Human-Oriented Robotics

Octave/Matlab Tutorial

Kai Arras

Social Robotics Lab, University of Freiburg

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
- 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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GNU Octave

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.

Variables and Data Types

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';
```

Variables and Data Types

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
```

Matrices

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

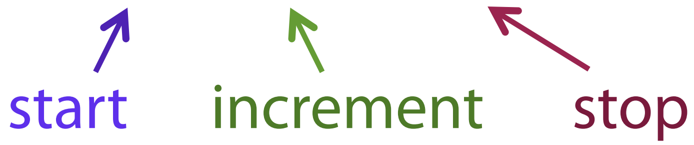
The two meaning of colon ':'

- **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
```



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

Matrices

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
```

Matrices

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

Matrices

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

Matrices

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)

Matrices

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)` Row vector 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`

Matrices

Matrix Massage

• `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

Matrices

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);
```

Strings

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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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

Plotting

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

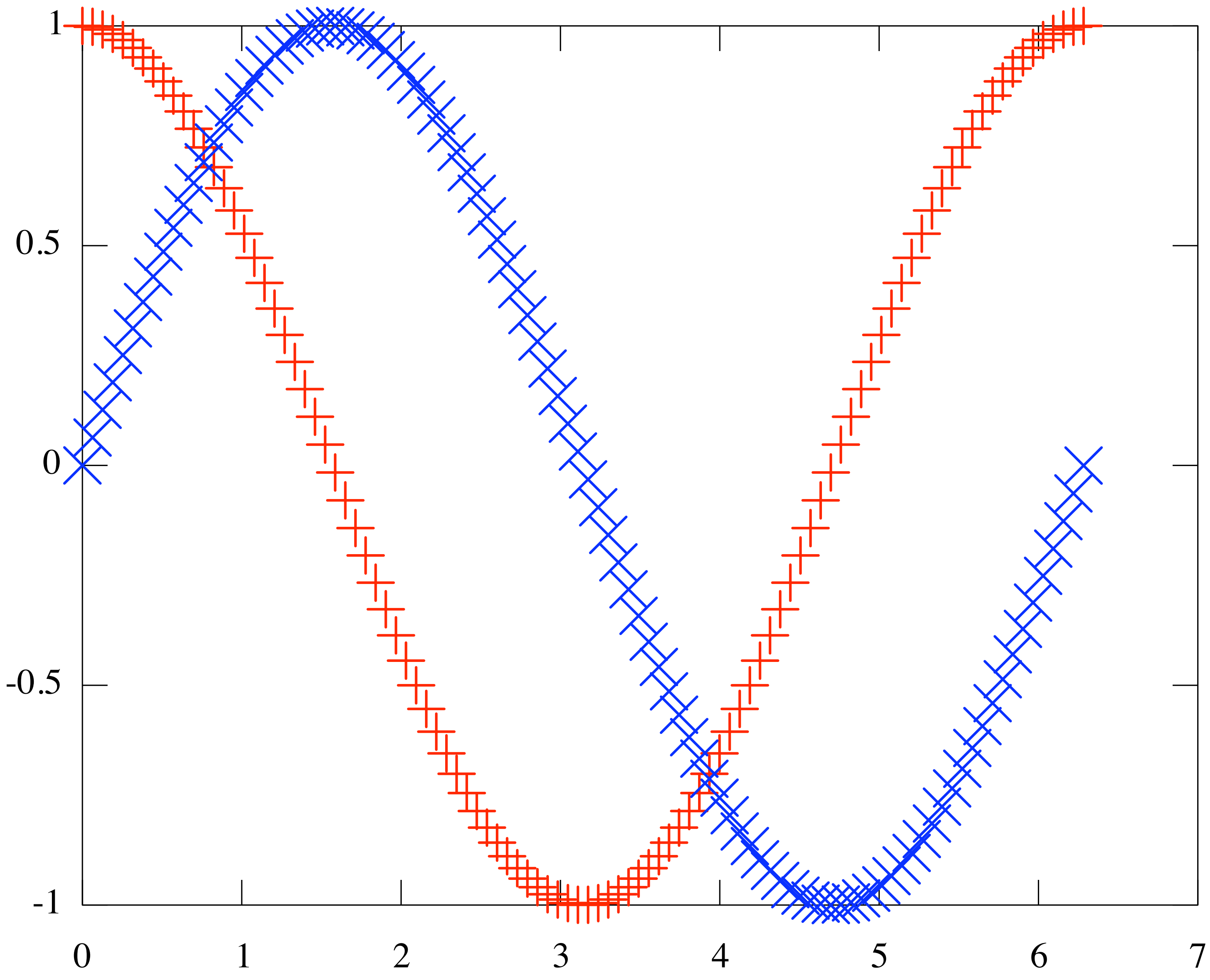
- In `plot(x,cos(x),'r+')` the format expression `'r+'` means **red cross**
- There are a number of line styles and colors, see `help plot`

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**

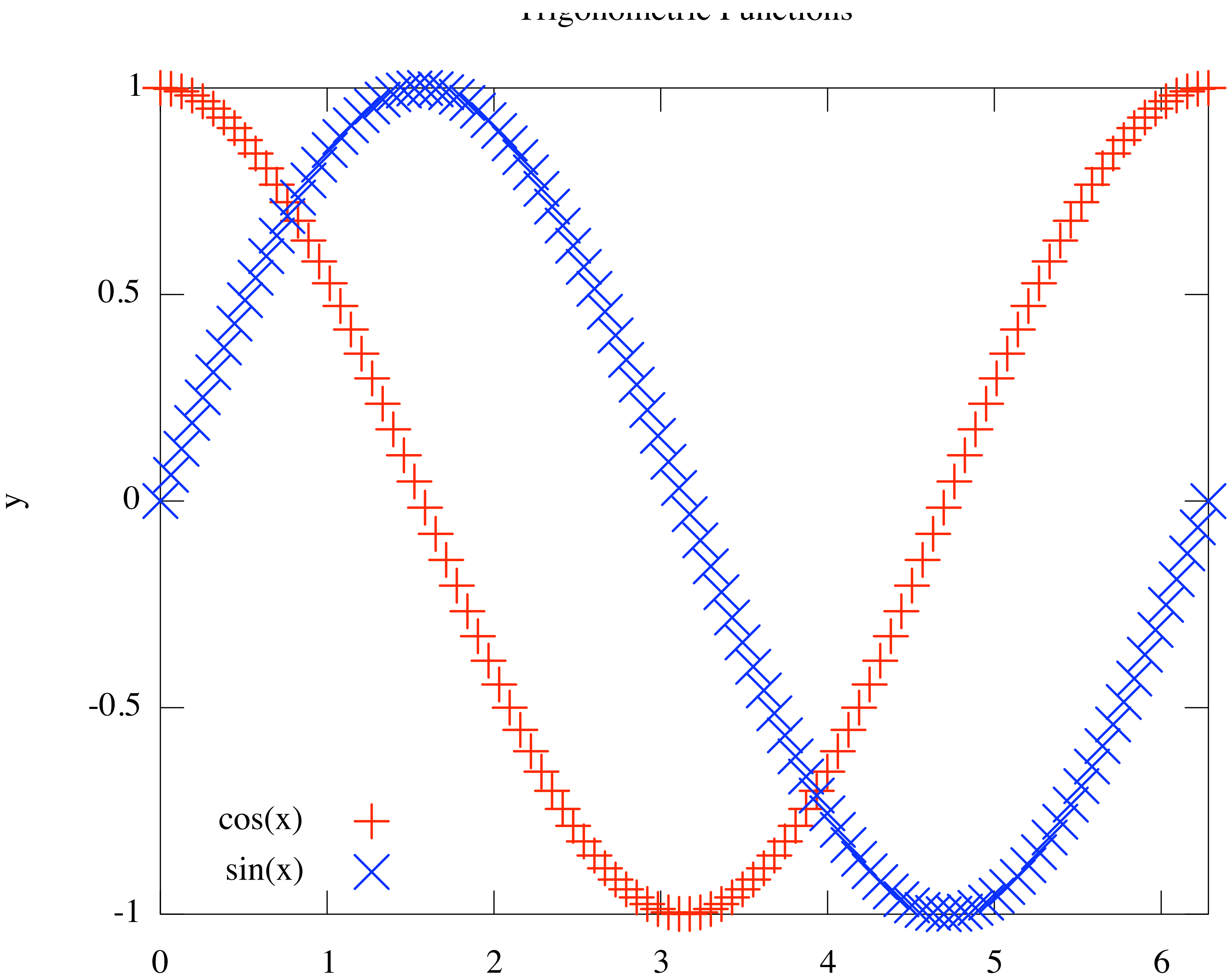
```
octave:4>
legend('cos(x)','sin(x)','Location','Southwest')
```

