparison Matlab vs. Octave

- Matlab is more flexible/advanced/powerful/costly
  - Has an IDE and a proper GUI, windows for help, variables, command history, etc.
- Octave is for free (GPL license)
- There are minor differences in syntax

This tutorial

- Applies to **Matlab AND Octave** unless stated otherwise!
- Is valid for the **2009 versions**
  - Octave 3.2.3
  - Matlab 7.6

  or higher

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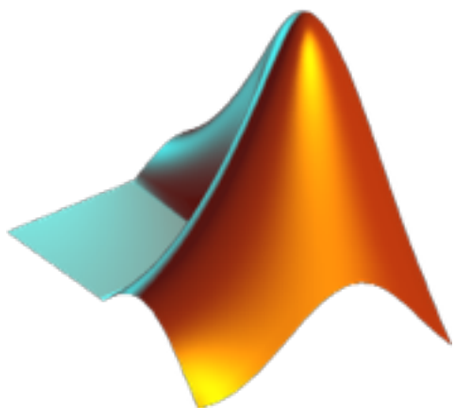

Matlab

Start, Quit, Getting Help

- To **start Octave** type the shell command `octave` or whatever your OS needs.
  You should see the prompt:

  ```
  octave:1>
  ```

- **Matlab** will start its own window-based development environment

- If you get into trouble, you can **interrupt Octave** by typing `Ctrl-C`

- To **exit Octave**, type `quit` or `exit`

Start, Quit, Getting Help

- To get **help**, type `help` **or** `doc`

- To get **help** on a **specific command** (= built-in function), type `help command`

- Examples: `help size, help plot, help figure, help inv,` …

- To get **help** on the **help system**, type `help help`

- In Octave: type `q` to **exit** help mode (like man pages)

Start, Quit, Getting Help

- In the help text of **Matlab** functions, function names and variables are in **capital letters**
- Example: `help round` **returns**

```
ROUND  Round towards nearest integer.
   ROUND(X) rounds the elements of X to the nearest
   integers.
   See also floor, ceil, fix.
   [...]
```

- **Don't get confused!** The naming convention specifies **lowercase letters** for built-in commands. It is just a way to highlight text
- **Octave** texts are **mixed**, in lower- and uppercase
- **Update:** this finally changed in new Matlab versions

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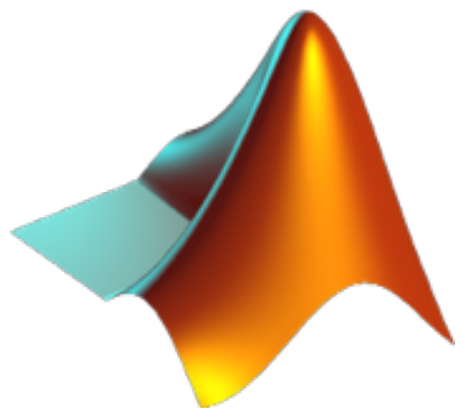

Matlab

Variables and Data Types

In Octave/Matlab almost **everything** is a **matrix**!

- **Matrices**

("Matlab" comes from "Matrix Laboratory")

Main matrix classes

- **Strings**: matrices of characters
- **Structures**: matrices of named fields for data of varying types and sizes
- **Logical**: matrices of boolean 0/1-values

Not treated in this tutorial

- Cells (like structures)
- Function handles (pointer to functions)

Variables and Data Types

What about...

- **Vectors** or **arrays?**
  → A matrix with one column or row
- **Scalars?**
  → A matrix of dimension 1x1
- **Integers?**
  → A double (you never have to worry)
- **Characters?**
  → A string of size 1

- **Matlab** has more types than Octave, e.g. user-defined OO-classes

Variables and Data Types

Creating a Matrix

- Simply type:

```
octave:1> A = [8, 2, 1; 3, -1, 4; 7, 6, -5]
```

Octave will respond with a matrix in pretty-print:

```
A =

   8   2   1
   3  -1   4
   7   6  -5
```

- More on matrices, further down this tutorial.

Creating a Character String

- Simply type

```
octave:4> str = 'Hello World'
```

Opposed to Matlab, Octave can also deal with double quotes.
For compatibility reasons: always use **single quotes**

Creating a Structure

- Type for instance

```
octave:5> data.id = 3;
octave:6> data.timestamp = 1265.5983;
octave:7> data.name = 'sensor 1 front';
```

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Creating a Vector of Structures

- Oh, a new measurement has arrived. Extend struct by:

```
octave:8> data(2).id = 4;
octave:9> data(2).timestamp = 1268.9613;
octave..> data(2).name = 'sensor 1 back';
```

Octave will respond with:

```
data =
{
     1x2 struct array containing the fields:
     id
     timestamp
     name
}
```

Variables and Data Types

Display Variables

- Simply type its name

```
octave:1> a
a = 4
```

Suppress Output

- Add a semicolon

```
octave:2> a;
octave:3> sin(phi);
```

- Applies also to function calls

Variables and Data Types

- **Variables** have **no permanent type**. Octave/Matlab are weakly typed languages

  `s = 3` followed by `s = 'octave'` is fine

- Use `who` (or the more detailed `whos`) to **list** the **currently defined variables**. Example output:

```
Variables in the current scope:
  Attr Name        Size                     Bytes  Class
  ==== ====        ====                     =====  =====
       A           3x3                         72  double
       a           1x1                          8  double
       ans        21x1                        168  double
       s           1x5                          5  char
       v           1x21                        24  double
```

Variables and Data Types

Numerical Precision

Variables are stored as double precision numbers in IEEE floating point format

- `realmin` Smallest positive floating point number: 2.23e-308
- `realmax` Largest positive floating point number: 1.80e+308
- `eps` Relative precision: 2.22e-16

- These keywords are **reserved** and can be used in your code

Variables and Data Types

Control Display of Float Variables

- `format short` Fixed point format with 5 digits
- `format long` Fixed point format with 15 digits
- `format short e` Floating point format, 5 digits
- `format long e` Floating point format, 15 digits
- `format short g` Best of fixed or floating point with 5 digits (good choice)
- `format long g` Best of fixed or floating point with 15 digits

See `help format` for more information

Variables and Data Types

Talking about Float Variables...

- `ceil(x)` Round to smallest integer not less than x
- `floor(x)` Round to largest integer not greater than x
- `round(x)` Round towards nearest integer
- `fix(x)` Round towards zero

If x is a **matrix**, the functions are applied to **each element** of x.

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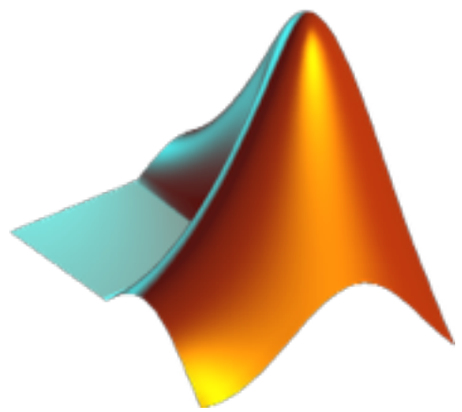

Matlab

Matrices

Creating a Matrix

- Simply type:

```
octave:1> A = [8, 2, 1; 3, -1, 4; 7, 6, -5]
```

- To delimit **columns**, use comma or space
- To delimit **rows**, use semicolon

The following expressions are **equivalent**:

```
A = [8 2 1;3 -1 4;7 6 -5]
A = [8,2,1;3,-1,4;7,6,-5]
```

Matrices

Creating a Matrix

- Octave will respond with a matrix in pretty-print:

```
A =

    8    2    1
    3   -1    4
    7    6   -5
```

- Alternative Example:

```
octave:2> phi = pi/3;
octave:3> R = [cos(phi) -sin(phi); sin(phi) cos(phi)]
R =
     0.50000  -0.86603
     0.86603   0.50000
```

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Creating a Matrix from Matrices

```
octave:1> A = [1 1 1; 2 2 2];  B = [33; 33];
```

- Column-wise

```
octave:2> C = [A B]
C =
     1    1    1   33
     2    2    2   33
```

- Row-wise:

```
octave:3> D = [A; [44 44 44]]
D =
     1    1    1
     2    2    2
    44   44   44
```

Matrices

Indexing

Always "row before column"!

- `aij = A(i,j)` Get an element
- `r = A(i,:)` Get a row
- `c = A(:,j)` Get a column
- `B = A(i:k,j:l)` Get a submatrix

- **Useful indexing command** `end` **:**

```
octave:1> data = [4 -1 35 9 11 -2];
octave:2> v = data(3:end)
v =
     35   9   11   -2
```

Matrices

The two meaning of colon ':'

- **Wildcard** to select entire matrix **row** or **column**

```
A(3,:), B(:,5)
```

- **Defines a *range*** in expressions like

```
indices = 1:5    Returns row vector 1,2,3,4,5
steps = 1:3:61   Returns row vector 1,4,7,...,61
t = 0:0.01:1     Returns vector 0,0.01,0.02,...,1
```

start increment stop

- **Useful command** to define ranges: `linspace`

Assigning a Row/Column

- All referenced elements are set to the scalar value.

```
octave:1> A = [1 2 3 4 5; 2 2 2 2 2; 3 3 3 3 3];
octave:2> A(3,:) = -3;
```

Adding a Row/Column

- If the referenced row/column doesn't exist, it's added.

```
octave:3> A(4,:) = 4
A =
     1    2    3    4    5
     2    2    2    2    2
    -3   -3   -3   -3   -3
     4    4    4    4    4
```

Deleting a Row/Column

- Assigning an empty matrix [] deletes the referenced rows or columns. Examples:

```
octave:4> A(2,:) = []
A =
    1    2    3    4    5
   -3   -3   -3   -3   -3
    4    4    4    4    4

octave:4> A(1:2:5,:) = []
A =
          2    4
          2    2
         -3   -3
          4    4
```

Matrices

Get Size

- `nr = size(A,1)` Get number of rows of A
- `nc = size(A,2)` Get number of columns of A
- `[nr nc] = size(A)` Get both (remember order)
- `l = length(A)` Get whatever is bigger
- `numel(A)` Get number of elements in A
- `isempty(A)` Check if A is empty matrix []

Octave only:

- `nr = rows(A)` Get number of rows of A
- `nc = columns(A)` Get number of columns of A

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Matrix Operations

- `B = 3*A` — Multiply by scalar
- `C = A*B + X - D` — Add and multiply
- `B = A'` — Transpose A
- `B = inv(A)` — Invert A
- `s = v'*Q*v` — Mix vectors and matrices

- `d = det(A)` — Determinant of A
- `[v lambda] = eig(A)` — Eigenvalue decomposition
- `[U S V] = svd(A)` — Singular value decomposition

- many many more...

Matrices

Vector Operations

With x being a column vector

- `s = x'*x` Inner product, result is a scalar
- `X = x*x'` Outer product, result is a matrix
- `e = x*x` Gives an error

Element-Wise Operations

- `s = x.+x` Element-wise addition
- `p = x.*x` Element-wise multiplication
- `q = x./x` Element-wise division
- `e = x.^3` Element-wise power operator

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Useful Vector Functions

- `sum(v)` — Compute sum of elements of v
- `cumsum(v)` — Compute cumulative sums of elements of v (returns a vector)
- `prod(v)` — Compute product of elements of v
- `cumprod(v)` — Compute cumulative products of elements of v (returns a vector)
- `diff(v)` — Compute difference of subsequent elements [v(2)-v(1) v(3)-v(2) ...]
- `mean(v)` — Mean value of elements in v
- `std(v)` — Standard deviation of elements

Matrices

Useful Vector Functions

- `min(v)` Return smallest element in v
- `max(v)` Return largest element in v

- `sort(v,'ascend')` Sort in ascending order
- `sort(v,'descend')` Sort in descending order

- `find(v)` Find indices of non-zero elements.
  Great in combination with vectorization
  Example:

```
ivec = find(datavec == 5)
```

Matrices

Special Matrices

- `A = zeros(m,n)` — Zero matrix of size m x n (Often used for preallocation)
- `B = ones(m,n)` — Matrix of size m x n with all 1's
- `I = eye(n)` — Identity matrix of size n
- `D = diag([a b c])` — Diagonal matrix of size 3 x 3 with a,b,c in the main diagonal

Just for fun

- `M = magic(n)` — Magic square matrix of size n x n. (All rows, columns sum up to same number)

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Random Matrices and Vectors

- `R = rand(m,n)` — Matrix with m x n uniformly distributed random numbers from interval [0..1]

- `N = randn(m,n)` — Matrix with m x n normally distributed random numbers with zero mean, unit variance

- `v = randperm(n)` — Row vector with a random permutation of the numbers 1 to n

Matrices

Multi-Dimensional Matrices

Matrices can have more than two dimensions.