```
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
```

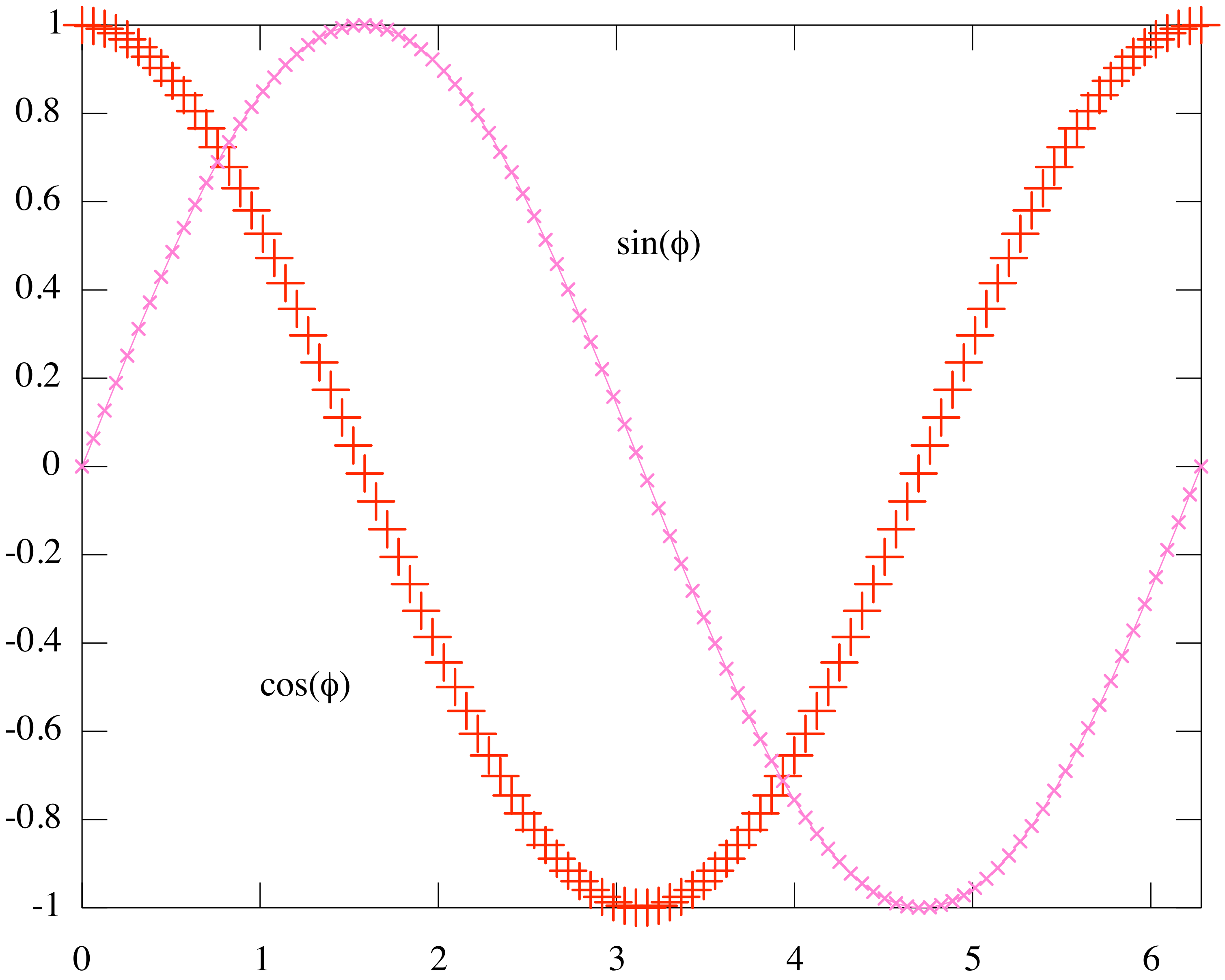
- **Adding Text**

```
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

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
```

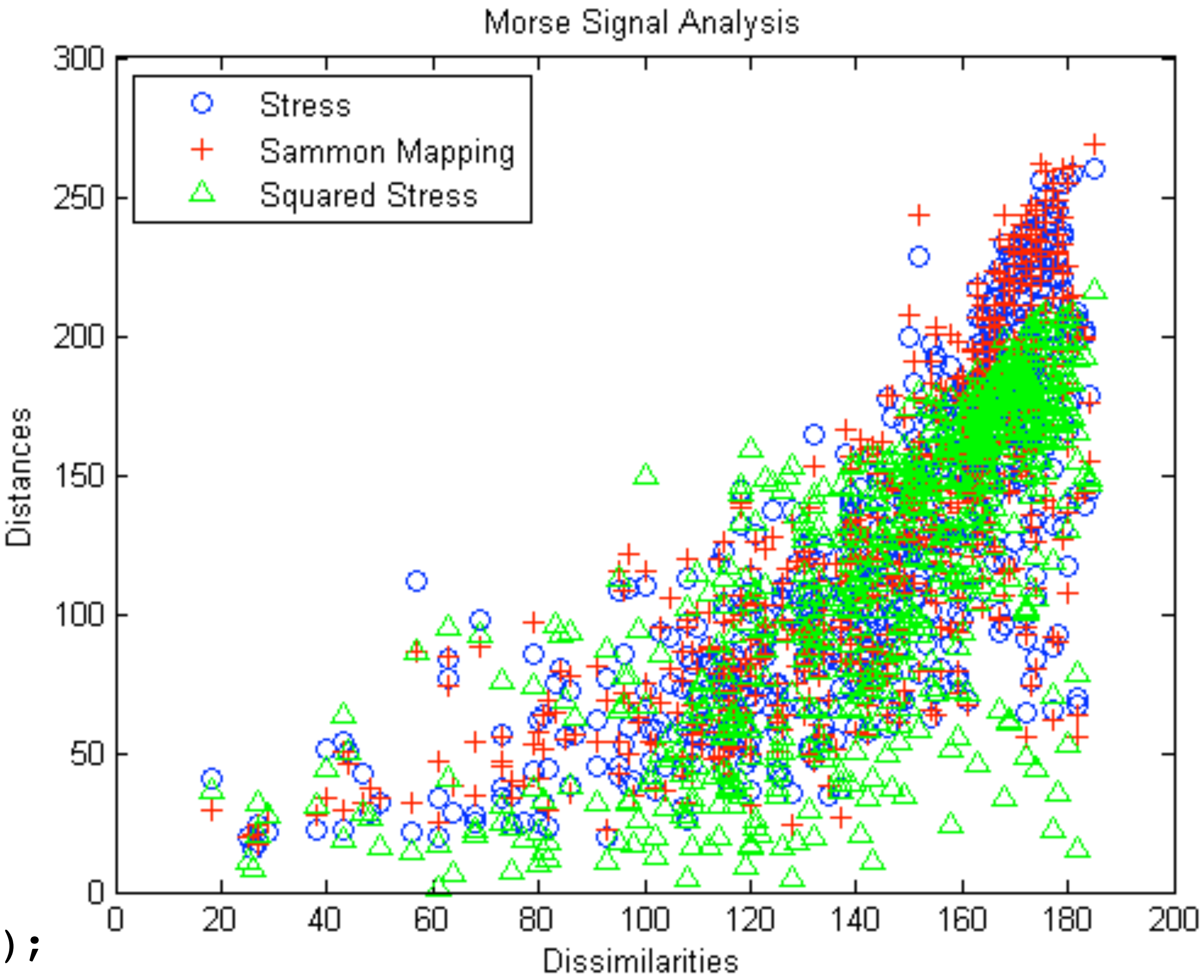
Let us look at some **examples...**

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');
```