- **Create a 3-dimensional matrix** by typing, e.g.,

```
octave:1> A = ones(2,5,2)
```

Octave will respond by

```
A =
ans(:,:,1) =
        1   1   1   1   1
        1   1   1   1   1
ans(:,:,2) =
        1   1   1   1   1
        1   1   1   1   1
```

Matrices

Multi-Dimensional Matrices

- All operations to create, index, add, assign, delete and get size apply in the same fashion

Examples:

- `[m n l] = size(A)`
- `A = ones(m,n,l)`
- `m = min(min(min(A)))`
- `aijk = A(i,j,k)`
- `A(:,:,5) = -3`

Matrix Massage

Matrix operations that have no mathematical meaning. Useful for manipulating data which is organized in matrices

- `reshape(A,m,n)` — **Change size** of matrix A to have dimension m x n. An error results of A does not have m x n elements
- `circshift(A,[m n])` — **Shift elements** of A m times in row dimension and m times in column dimension. Has no mathematical meaning
- `shiftdim(A,n)` — Shift the dimension of A by n. **Generalizes transpose** for multi-dimensional matrices

Matrices

Matrix Massage

- `fliplr(A)` — **Reverses the order** of columns of matrix A in left/right-direction. Rows are not changed
- `flipud(A)` — **Reverses the order** of rows of matrix A in up/down-direction. Columns are not changed
- `flipdim(A,dim)` — **Flip** matrix A along **dimension dim**. Typically for multi-dimensional matrices
- `rot90(A)` — **90 degree counterclockwise rotation** of matrix A. This is **not** the transpose of A

Matrix Massage Example

Let P = [x1; y1; x2; y2; ...] be a 2nx1 column vector of n (x,y)-pairs.
Make it a column vector of (x,y,theta)-tuples with all theta being pi/2

- Make P it a 2 x n matrix

```
octave:1> P = reshape(P,2,numel(P)/2);
```

- Add a third row, assign pi/2

```
octave:2> P(3,:) = pi/2;
```

- Reshape it to be a 3n x 1 column vector

```
octave:3> P = reshape(P,numel(P),1);
```

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Most Often Used Commands

- `strcat` Concatenate strings
- `int2str` Convert integer to a string
- `num2str` Convert floating point numbers to a string
- `sprintf` Write formatted data to a string.
  Same as C/C++ fprintf for strings

- **Example**

```
s = strcat('At step ',int2str(k),', p = ',num2str(p,4))
```

Given that strings are matrices of characters, this is equivalent to

```
s = ['At step ' int2str(k) ', p = ' num2str(p,4)]
```

Octave responds with

```
s = At step 56, p = 0.142
```

Strings

Octave/Matlab has virtually all common string and parsing functions

- You are encouraged to browse through the list of commands or simply type `help command`:

```
strcmp, strncmp, strmatch, char, ischar, findstr,
strfind, str2double, str2num, num2str, strvcat,
strtrim, strtok, upper, lower,...
```

and many more...

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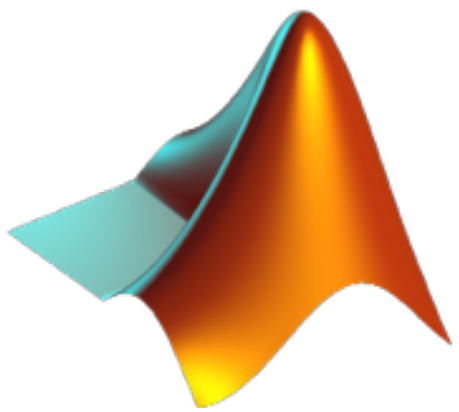

Matlab

Plotting

Plotting in 2D

- `plot(x,cos(x))` Display x,y-plot

  Creates automatically a figure window. **Octave uses gnuplot to handle graphics**.

- `figure(n)` Create figure window 'n'

  If the figure window **already exists**, brings it into the foreground (= makes it the current figure)

- `figure` Create new figure window with identifier incremented by 1

Plotting

Several Plots

- Series of x,y-pairs: `plot(x1,y1,x2,y2,...)`

  e.g. `plot(x,cos(x),x,sin(x),x,x.^2)`

- Add **legend** to plot: command `legend`

```
legend('cos(x),'sin(x)','x^2')
```

- Alternatively, `hold on` does the same job:

```
octave:1> hold on; plot(x,cos(x));
octave:2> plot(x,sin(x));
octave:3> plot(x,x.^2);
```

Plotting

Frequent Commands

- `clf` — Clear figure
- `hold on` — Hold axes. Don't replace plot with new plot, superimpose plots
- `grid on` — Add grid lines
- `grid off` — Remove grid lines

- `title('My Plot')` — Set title of figure window
- `xlabel('time')` — Set label of x-axis
- `ylabel('prob')` — Set label of y-axis

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Controlling Axes

- `axis equal` — Set equal scales for x-/y-axes **(Use it!)**
- `axis square` — Force a square aspect ratio
- `axis tight` — Set axes to the limits of the data
- `a = axis` — Return current axis limits [xmin xmax ymin ymax]
- `axis([-1 1 2.5 5])` — Set axis limits (freeze axes)
- `axis off` — Turn off tic marks

- `box on` — Adds a box to the current axes
- `box off` — Removes box

Plotting

Controlling Plot Styles

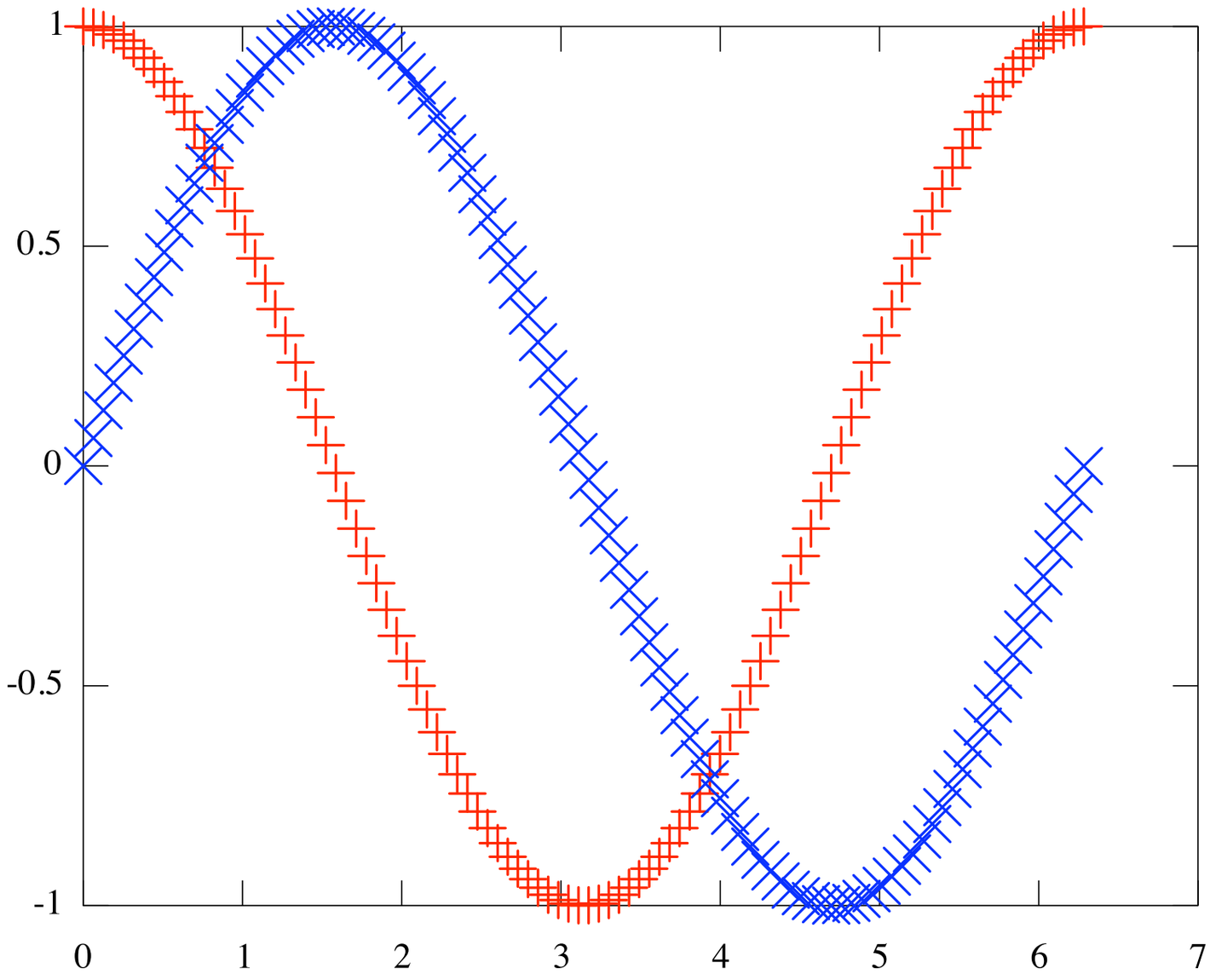
- In `plot(x,cos(x),'r+')` the format expression `'r+'` means **red cross**
- There are a number of line styles and colors, see `help plot`

Example:

```
octave:1> x = linspace(0,2*pi,100);
octave:2> plot(x,cos(x),'r+',x,sin(x),'bx');
```

produces this plot:

Plotting




```
plot(x,cos(x),'r+',x,sin(x),'bx');
```

Plotting

- **Adjusting the axes**

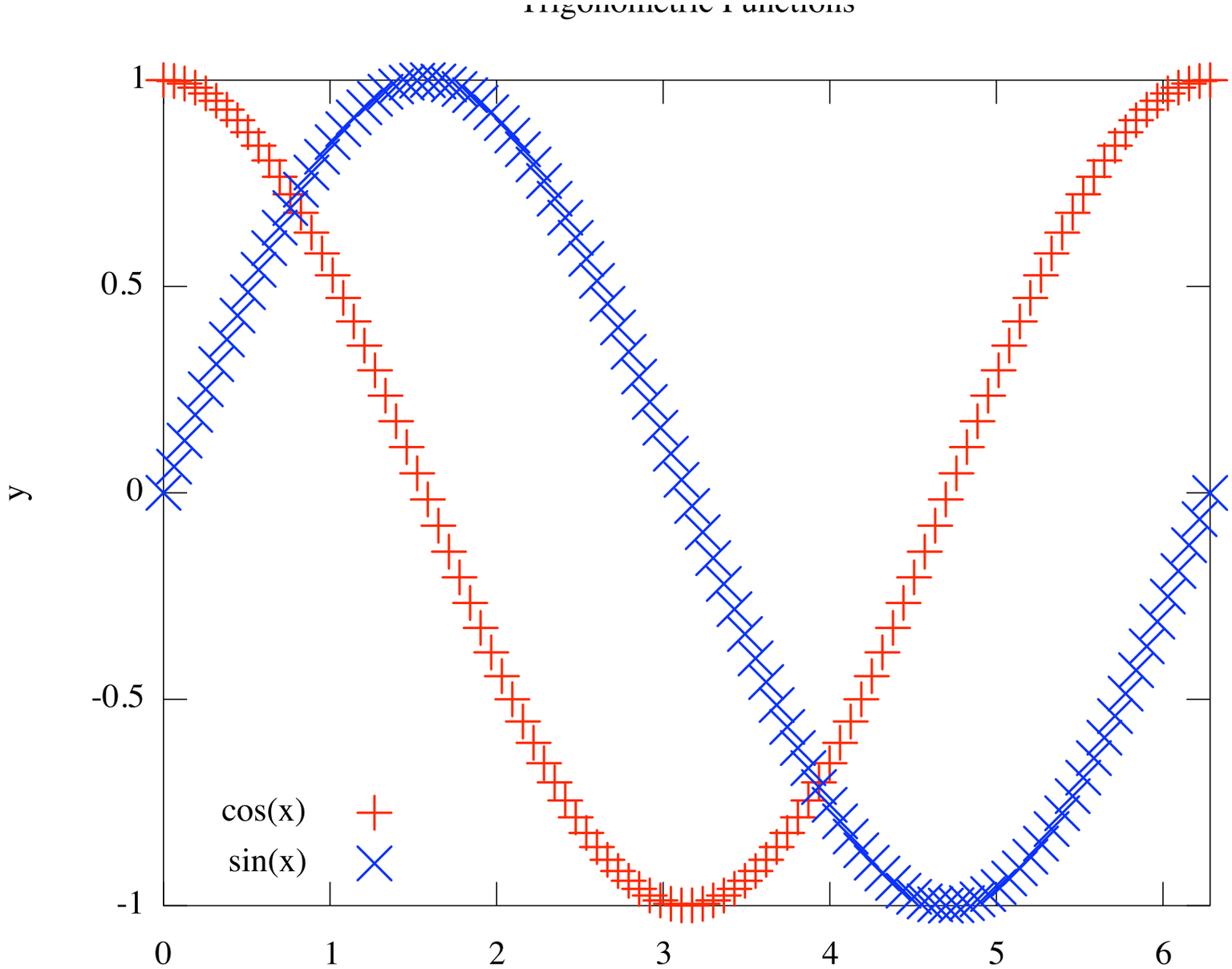
```
octave:3> axis([0 2*pi -1 1])
```

(try also `axis tight`)

- **Adding a legend, labels and a title**

```
octave:4>
legend('cos(x)','sin(x)','Location','Southwest')
octave:5> title('Trigonometric Functions')
octave:6> xlabel('x')
octave:7> ylabel('y')
```