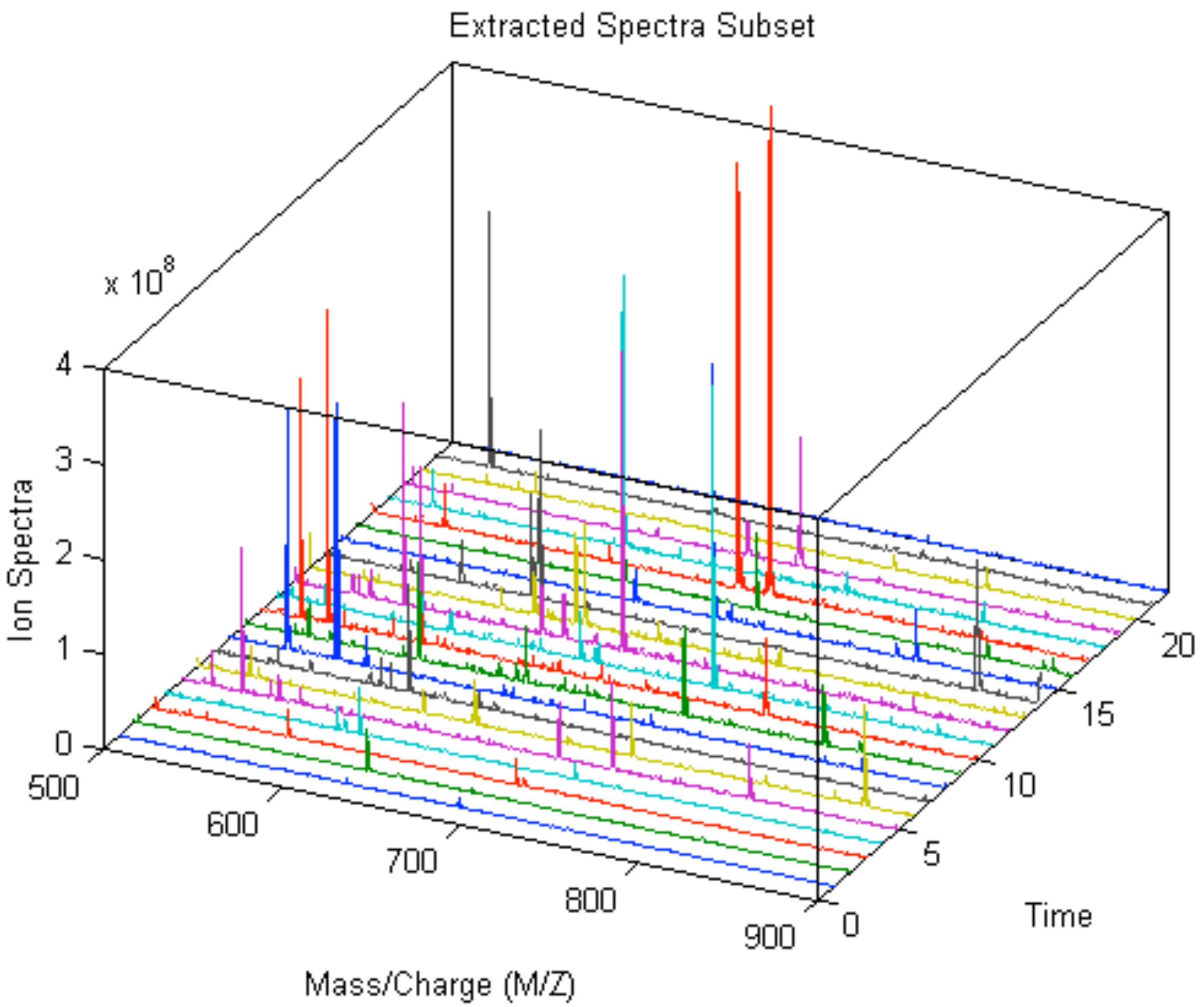
Example: plot3

```
% 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');
```

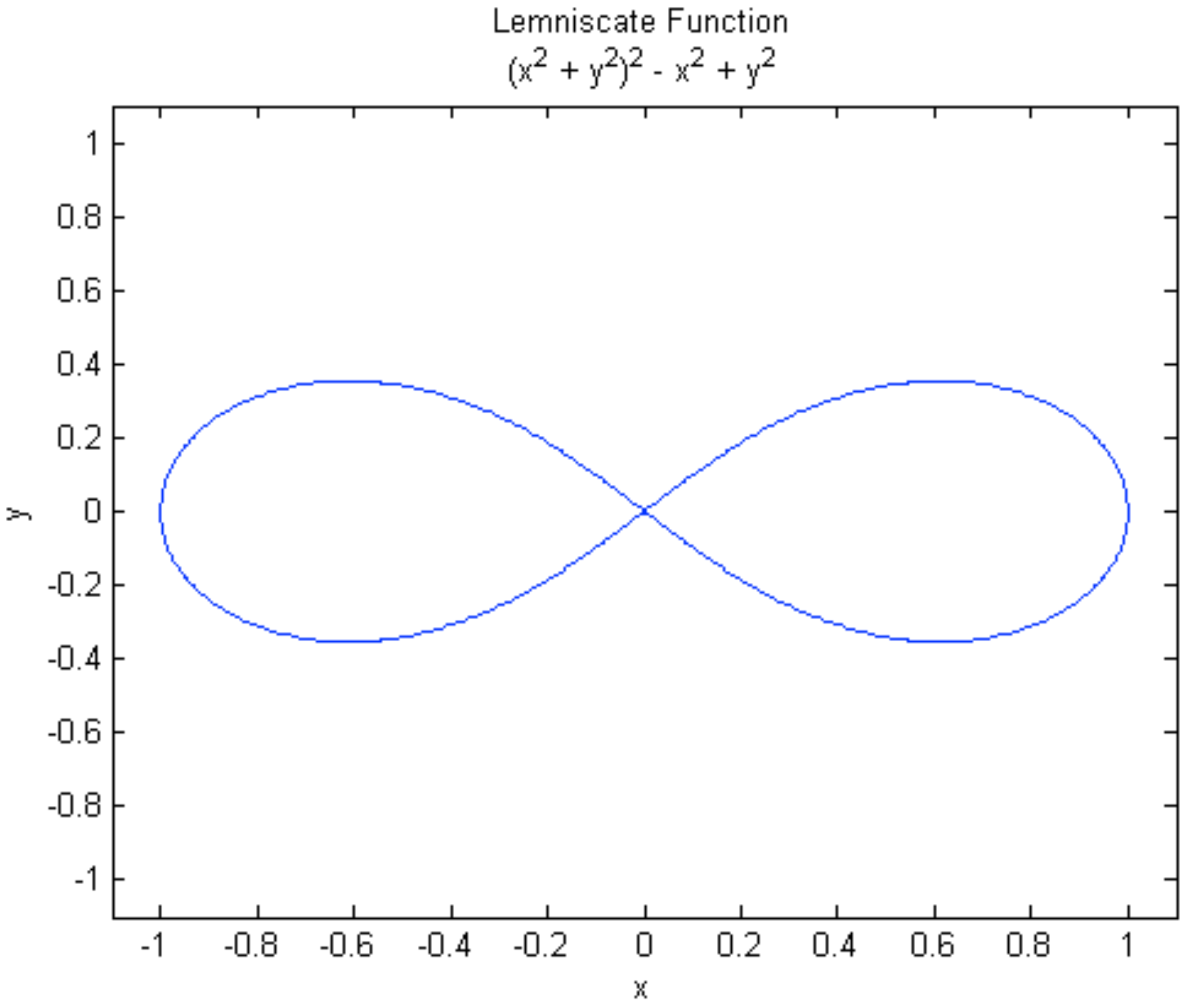


Plotting

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

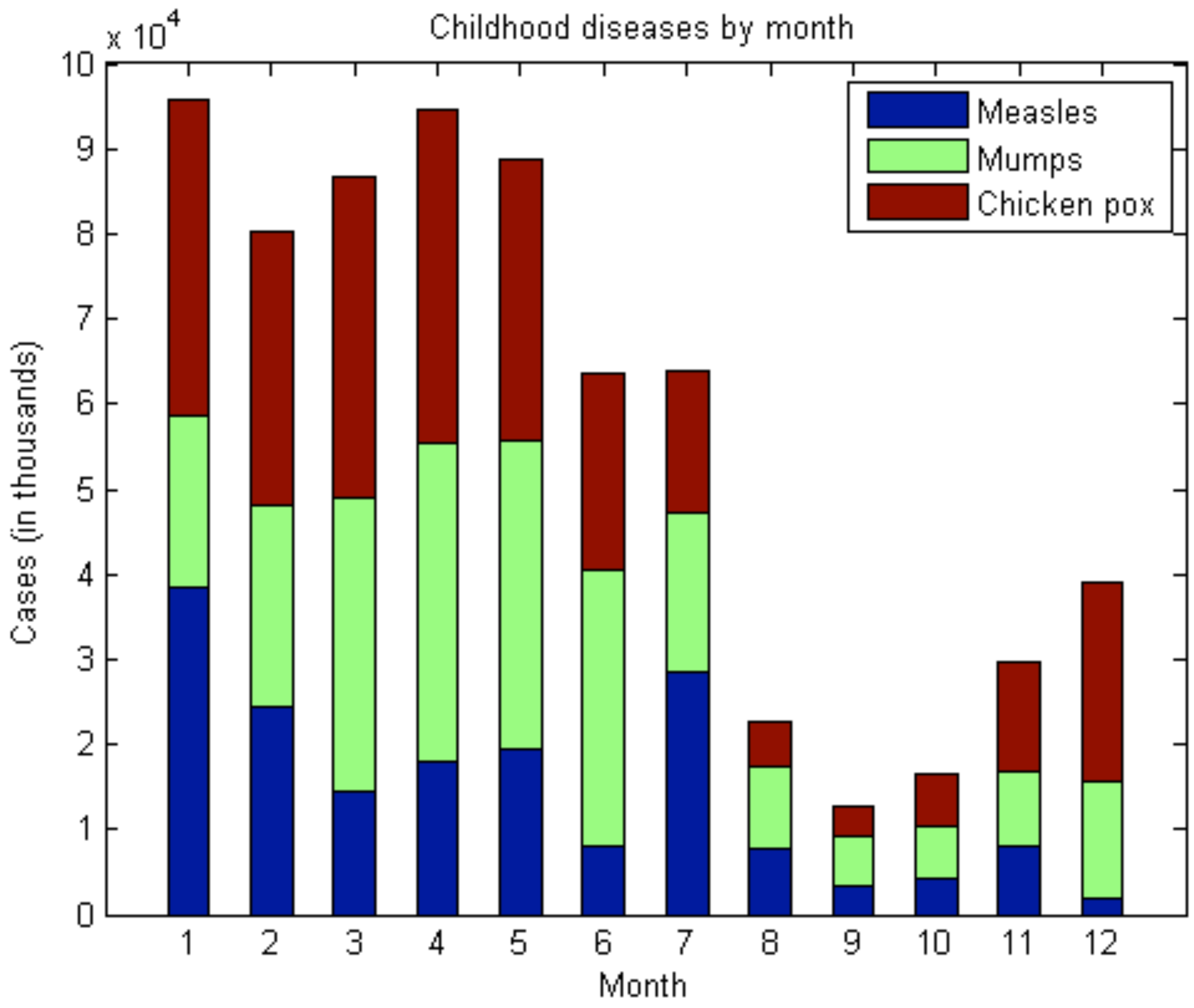
Example: bar

```
% 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');
```



Plotting

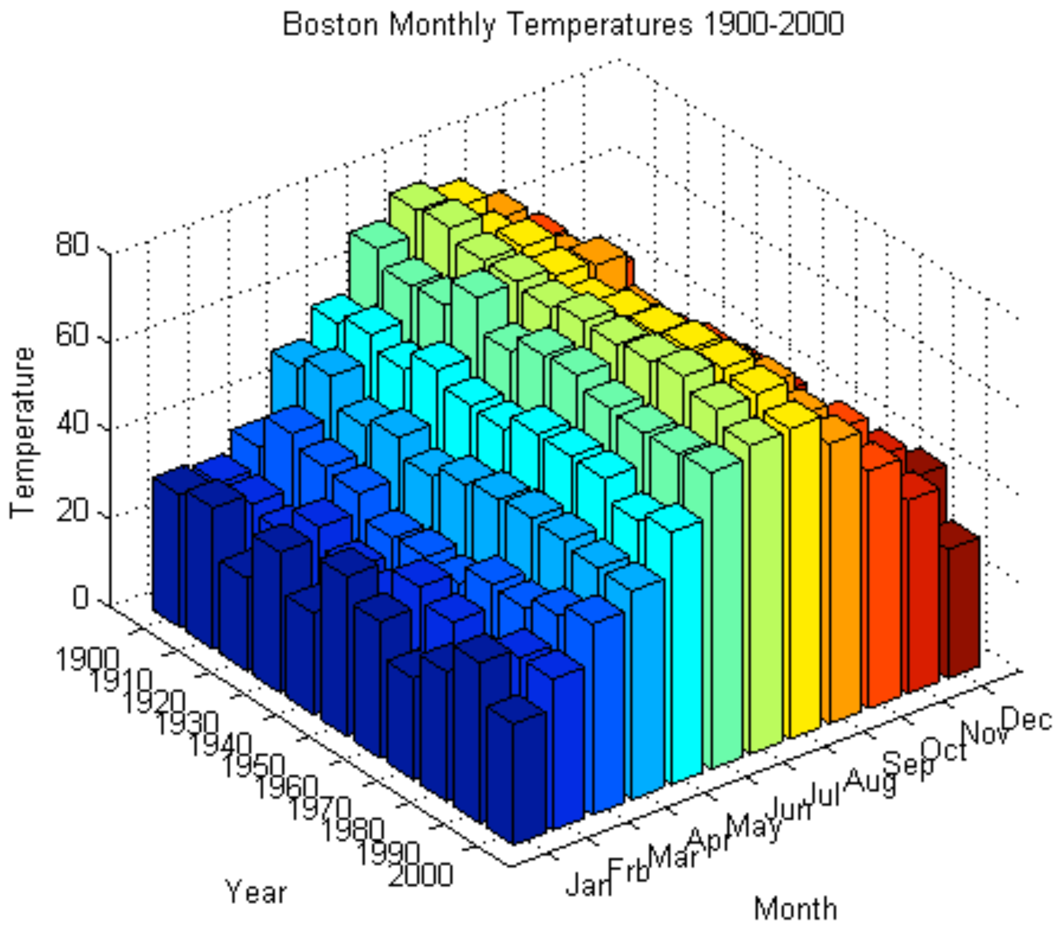
Example: bar3

```
% 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);
```