Plotting




```
plot(x,cos(x),'r+',x,sin(x),'bx');
```

Plotting

Uhm..., don't like it. Let's start over...

```
octave:1> clf;
```

- **Controlling Color and Marker Size**

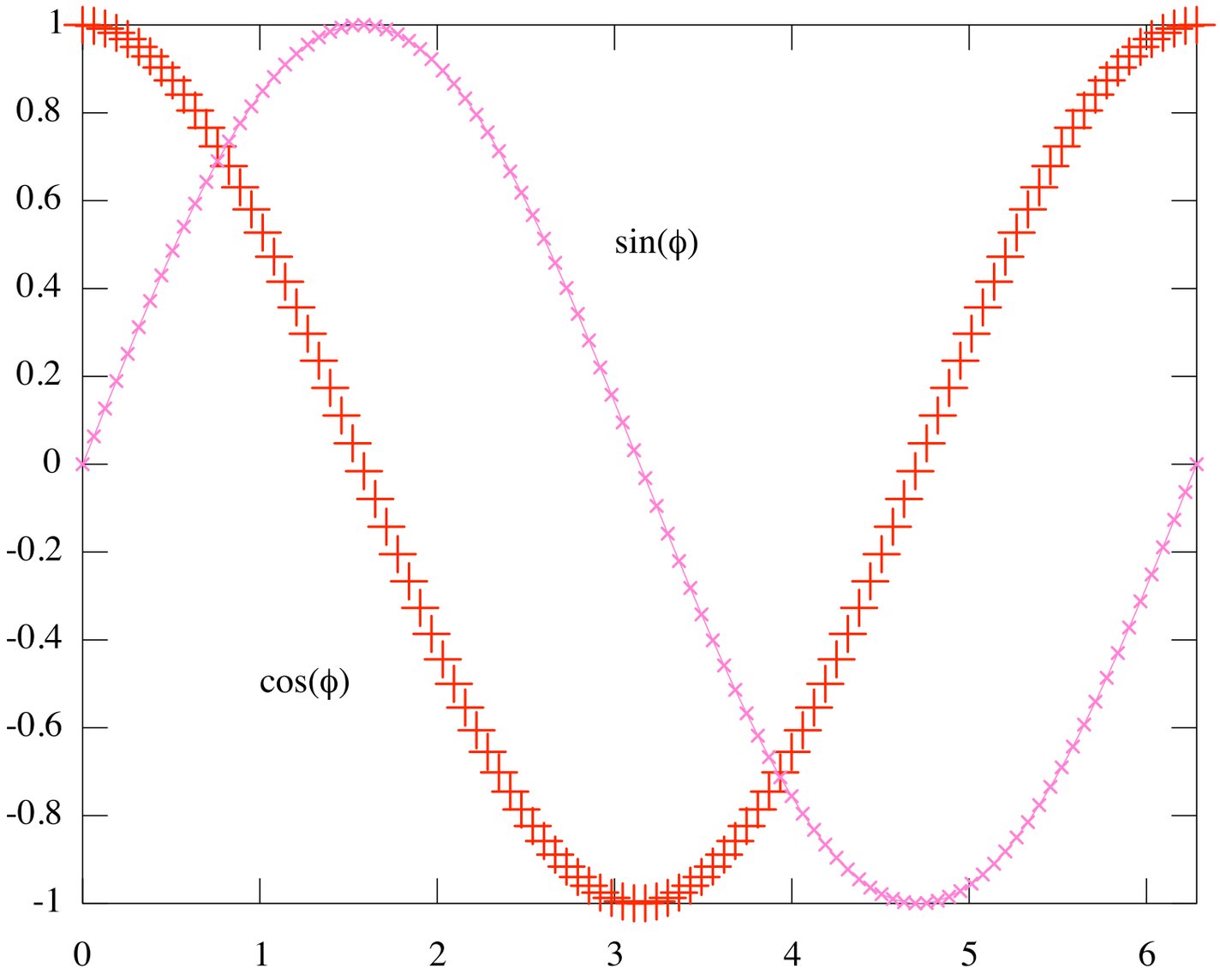
```
octave:2> plot(x,cos(x),'r+',x,sin(x),'-x',...
'Color',[1 .4 .8],'MarkerSize',2)
octave:3> axis tight
```

- **Adding Text**

```
octave:4> text(1,-0.5,'cos(\phi)')
octave:5> text(3,0.5,'sin(\phi)')
```

Note the LaTeX syntax!

Plotting




```
plot(x,cos(x),'r+',x,sin(x),'-x','Color',[1 .4 .8],'MarkerSize',2)
```

Plotting

Yepp, I like it... Get hardcopy!

Exporting Figures

- `print -deps myPicBW.eps` Export B/W .eps file
- `print -depsc myPic.eps` Export color .eps file
- `print -djpeg -r80 myPic.jpg` Export .jpg in 80 ppi
- `print -dpng -r100 myPic.png` Export .png in 100 ppi

See `help print` for more devices including specialized ones for Latex

- `print` can also be **called as a function**.
  Then it takes arguments and options as a comma-separated list.

```
print('-dpng','-r100','myPic.png');
```

Plotting

This tutorial cannot cover the **large variety of graphics commands** in Octave/Matlab

- You are encouraged to browse through the list of commands or simply type `help command`:

```
hist, bar, pie, area, fill, contour, quiver,
scatter, compass, rose, semilogx, loglog, stem,
stairs, image, imagesc
```

and many more!

Plotting in 3D

- `plot3` Plot lines and points in 3d
- `mesh` 3D mesh surface plot
- `surf` 3D colored surface plot

Most 2d plot commands have a **3D sibling**. Check out, for example,

```
bar3, pie3, fill3, contour3, quiver3,
scatter3, stem3
```

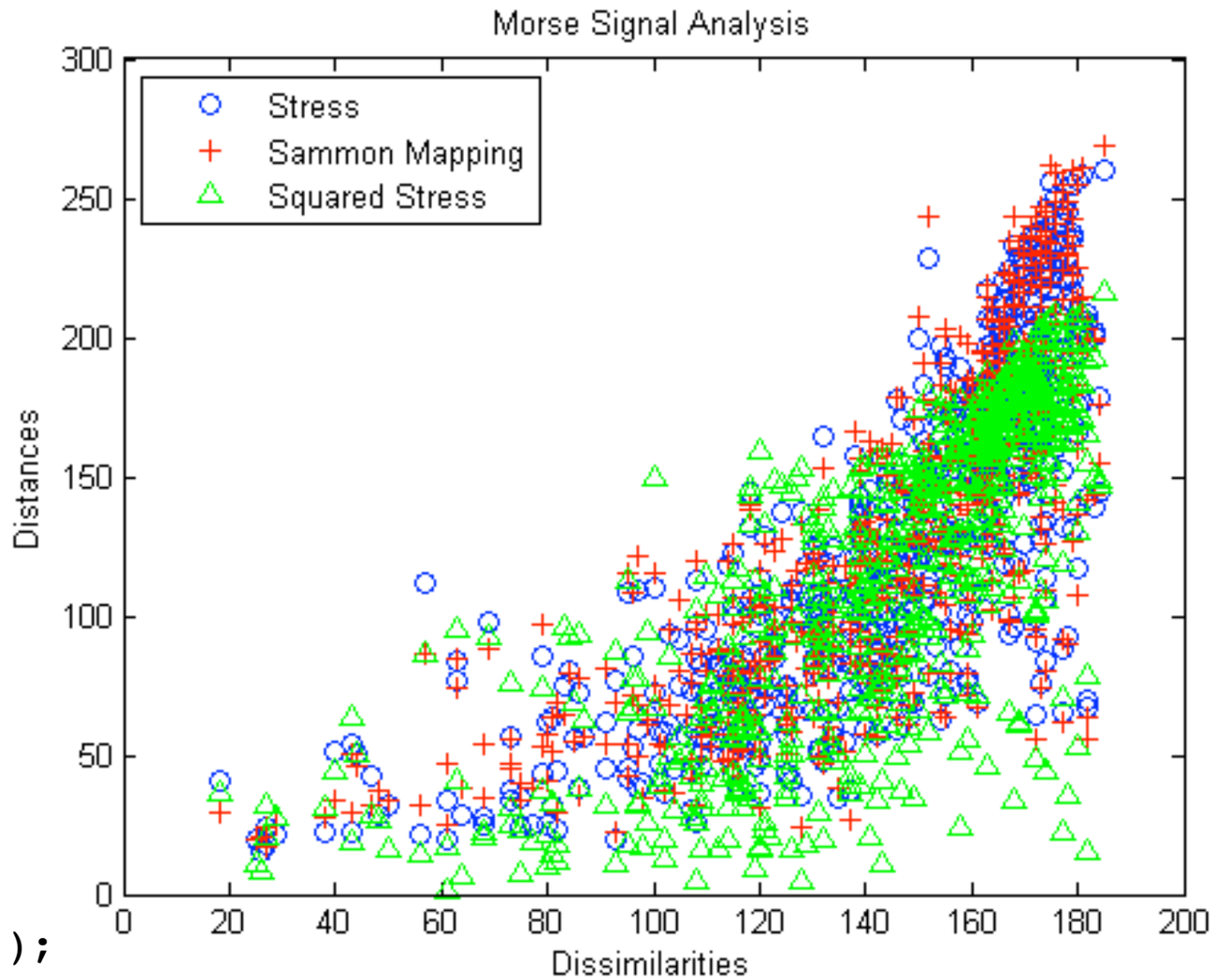
Let us look at some **examples...**

Example: `plot`

```
% Load data
load MDdata xdata dist1 dist2 dist3

% Plot the first set of data in blue
figure; hold on;
plot(xdata, dist1, 'bo');
plot(xdata, dist2, 'r+');
plot(xdata, dist3, 'g^');

% Add title, axis labels, legend
title('Morse Signal Analysis');
xlabel('Dissimilarities');
ylabel('Distances');
legend({'Stress', 'Sammon Mapping',
'Squared Stress'},'Location','NorthWest');
```



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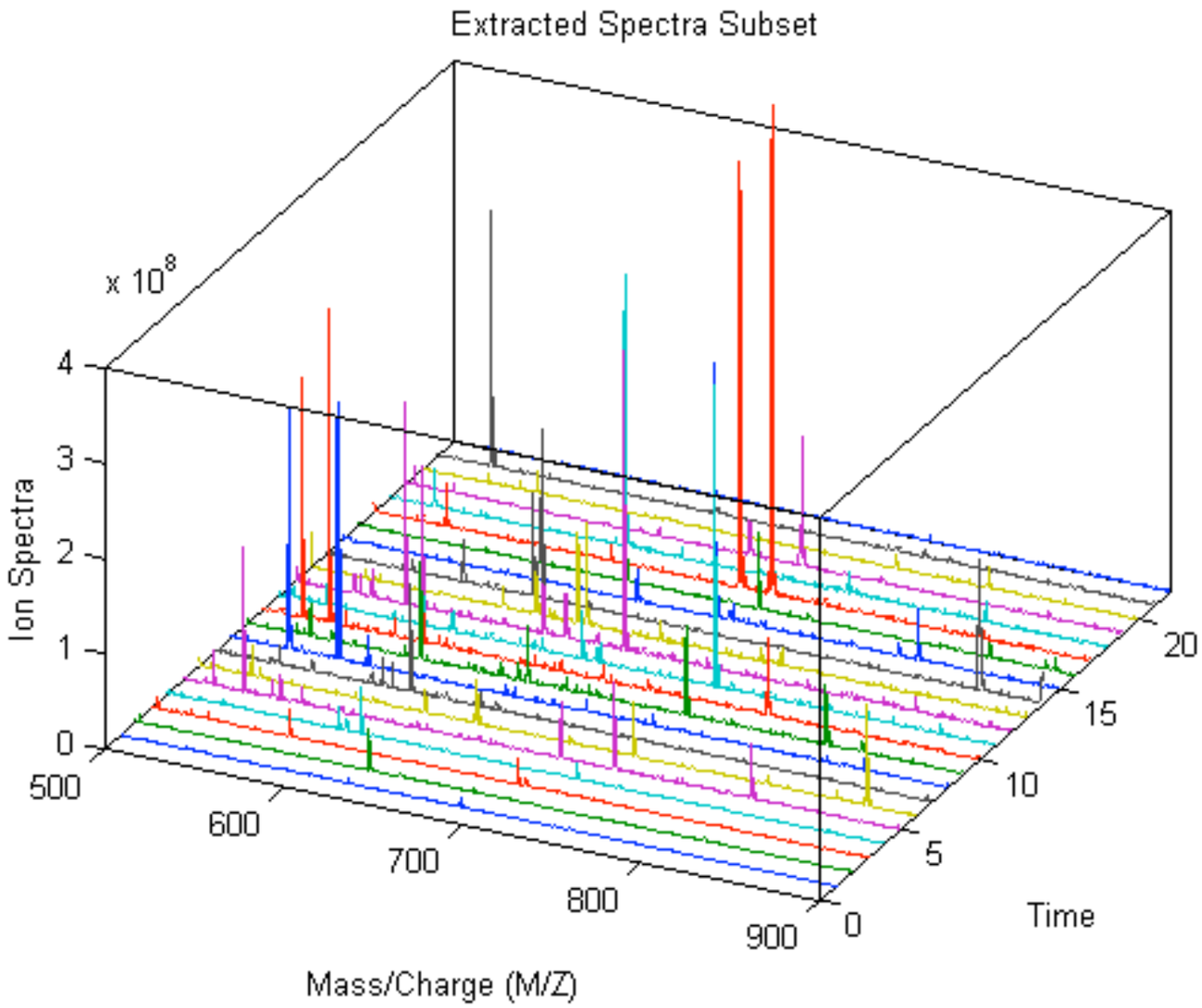
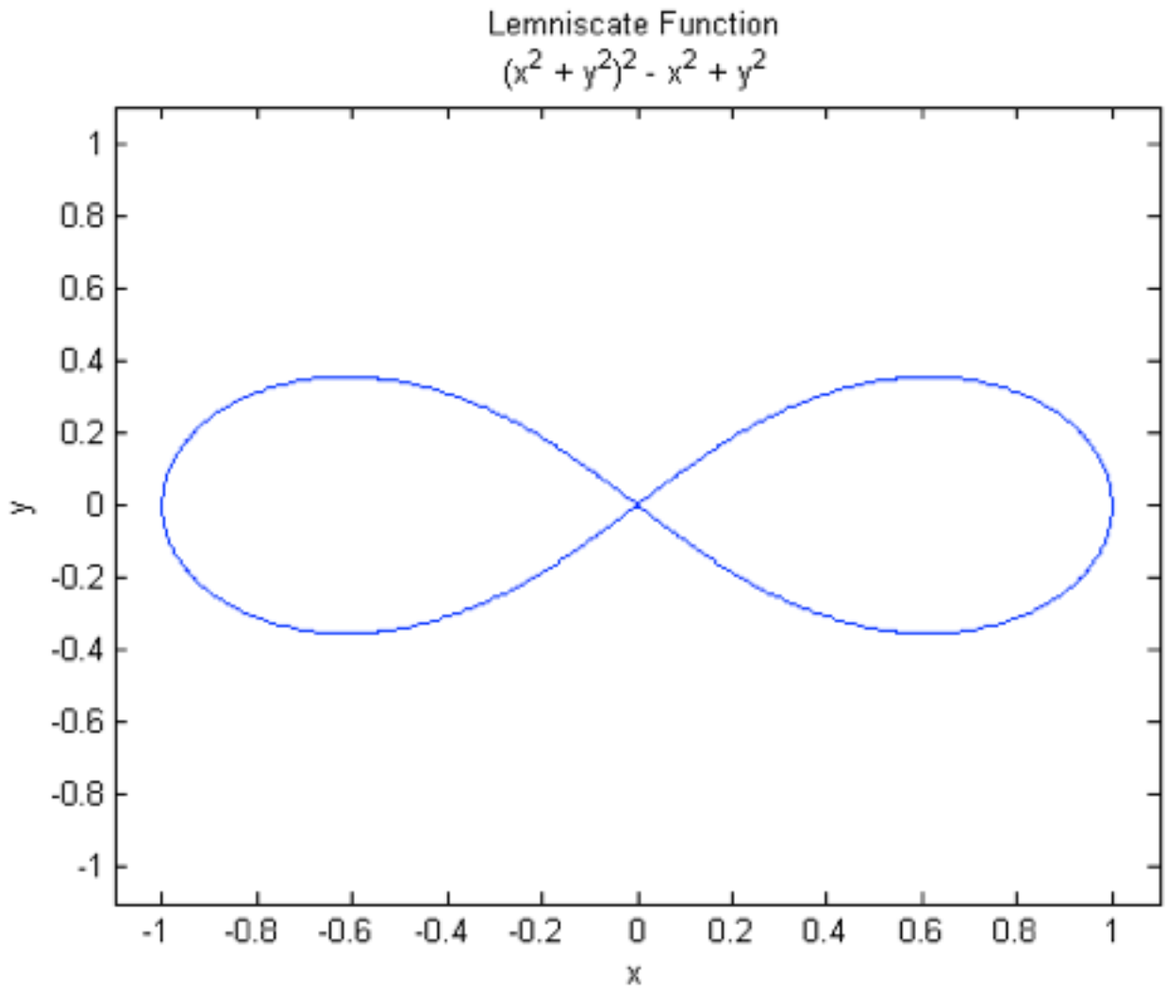
Example: `plot3`

```
% Load data
load SpectraData massc time spectra;

% Create the 3D plot
figure;
plot3(massc, time, spectra);
box on;

% Set viewing angle and axis limits
view(26, 42);
axis([500 900 0 22 0 4e8]);

% Add title and axis labels
xlabel('Mass/Charge (M/Z)');
ylabel('Time');
zlabel('Ion Spectra');
title('Extracted Spectra Subset');
```