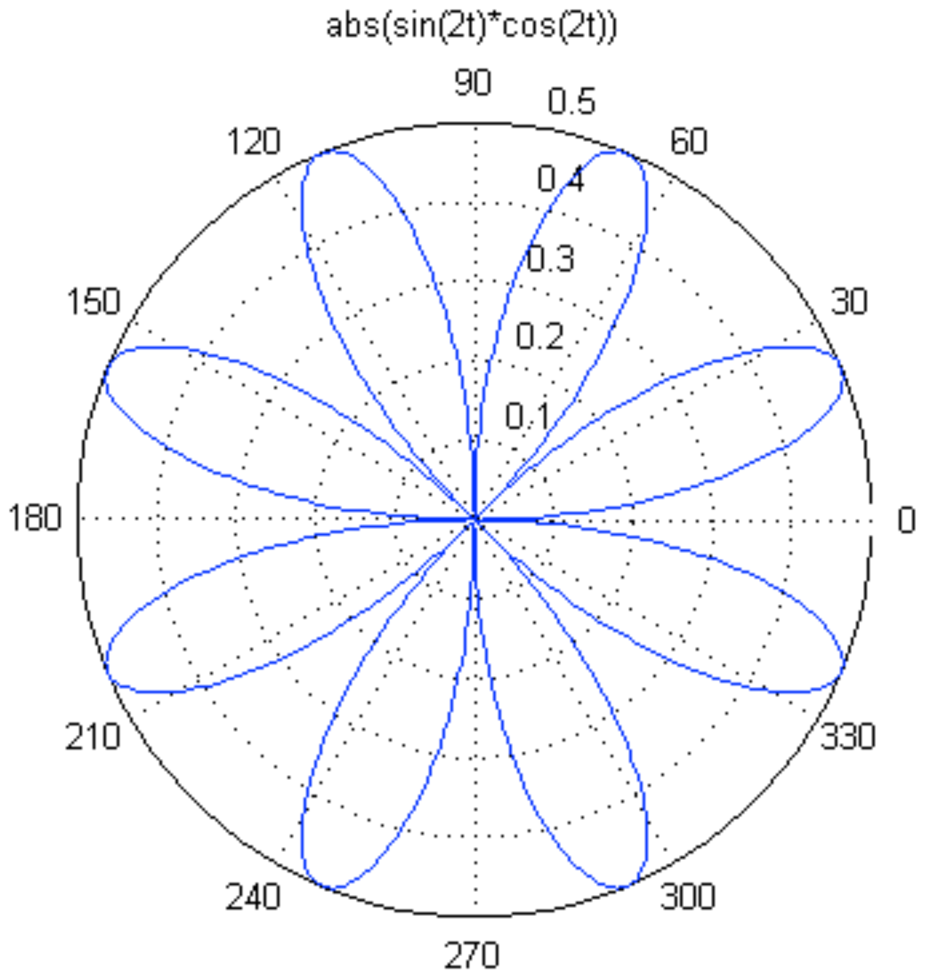
Plotting

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))');
```



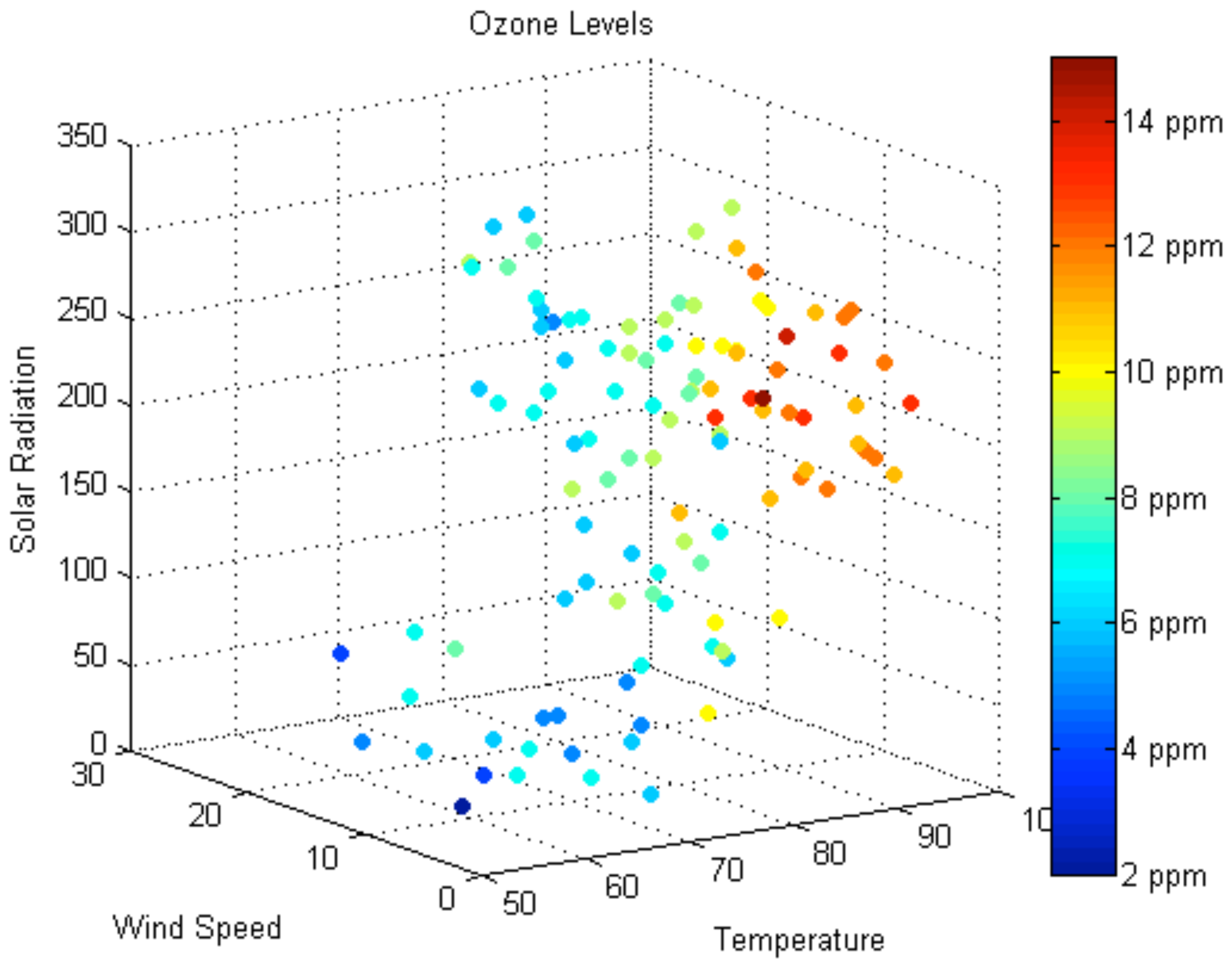
Example: `scatter3`