Example: `ezplot`

```
% Create the plot
figure;
ezplot('(x^2 + y^2)^2 - x^2 + y^2',...
[-1.1, 1.1], [-1.1, 1.1]);

% Add a multi-line title
title({'Lemniscate Function';...
'(x^2 + y^2)^2 - x^2 + y^2'});
```



Note: the **special character** . . . at the end of a line continues the current function on the next line

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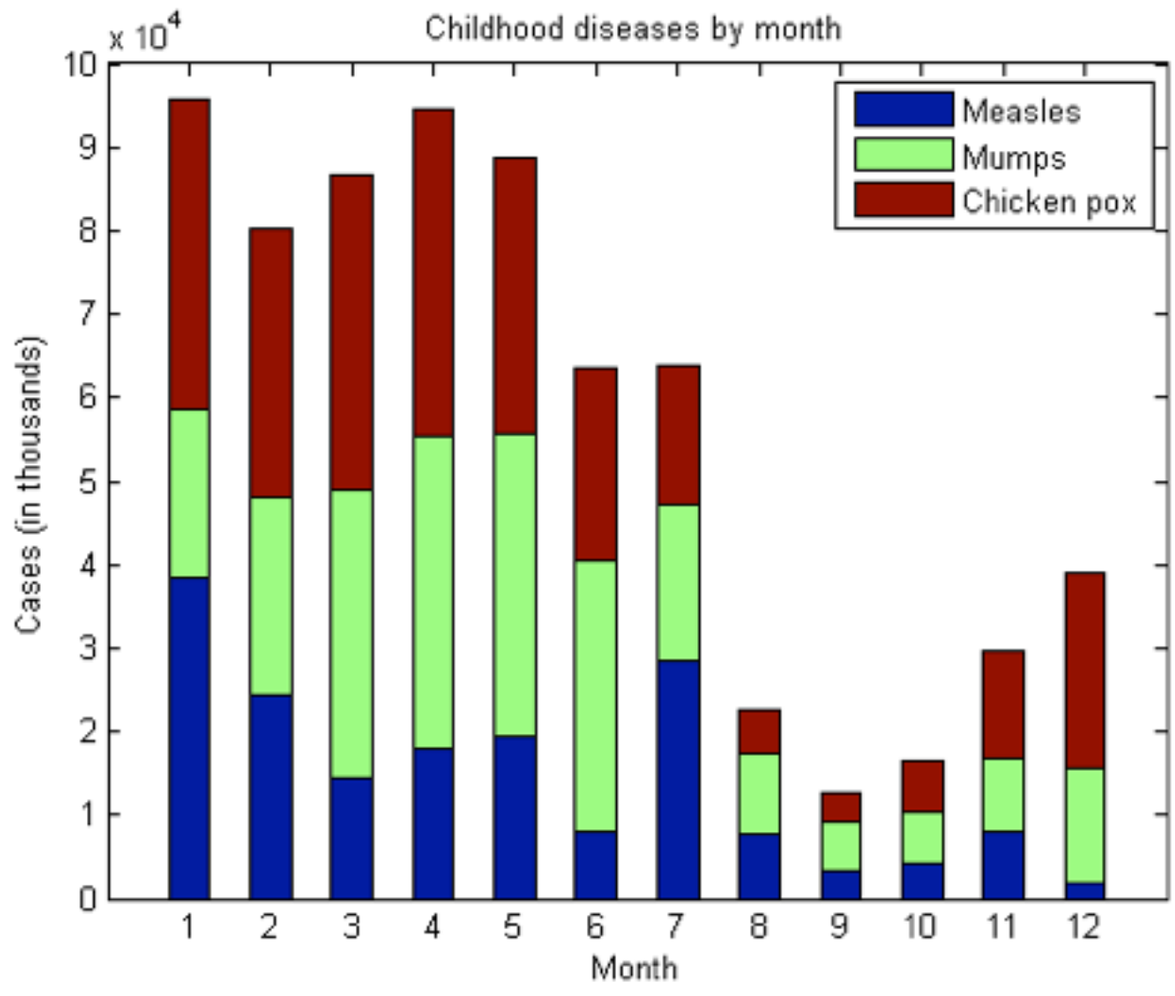
Example: `bar`

```
% Load data
load Datafile measles mumps chickenpox;

% Create a stacked bar chart bar
figure;
bar(1:12, [measles mumps chickenpox],...
0.5, 'stack');

% Adjust the axis limits
axis([0 13 0 100000]);

% Add title, axis labels, legend
title('Childhood diseases by month');
xlabel('Month');
ylabel('Cases (in thousands)');
legend('Measles', 'Mumps', 'Chicken pox');
```



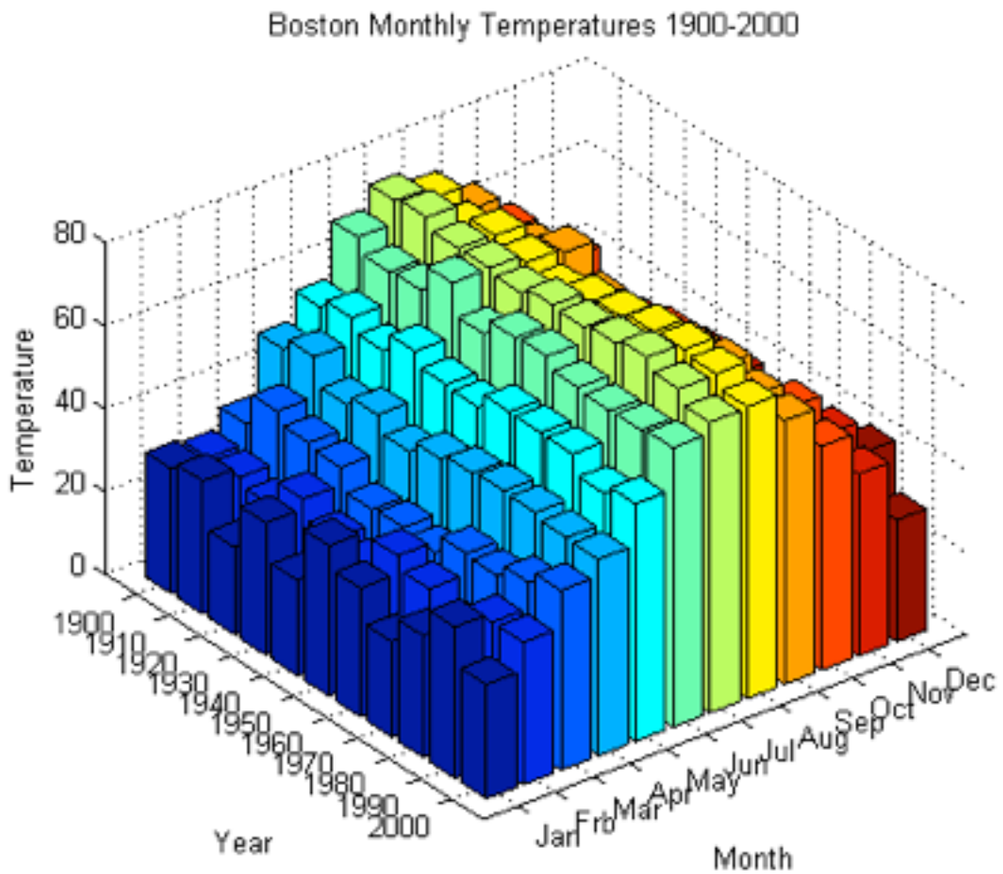
Example: `bar3`

```
% Load monthly temperature data
load MonthlyTemps temperatures months years;

% Create the 3D bar chart
figure;
bar3(temperatures);
axis([0 13 0 12 0 80]);

% Add title and axis labels
title('Boston Monthly Temps 1900-2000');
xlabel('Month');
ylabel('Year');
zlabel('Temperature');

% Change the x and y axis tick labels
set(gca, 'XTickLabel', months);
set(gca, 'YTickLabel', years);
```

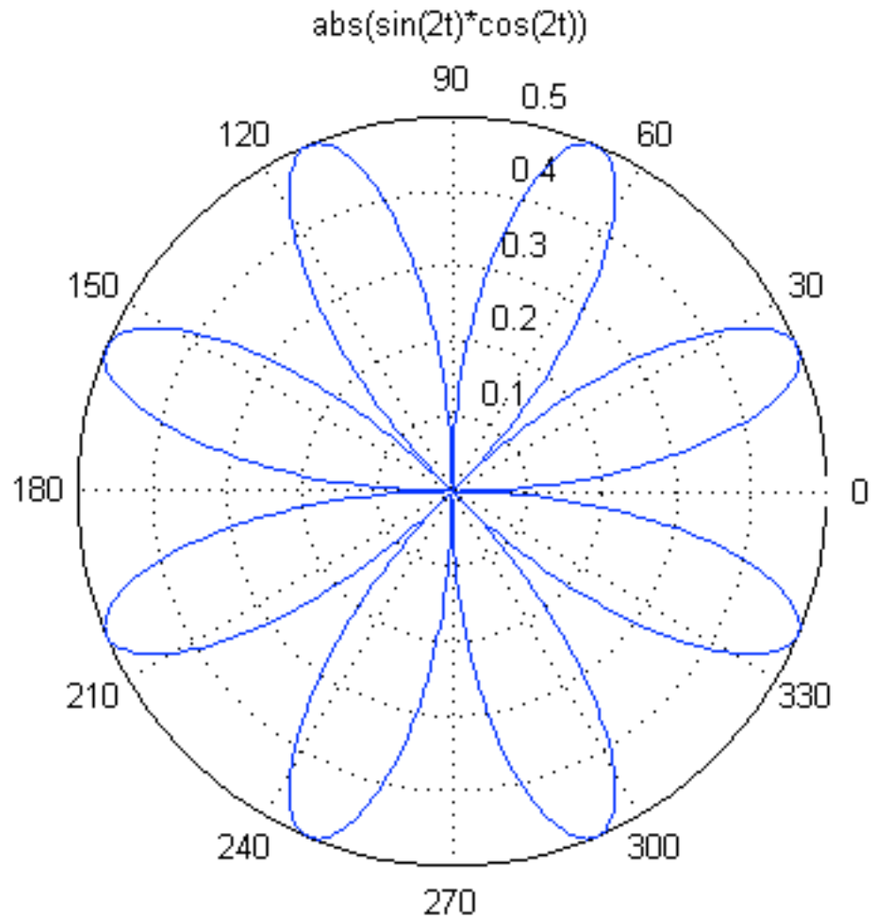


Example: `polar`

```
% Create data for the function
t = 0:0.01:2*pi;
r = abs(sin(2*t).*cos(2*t));

% Create a polar plot using polar
figure;
polar(t, r);

% Add a title
title('abs(sin(2t)*cos(2t))');
```