```
% 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!

Plotting

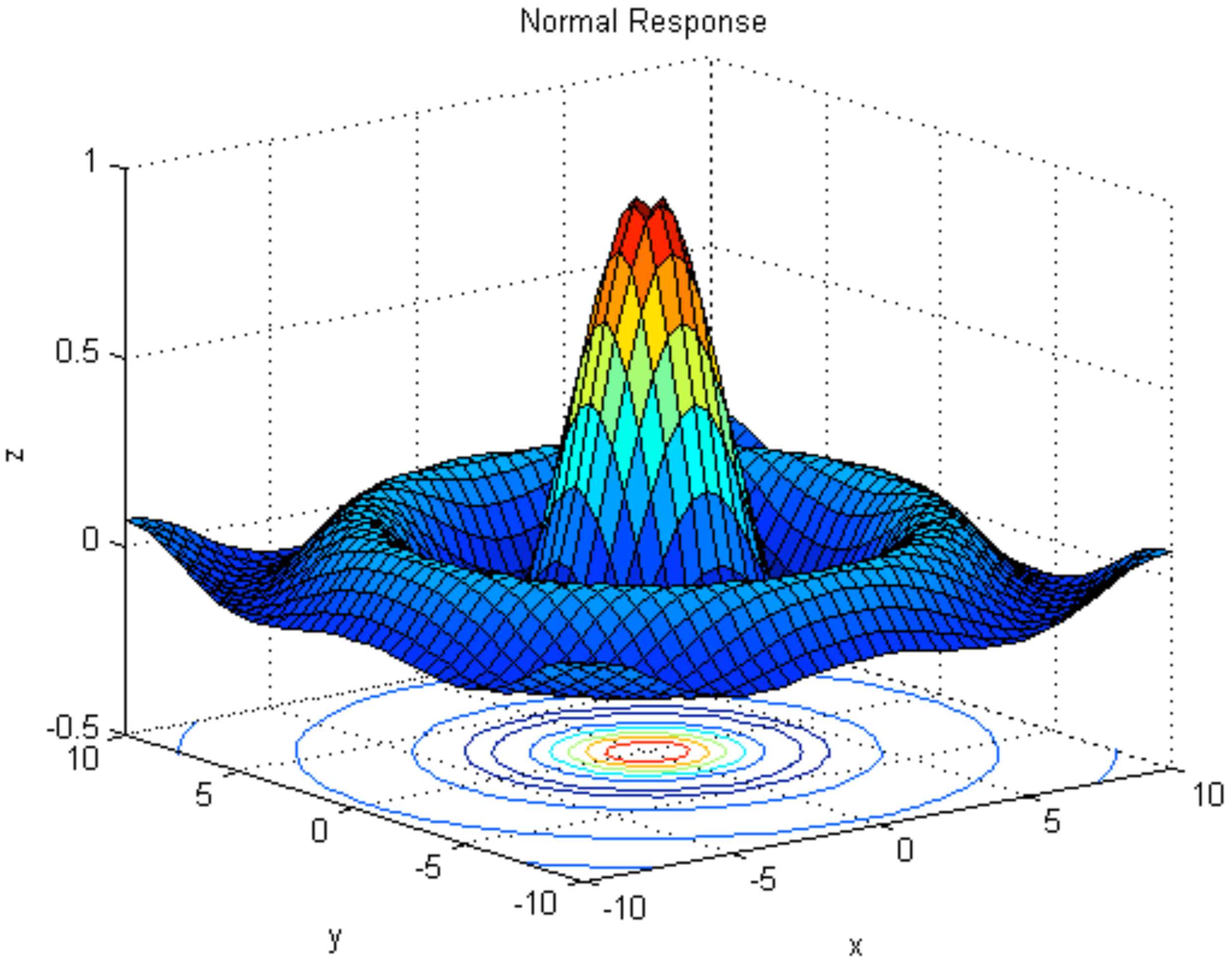
Example: `surfc`

```
% 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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Programming

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

Programming

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

Programming

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

Programming

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`

Programming

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]`

Programming

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)

Programming

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)

Programming

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**

Programming

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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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

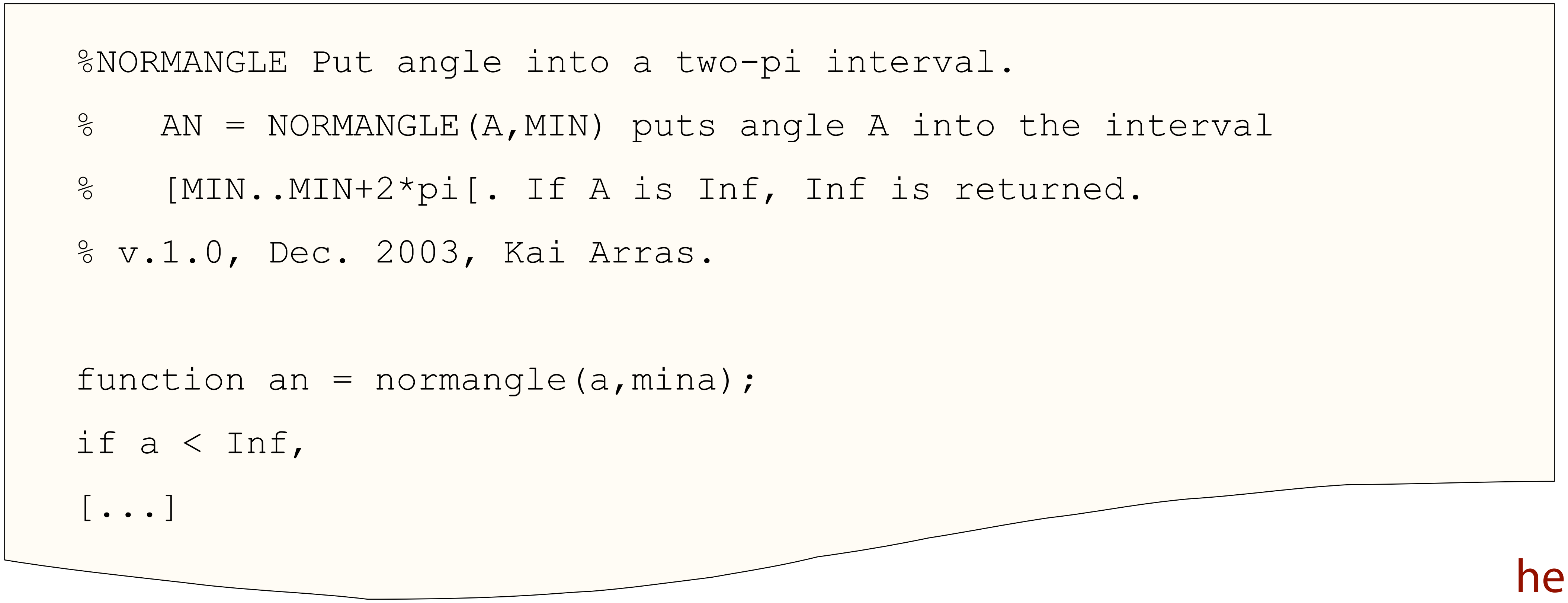
Scripts

- 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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Files I/O

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

Files I/O

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);
```