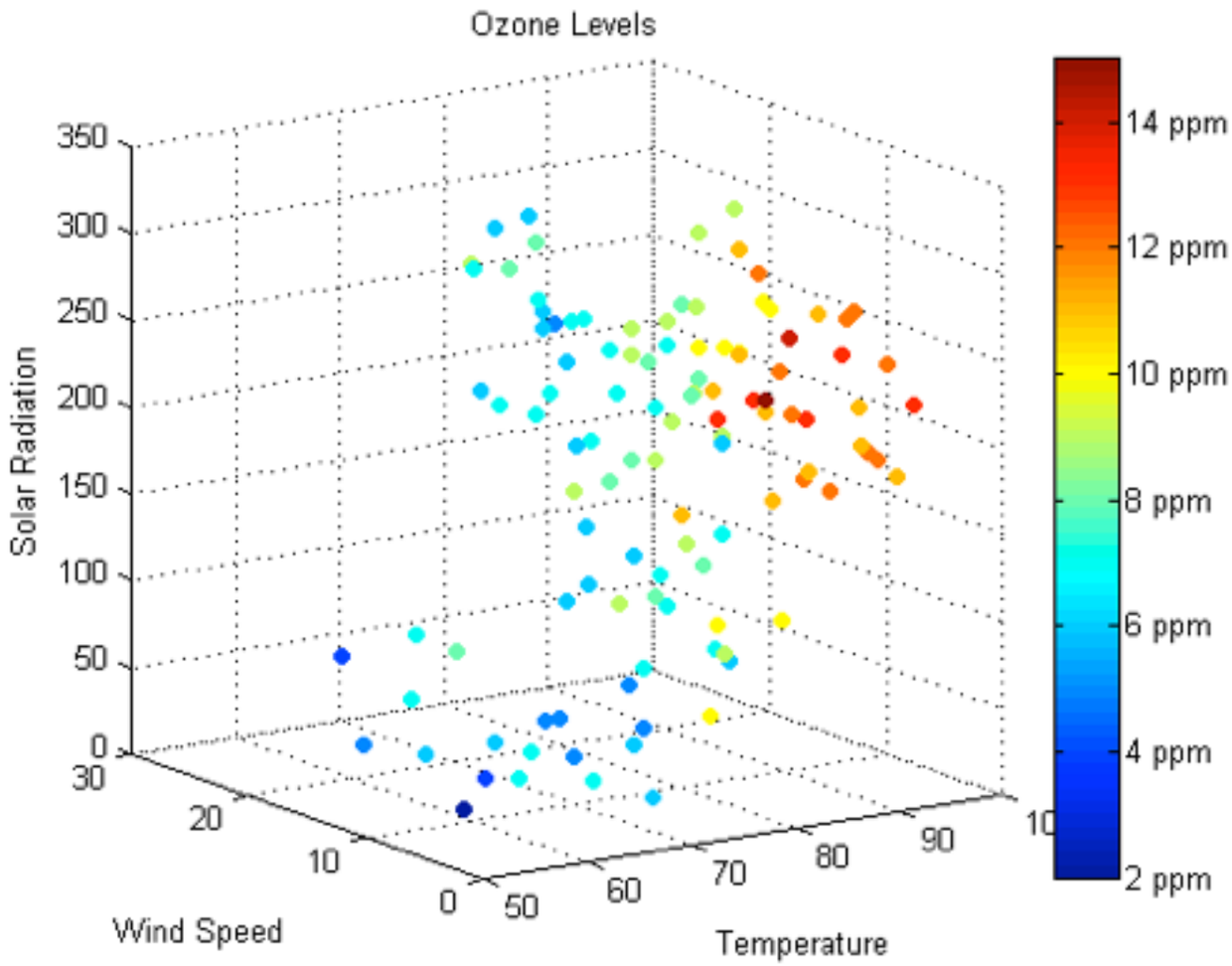
Example: `scatter3`

```
% Load data
load OzoneData ozoneidx temp wind rad;

% Create a 3D scatter plot
figure;
scatter3(temp, wind, rad, 30, ...
    ozoneidx, 'filled');
view(-34, 14);

% Add title and axis labels
title('Ozone Levels');
xlabel('Temperature');
ylabel('Wind Speed');
zlabel('Radiation');

% Add a colorbar with tick labels
colorbar('location', 'EastOutside', 'YTickLabel',...
    {'2 ppm', '4 ppm', '6 ppm', '8 ppm', '10 ppm', '12 ppm', '14 ppm'});
```



For individually colored points, **use** `scatter` instead of `plot` in a for-loop!

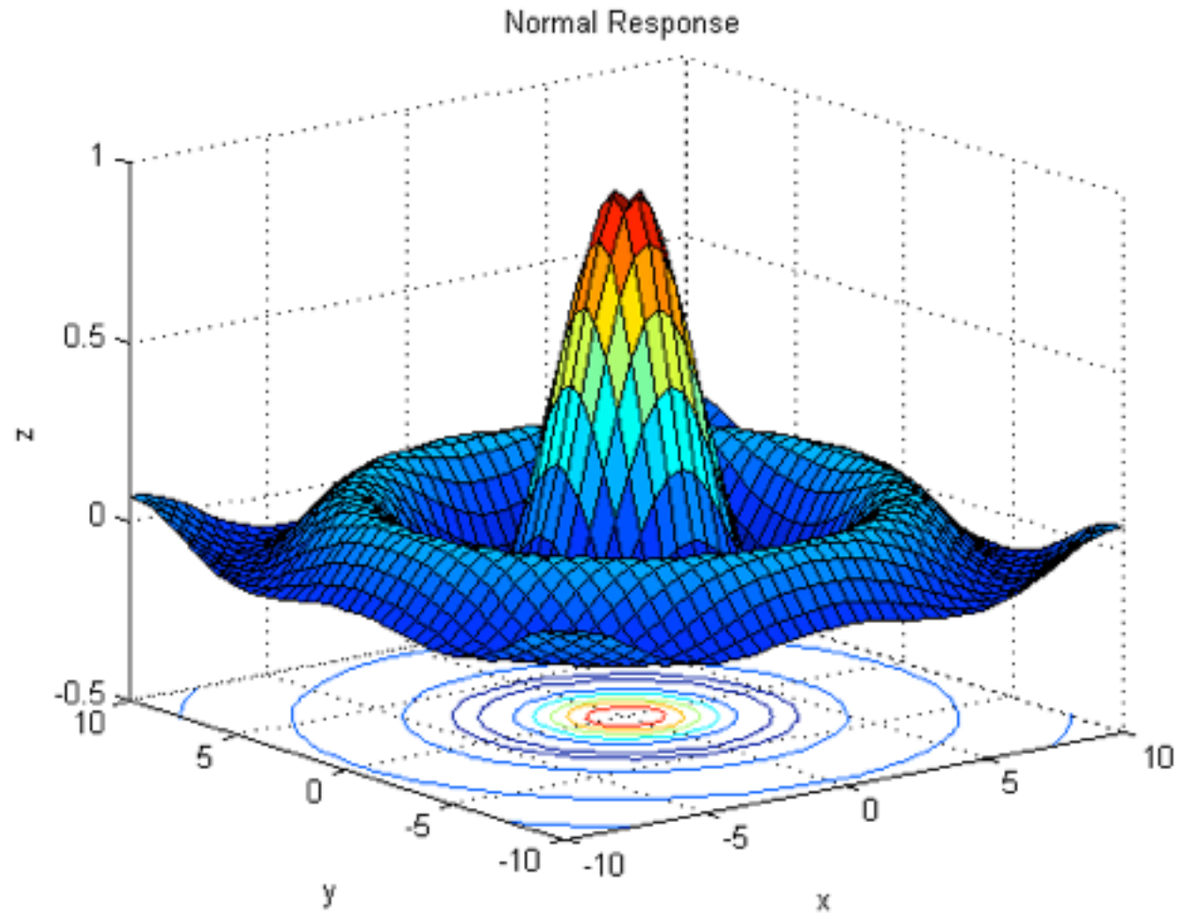
Example: `surfc`

```
% Create a grid of x and y data
y = -10:0.5:10;
x = -10:0.5:10;
[X, Y] = meshgrid(x, y);

% Create the function Z = f(X,Y)
Z = sin(sqrt(X.^2+Y.^2))./sqrt(X.^2+Y.^2);

% Create a surface contour plot
figure;
surfc(X, Y, Z);
view(-38, 18);

% Add title and axis labels
title('Normal Response');
xlabel('x');
ylabel('y');
zlabel('z');
```



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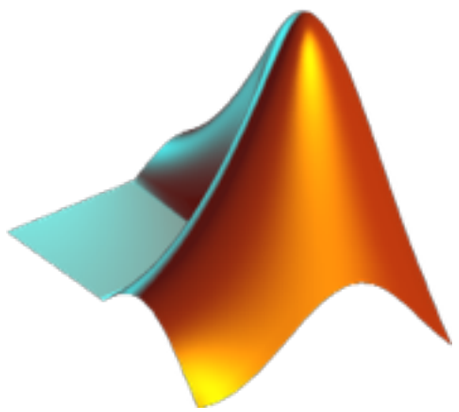
GNU Octave



Matlab

Programming in Octave/Matlab is super easy

- But keep in mind: indexing is one-based, i.e.
  Indices start with 1 !!!

```
octave:1> v = 1:10
octave:2> v(0)
error: subscript indices must be either positive integers or
logicals
```

- Octave/Matlab is **case-sensitive**

Text Editors

- Use an editor with m-file syntax highlighting/coloring
- Matlab has its own IDE

Control Structures

- **`if` Statement**

```
if condition,
  then-body;
elseif condition,
  elseif-body;
else
  else-body;
end
```

- The else and elseif clauses are optional
- Any number of elseif clauses may exist

Control Structures

- **`switch` Statement**

```
switch expression
  case label
    command-list;
  case label
    command-list;
...
otherwise
  command-list;
end
```

- Any number of case labels are allowed

Control Structures

- **`while` Statement**

```
while condition,
  body;
end
```

- **`for` statement**

```
for var = expression,
  body;
end
```

Interrupting and Continuing Loops

- `break`

  Jumps out of the innermost `for` or `while` loop that encloses it

- `continue`

  Used only inside `for` or `while` loops. It skips over the rest of the loop body, causing the next cycle to begin. Use with care

Increment Operators (Octave only!)

Increment operators increase or decrease the value of a variable **by 1**

- `i++` Increment scalar i by 1
- `i--` Decrement scalar i by 1
- `A++` Increment all elements of matrix A by 1
- `v--` Decrement all elements of vector v by 1

- There are the C/C++ equivalent operators `++i`, `--A`

Comparison Operators

- All of comparison operators return a **logical value of 1** if the comparison is **true** or a **logical value of 0** if it is **false**

```
i == 6, cond1 = (d > theta)
```

- For the **matrix-to-matrix case**, the comparison is made on an element-by-element basis

`[1 2; 3 4] == [1 3; 2 4]` **returns** `[1 0; 0 1]`

- For the **matrix-to-scalar case**, the scalar is compared to each element in turn

`[1 2; 3 4] == 2` **returns** `[0 1; 0 0]`

Comparison Operators

- `any(v)` — Returns 1 if **any element** of vector v is **non-zero** (e.g. 1)
- `all(v)` — Returns 1 if **all elements** in vector v are **non-zero** (e.g. 1)

For **matrices**, any and all return a row vector with elements corresponding to the columns of the matrix

- `any(any(C))` — Returns 1 if **any element** of matrix C is **non-zero** (e.g. 1)
- `all(all(C))` — Returns 1 if **all elements** in matrix C are **non-zero** (e.g. 1)

Relational Operators

- `x < y` — True if x is less than y
- `x <= y` — True if x is less than or equal to y
- `x == y` — True if x is equal to y
- `x >= y` — True if x is greater than or equal to y
- `x > y` — True if x is greater than y
- `x ~= y` — True if x is not equal to y

- `x != y` — True if x is not equal to y (Octave only)
- `x <> y` — True if x is not equal to y (Octave only)

Boolean Expressions

- `B1 & B2` Element-wise logical **and**
- `B1 | B2` Element-wise logical **or**
- `~B` Element-wise logical **not**
- `!B` Element-wise logical not (Octave only)

Short-circuit operations: evaluate expression only as long as needed (more efficient)

- `B1 && B2` Short-circuit logical **and**
- `B1 || B2` Short-circuit logical **or**

Recommended Naming Conventions

- **Functions:** underscore-separated or lowercase notation

  Examples: `drawrobot.m`, `calcprobability.m`, `intersect_line_circle.m`

- **Scripts:** UpperCamelCase

  Examples: `LocalizeRobot.m`, `MatchScan.m`

- Matlab/Octave commands are all in **lowercase notation** (no underscores, no dashes)

  Examples: `continue`, `int2str`, `isnumeric`

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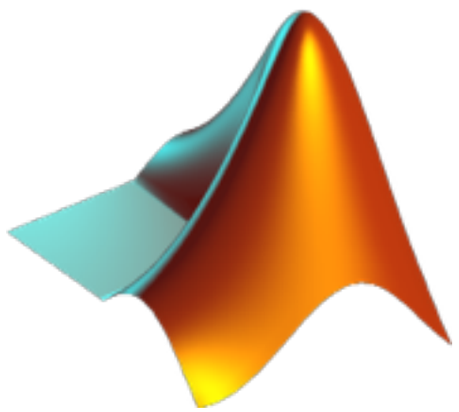
GNU Octave



Matlab

Functions and Scripts

Functions

Octave/Matlab programs can often be simplified and structured by **defining functions**. Functions are typically defined in **external files**, and can be called just like built-in functions

- In its simplest form, the definition of a function looks like this:

```
function name
  body
end
```

- It is recommended to define **one function per file**
- These files are called **m-file** or .m-file

Functions and Scripts

Passing Parameters to/from Functions

- Simply write

```
function [ret-var] = name(arg-list)
  body
end
```

- `arg-list` is a comma-separated list of **input arguments** arg1, arg2, ..., argn
- `ret-var` is a comma-separated list of **output arguments**. Note that `ret-var` is a vector enclosed in square brackets [arg1, arg2, ..., argm].

Functions and Scripts

Examples Please:

```
function [mu sigma] = calcmoments(data)
  mu = mean(data);
  sigma = std(data);
end
```

```
function [haspeaks i] = findfirstpeak(data, thresh)
  indices = find(data > thresh);
  if isempty(indices),
    haspeaks = 0; i = [];
  else
    haspeaks = 1; i = indices(1);
  end
end
```

Functions and Scripts

Local Variables, Variable Number of Arguments

- Of course, all variables defined within the body of the function are **local variables**

- `varargin` Collects all input argument in a cell array. Get them with varargin{i}
- `varargout` Collects all output argument in a cell array. Get them with varargout{i}
- `nargin` Get the number of input args
- `nargout` Get the number of output args

- See `help varargin`, `help varargout` for details

Functions and Scripts

Functions and their m-File

- When putting a function into an m-file, the **name of that file must be the same** than the **function name plus the .m extension**
  Examples: `calcmoments.m`, `findfirstpeak.m`

- To call a function, type its name **without the .m extension**.
  Example:
```
[bool i] = findfirstpeak(myreadings, 0.3);
```

- **Comments** in Octave/Matlab start with `%`. Use them a lot!

Functions and Scripts

Scripts

- The second type of m-files is called script. Again, Octave/Matlab scripts are **text files** with an **.m extension**
- **Scripts** contain executable code. They are basically the "main" programs
- Execute a script by typing its name **without the .m extension**
  Example: `octave:1> LocalizeRobot`
- Again, **comments** in Octave/Matlab start with `%`.
  (I can't repeat this often enough ;-)

Functions and Scripts

Document your Function/Script

- You can **add a help text to your own functions or scripts** that then appears on `help command`
- **The first block of comment lines** in the beginning of an m-file is defined to be help text. Example:

```
%NORMANGLE Put angle into a two-pi interval.
%   AN = NORMANGLE(A,MIN) puts angle A into the interval
%   [MIN..MIN+2*pi[. If A is Inf, Inf is returned.
% v.1.0, Dec. 2003, Kai Arras.

function an = normangle(a,mina);
if a < Inf,
[...]
```

help text

Functions and Scripts

Setting Paths

- `path` — **Print** search path list
- `addpath('dir')` — **Prepend** the specified directory to the path list
- `rmpath('dir')` — **Remove** the specified directory from the path list
- `savepath` — **Save** the current path list

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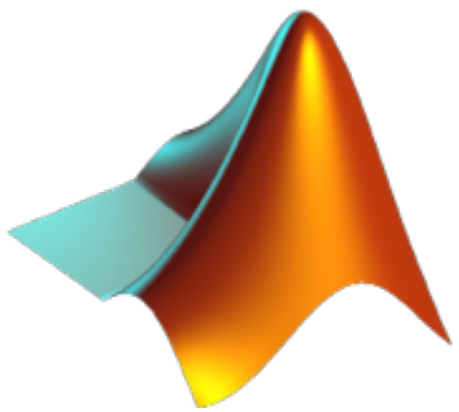
GNU Octave



Matlab

Save Variables

After a complex or lengthy computation, it is recommended to save variables on the disk

- `save my_vars.mat`
  Saves **all current variables** into file my_vars.mat

- `save results.mat resultdata X Y`
  Saves variables resultdata, X and Y in file results.mat

- `save ... -ascii`
  Saves variables in ASCII format

- `save ... -mat`
  Saves variables in binary MAT format

Load Variables

The corresponding command is `load`

- `load my_vars.mat`

  Retrieves all variables from the file my_vars.mat

- `load results.mat X Y`

  Retrieves only X and Y from the file results.mat

An **ASCII file** that contains **numbers in a row/column format** (columns separated by spaces or commas, rows separated by new lines) can be simply read in by

- `A = load('data.txt')`

  Matrix A will then contain the data

Files I/O

Open, Write, Close Files

- `fopen` Open or create file for writing/reading
- `fclose` Close file
- `fprintf` Write formatted data to file. C/C++ format syntax

Example:

```
v = randn(1000,1);
fid = fopen('gauss.txt','w');
for i = 1:length(v),
  fprintf(fid,'%7.4f\n',v(i));
end
fclose(fid);
```

Attention, Popular Bug

- If your program writes to and reads from files, **floating point precision of fprintf is crucial**!
- Be sure to always write floating point numbers into files using the **appropriate precision**
- In the above example, with format definition `'%7.4f\n'`, this file will be a very poor source of Gaussian random numbers

Files I/O

Reading Files (more advanced stuff)

- `textread` Read formatted data from text file
- `fscanf` Read formatted data from text file
- `fgetl` Read line from file
- `fread` Read binary data file

Read/write images

- `imread` Read image from file (many formats)
- `imwrite` Write image to file (many formats)

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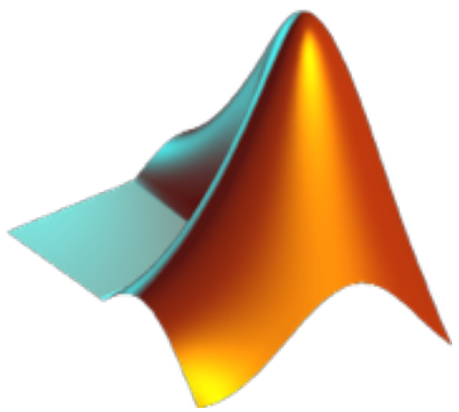

Matlab

Miscellaneous

Cleaning Up

- `clear A` — Clear variable A
- `clear frame*` — Clear all variables whose names start with frame, e.g. frame001, frames
- `clear` — Clear **all** variables
- `clear all` — Clear **everything**: variables, globals, functions, links, etc.
- `close` — Close foreground figure window
- `close all` — Close all open figure windows

- `clc` — Clear command window (shell)

Miscellaneous

Displaying (Pretty) Messages

- `disp(A)` Display matrix A without printing the matrix name
- `disp(str)` Display string str without printing the string name

Example: when typing

```
octave:1> disp('done')
```

Octave will print

```
done
```

instead of

```
ans = done
```

from `sprintf('done')` or `'done'`

Command History

- Navigate **up and down** the command history using the up/down **arrow keys**
- The command history is **start-letter sensitive**. Type one or more letters and use the arrow keys to navigate up and down the history of commands that **start with the letters you typed**

Tab completion

- Octave/Matlab have **tab completion**. Type some letters followed by tab to get a list of all commands that **start with the letters you typed**

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Built-in Unix Commands

- `pwd` — Display current working directory
- `ls` — List directory. See also `dir`
- `cd` — Change directory
- `mkdir` — Make new directory
- `rmdir` — Delete directory

Related Commands

- `movefile` — Move file
- `copyfile` — Copy file

Miscellaneous

Random Seeds

- `rand` and `randn` obtain their initial seeds from the system clock
- To generate **repeatable sequences** of random numbers, set the random generator seeds **manually**

To set the random seeds:

- `rand('seed',val)` Set seed to scalar integer value val
- `randn('seed',val)` Set seed to scalar integer value val

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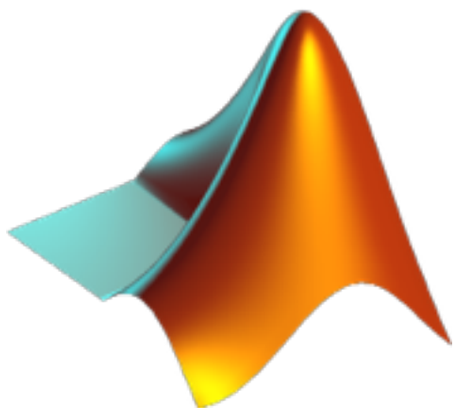

Matlab

Useful Stuff in Practice

We will cover:

1. **Generating output** from a C/C++/Python/Java/... program in Matlab syntax, e.g. using Octave/Matlab as a visualizer front-end

2. Making **animations** (without Matlab's movie function)

3. Calling **unix/dos functions** from within Octave/Matlab programs

4. Increasing **speed** through **vectorization** and preallocation

Writing Files in Matlab Syntax

- Octave/Matlab are **very powerful visualization tools**
- Regular languages such as C/C++/Python/Java/etc. have some support for graphical output but in comparison their libraries are not as **flexible**, **powerful** and **easy-to-use** than Octave/Matlab
- So, how can we **combine the advantages**?
- For **testing** or **developing an algorithm** in C/C++/Python/Java/etc., it is typically necessary to plot many variables, visualize intermediate and final results or make animations. Instead of writing complex visualizations in those languages, use Octave/Matlab as **visualizer front-end**
- Drawback: **not real-time** (can be made quasi real-time)

Writing Files in Matlab Syntax

- **Data** written into plain text file in **matrix format**.
  Example:

`filtered_readings.txt`

```
0.792258   0.325823   0.957683   0.647680   0.498282
0.328679   0.414615   0.270472   0.975753   0.043852
0.601800   0.062914   0.837494   0.621332   0.870605
0.940364   0.036513   0.843801   0.806506   0.804710
0.937506   0.872248   0.134889   0.042745   0.228380
```

- **Read in** using the command `load`.
  Example: `A = load('filtered_readings.txt');`

Writing Files in Matlab Syntax

- File may also contain **Matlab code snippets**. Example:

`PlotFilteredReadings.m`

```
A = [
      0.792258   0.325823   0.957683   0.647680   0.498282
      0.328679   0.414615   0.270472   0.975753   0.043852
      0.601800   0.062914   0.837494   0.621332   0.870605
      0.940364   0.036513   0.843801   0.806506   0.804710
];
figure(1); clf; hold on;
plot(1:size(A,1),A(:,1));
```

- Must have the **.m extension**. It's a script.
- Simply **execute** by typing `PlotFilteredReadings`

Making Animations

- **Matlab** has commands such as `getframe` and `movie` to make animations from plots
- **Octave**, being free of charge, does not (yet) support these commands
- Never mind! Here is a **pretty obvious way** to **make movies:**

→ Export plots to a directory (e.g. "frames") using `print` from within a **loop**. Then compose frames to a movie using tools such as ImageMagick or Quicktime Pro.

Making Animations. Example:

- Let `data.txt` contain data in matrix format, we want to plot each column and save it as a frame

```
A = load('data.txt');
[nrow ncol] = size(A);
figure(1);
for i = 1:ncol,
  plot(1:nrow,A(:,i));
  fname = sprintf('frames/frame%04d.png',i);
  print('-dpng','-r100',fname);
end
```

- **Problem:** axis limits **change** for each plot/frame.

Making Animations. Example:

- To **freeze the axes** over the entire animation, use the command `axis([xmin xmax ymin ymax])` **after** the plot command

```
A = load('data.txt');
[nrow ncol] = size(A);
figure(1);
for i = 1:ncol,
  plot(1:nrow,A(:,i));
  axis([1 nrow min(min(A)) max(max(A))]);
  fname = sprintf('frames/frame%04d.png',i);
  print('-dpng','-r100',fname);
end
```

Calling unix/dos Functions

- For Unix/Linux/Mac OS X systems, there is the command `unix` to execute system commands and return the result.
  Examples:

```
unix('ls -al')
unix('ftp < ftp_script')
unix('./myprogram')
```

- For Windows PCs, there is the equivalent command `dos`.
- These commands allow for **powerful and handy combinations** with other programs or system commands
- Can help to accelerate **edit-compile-run cycles** or **edit-compile-run-visualize cycles** in particular when Octave/Matlab is used as a visualizer front-end

Octave and Matlab in Practice

Speed!

- The **low execution speed** of Octave/Matlab programs is commonly recognized to be their most important shortcoming
- Mostly **your program is slow**, not the built-in functions!

- This brings us to the following guidelines
  - **For-loops are evil**
  - **Vectorization** is **good**
  - **Preallocation** is **good**
  - Prefer **struct of arrays** over **arrays of struct**

- Advanced topics (not covered here): **Matlab compiler**, **linking C/C++**, Fortran **code** from Matlab programs (mex files), parallel computing, etc.

Speed: Vectorization

- Given `phi = linspace(0,2*pi,100000);`

  The code

```
for i = 1:length(phi),
  sinphi(i) = sin(phi(i));
end;
```

  is significantly slower than simply

```
sinphi = sin(phi);
```

- **All built-in commands** are vectorized, i.e. allow vector arguments
- You have to (and will) learn to think **vectorized**!

Speed: Preallocation

- If a for- or while-loop cannot be avoided, do not grow data structures in the loop, **preallocate them** if you can.
  Instead of, for example

```
for i = 1:100,
  A(i,:) = rand(1,50);
end;
```

write

```
A = zeros(100,50);     % preallocate matrix
for i = 1:100,
  A(i,:) = rand(1,50);
end;
```

Speed: Structure of Arrays

- Always prefer a struct of arrays over a array of structs (called plane organization vs. element-by-element organization)
- It requires **significantly less memory** and has a **corresponding speed benefit**
- Structure of arrays

```
data.x = linspace(0,2*pi,100);
data.y = sin(data.x);
```

- Array of structure

```
people(1).name = 'Polly J Harvey';
people(1).age = 29;

people(1000).name = 'Big Lebowski';
people(1000).age = 35;
```

Contents

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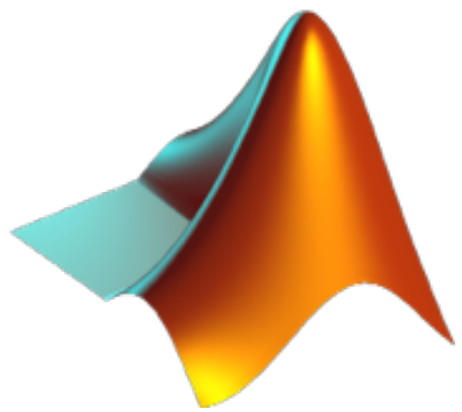
- librobotics

GNU Octave



Matlab

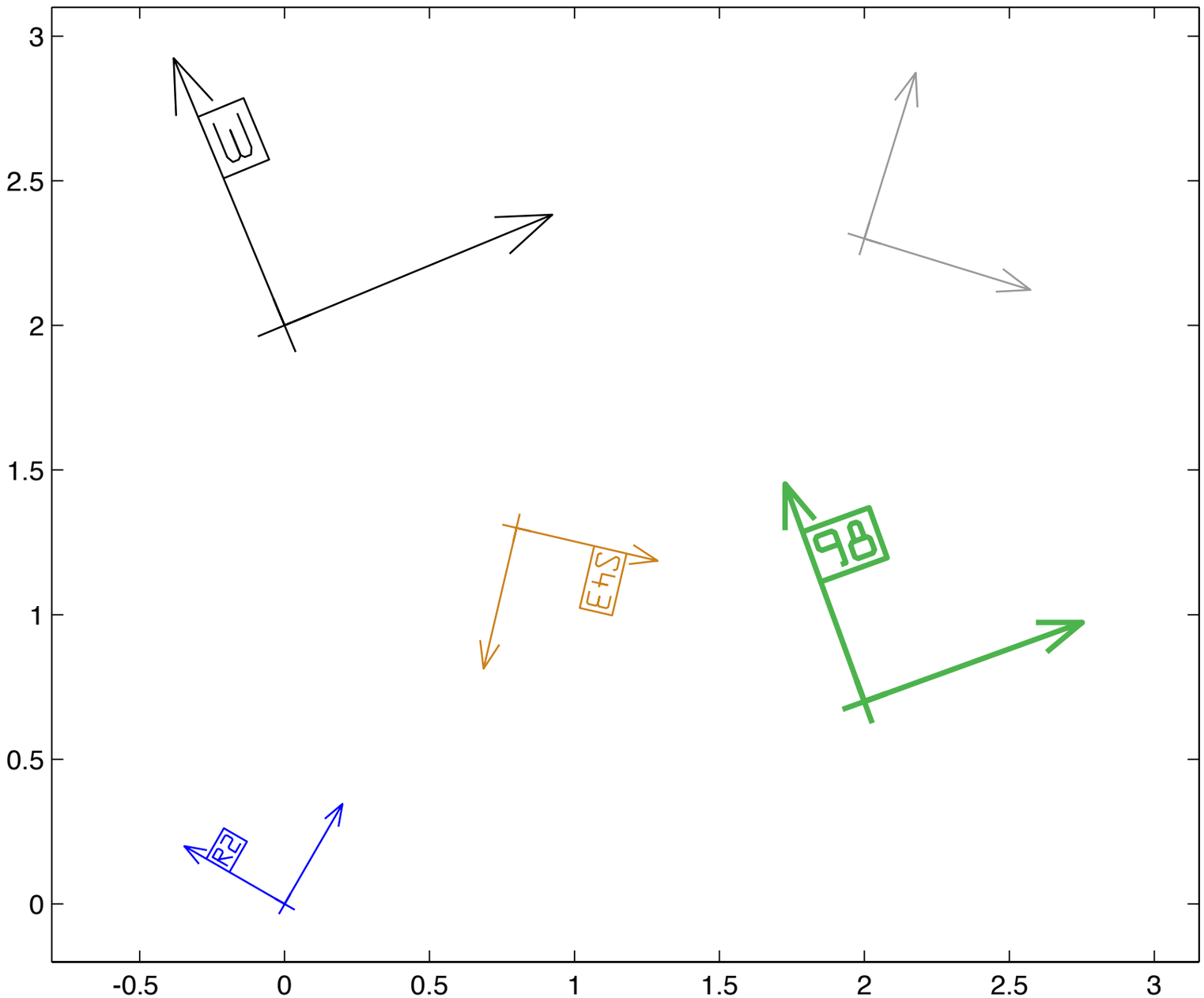
librobotics

- **librobotics** is a small library with frequently used Octave/Matlab functions in Robotics, especially for visualization

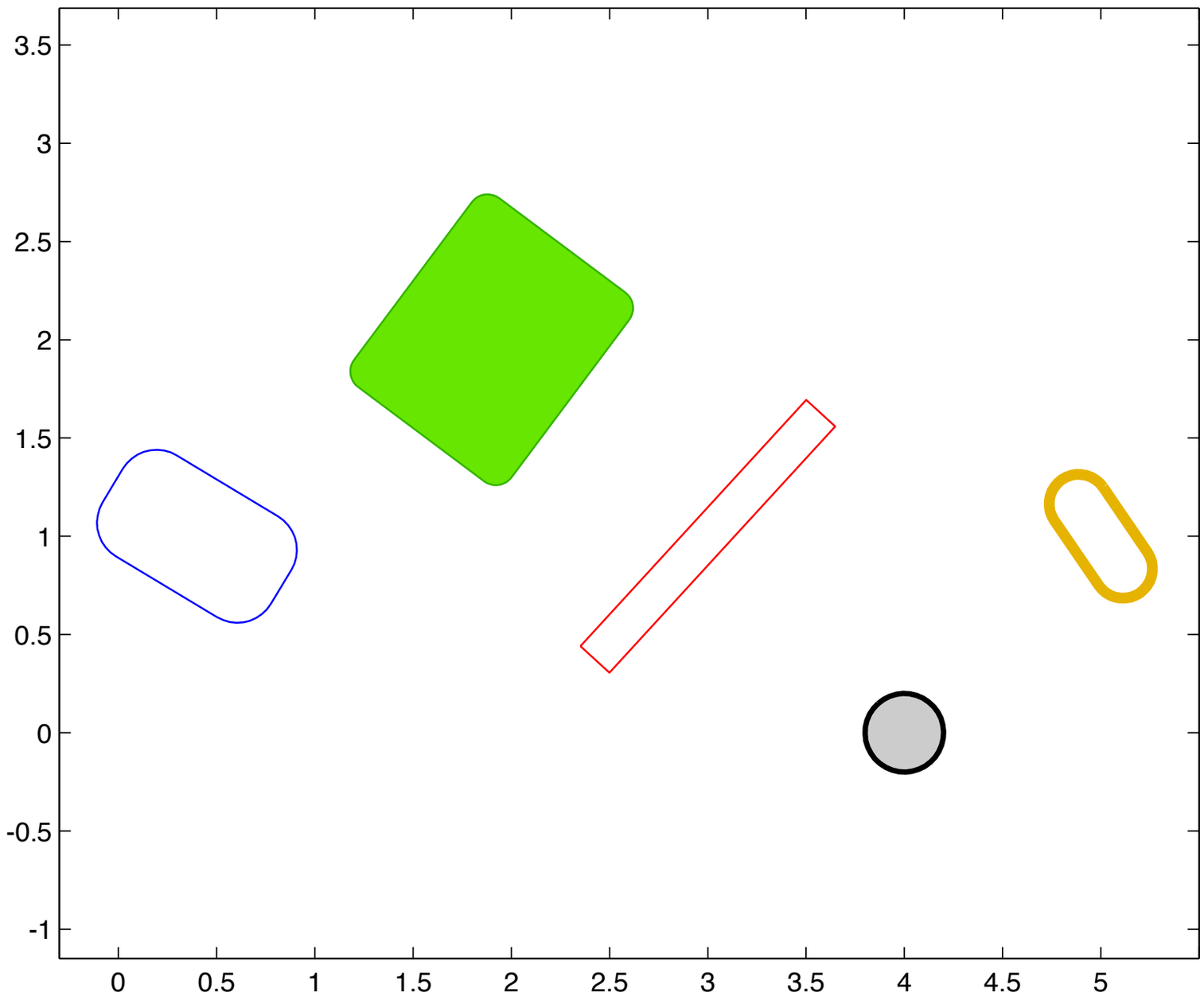
```
chi2invtable.m          drawrawdata.m           j2comp.m
compound.m              drawreference.m         jinv.m
diffangle.m             drawrobot.m             mahalanobis.m
drawarrow.m             drawroundedrect.m       meanwm.m
drawellipse.m           drawtransform.m         normangle.m
drawlabel.m             icompound.m
drawprobellipse.m       j1comp.m
```

- **Download** from SRL Homepage: srl.informatik.uni-freiburg.de/downloads

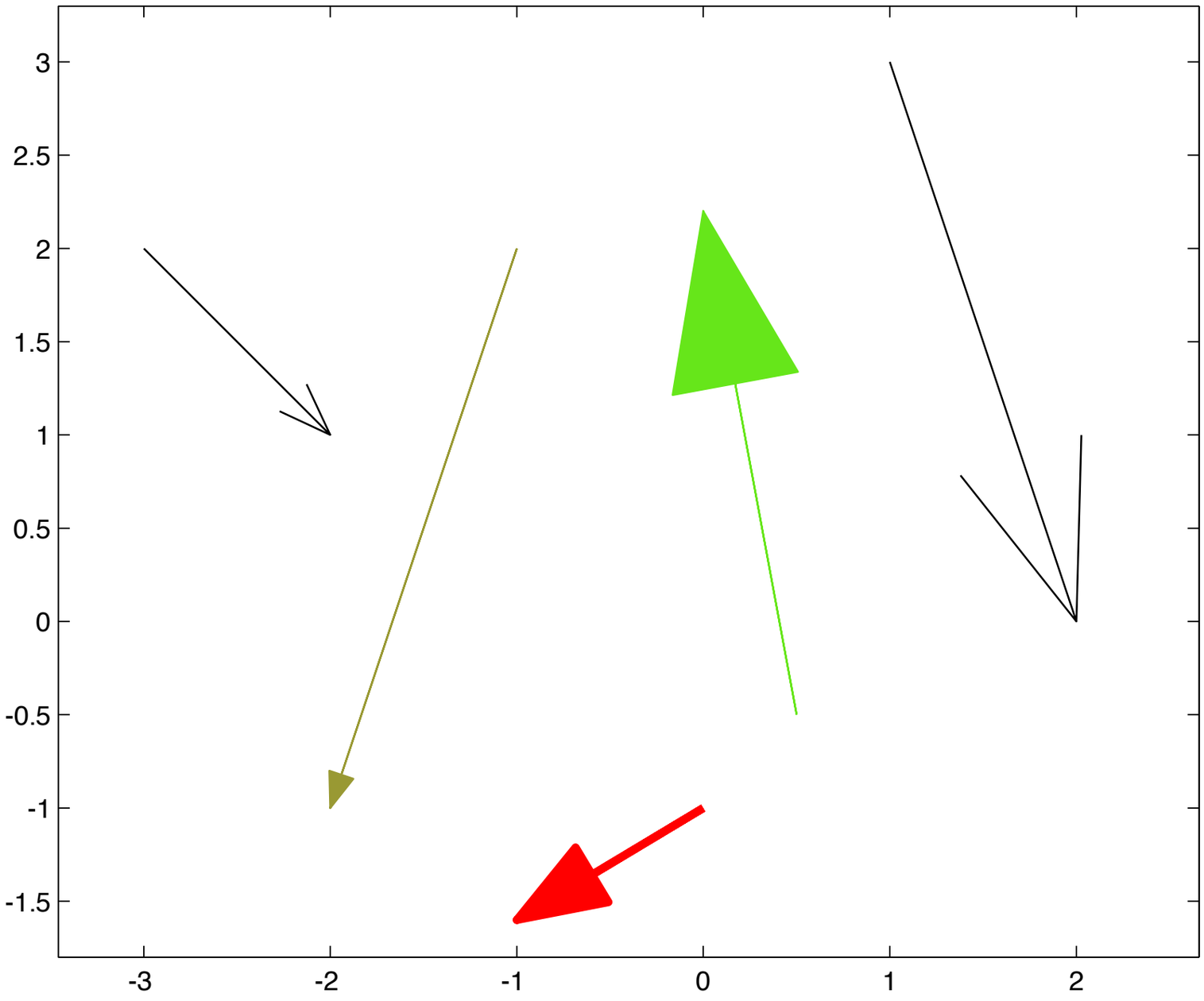
- **Command** `drawreference.m`



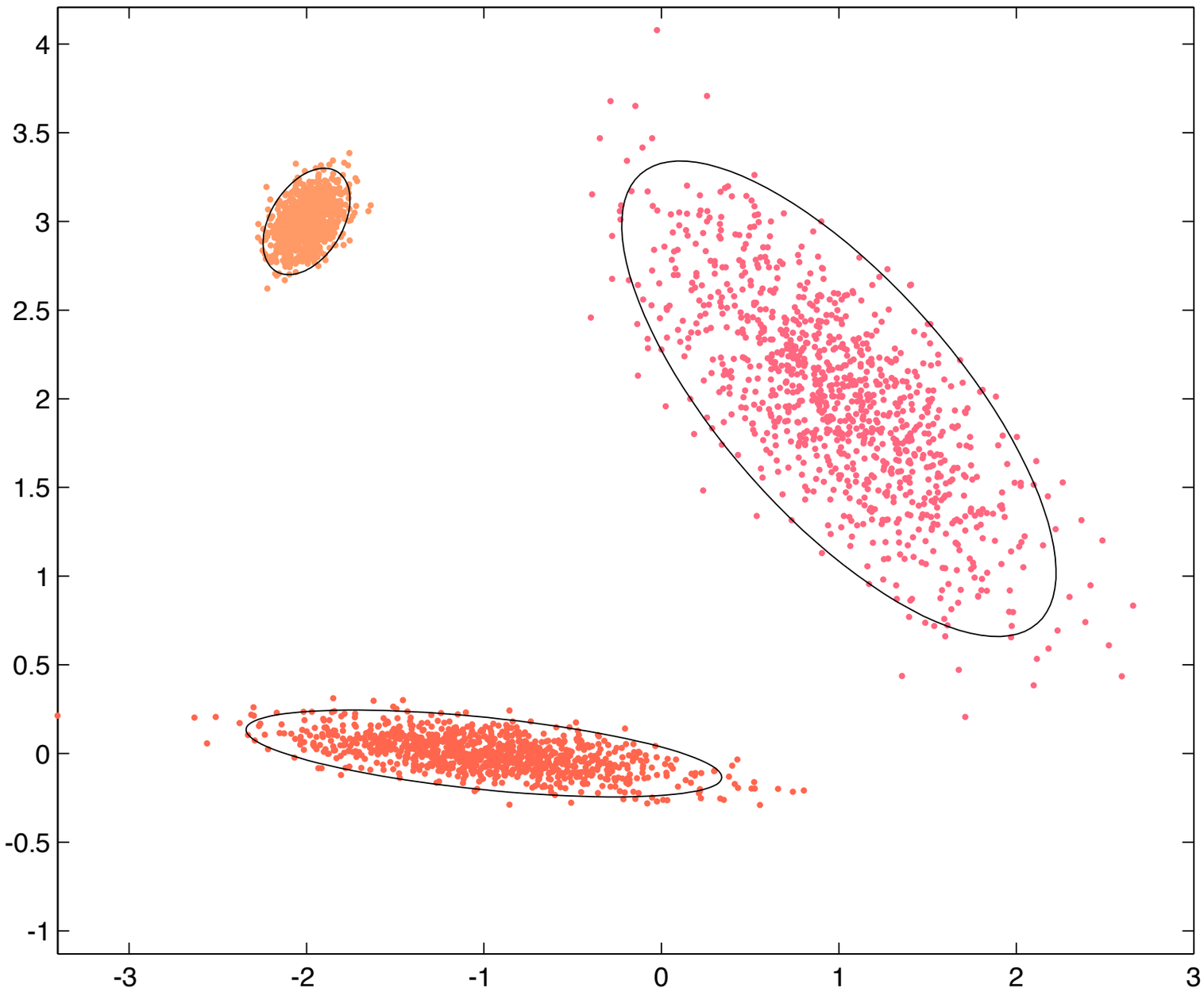
- **Command** `drawroundedrect.m`



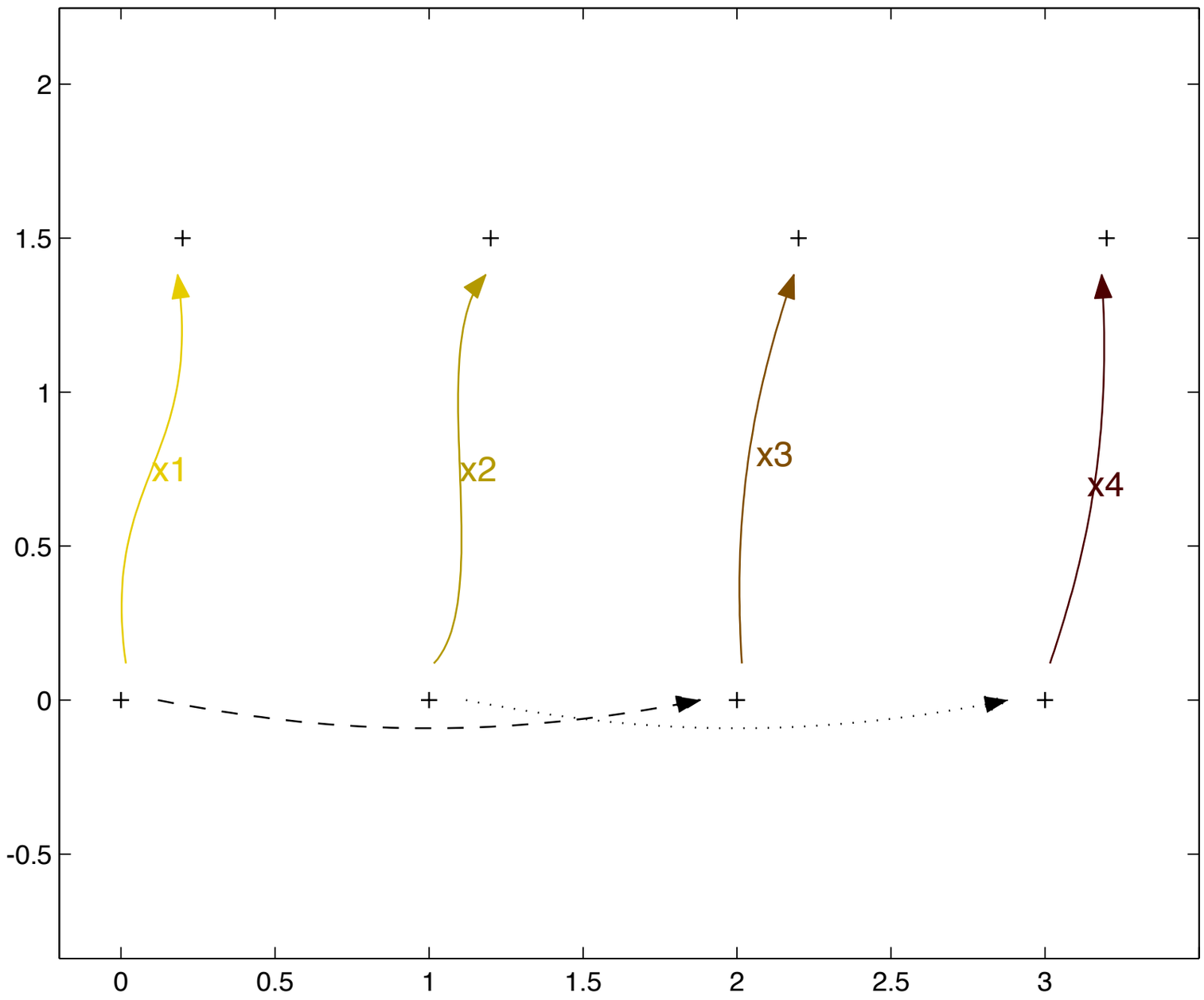
- **Command** `drawarrow.m`



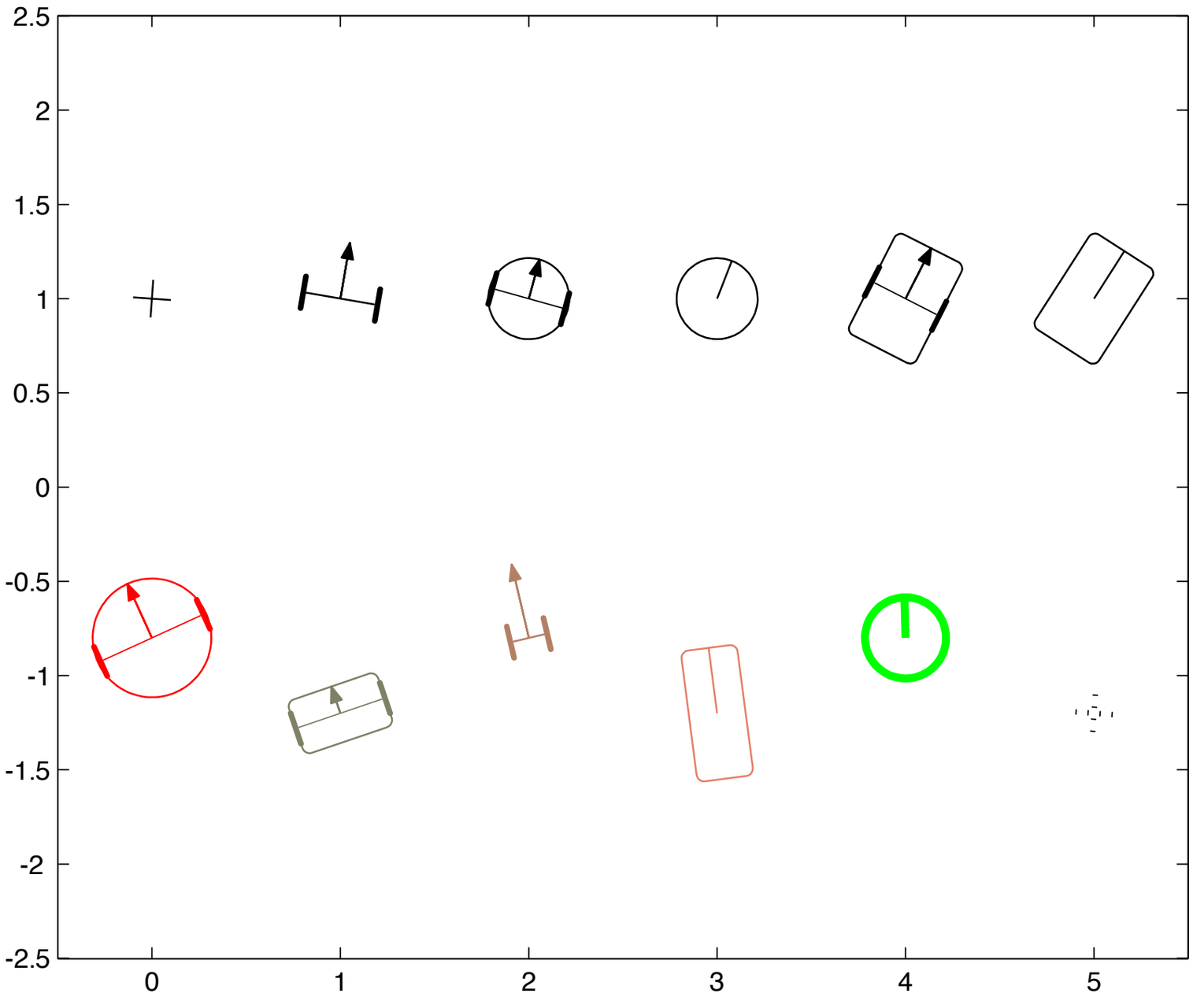
- **Command** `drawprobellipse.m`



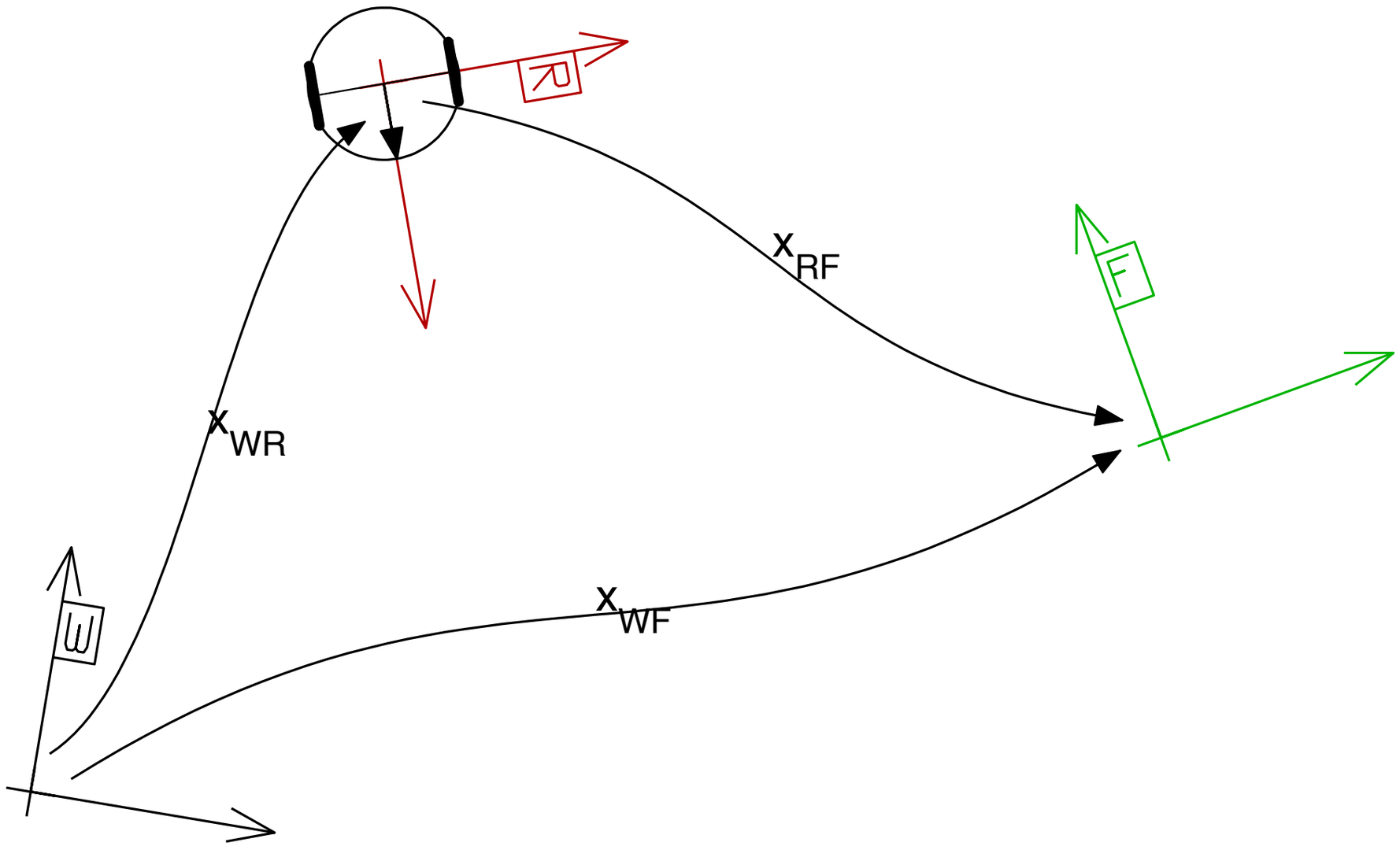
- **Command** `drawtransform.m`



- **Command** `drawrobot.m`



- **Example Figure**



librobotics

- All commands are **fully documented**, just type `help command`.

- The command `chi2invtable.m` returns values of the **cumulative chi-square distribution**, often used for gating and hypothesis testing. It replaces the `chi2inv` function from the Matlab statistics toolbox – a costly addition to Matlab – and is also much faster

- librobotics is **compatible with both**, **Matlab** and **Octave**

- It's **open source**, feel free to distribute and extend

- Link: http://srl.informatik.uni-freiburg.de/downloads

More Information on Octave and Matlab

Full Octave online documentation

- http://www.octave.org
  > Support
  > Documentation
  > Reference manual in HTML or pdf (800 pages)
- Directly: www.gnu.org/software/octave/octave.pdf (Oct 2013)

Full Matlab online documentation:

- http://www.mathworks.com
  > Products & Services
  > MATLAB
  > Documentation
- Directly: http://www.mathworks.com/help/matlab/index.html (Oct 2013)

Thanks and Enjoy!

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