Files I/O

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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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'`

Miscellaneous

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**

Miscellaneous

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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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

Octave and Matlab in Practice

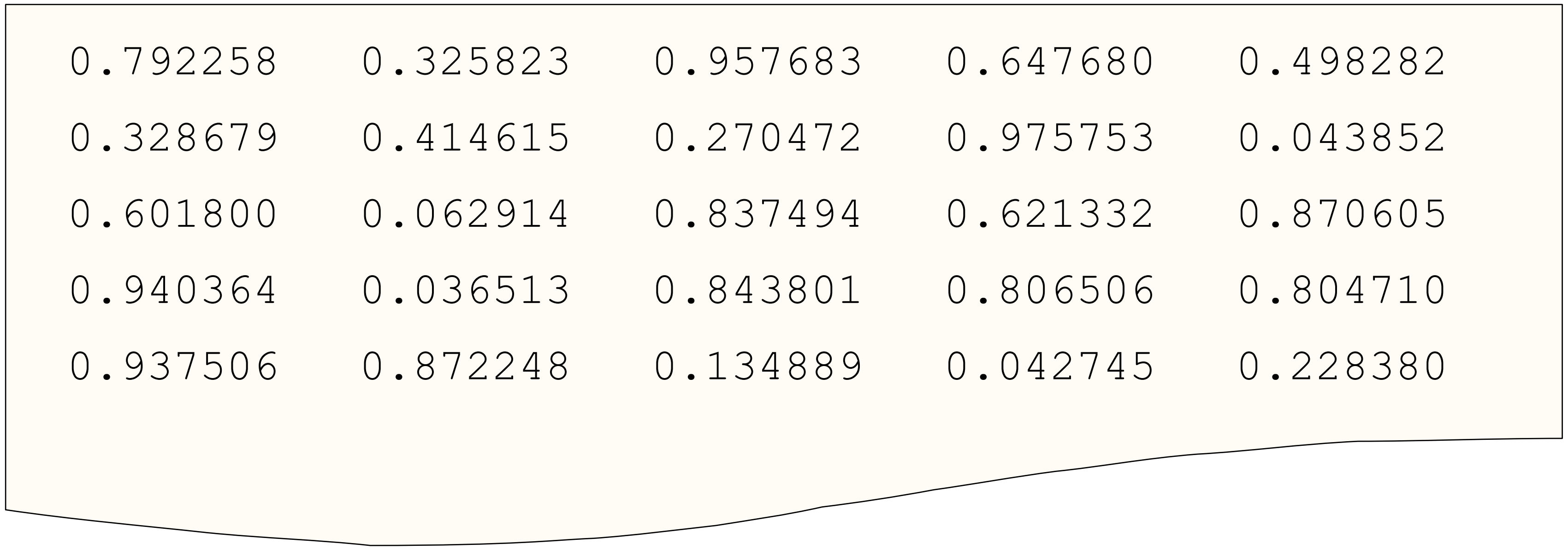
Writing Files in Matlab Syntax

- 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;
```

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librobotics

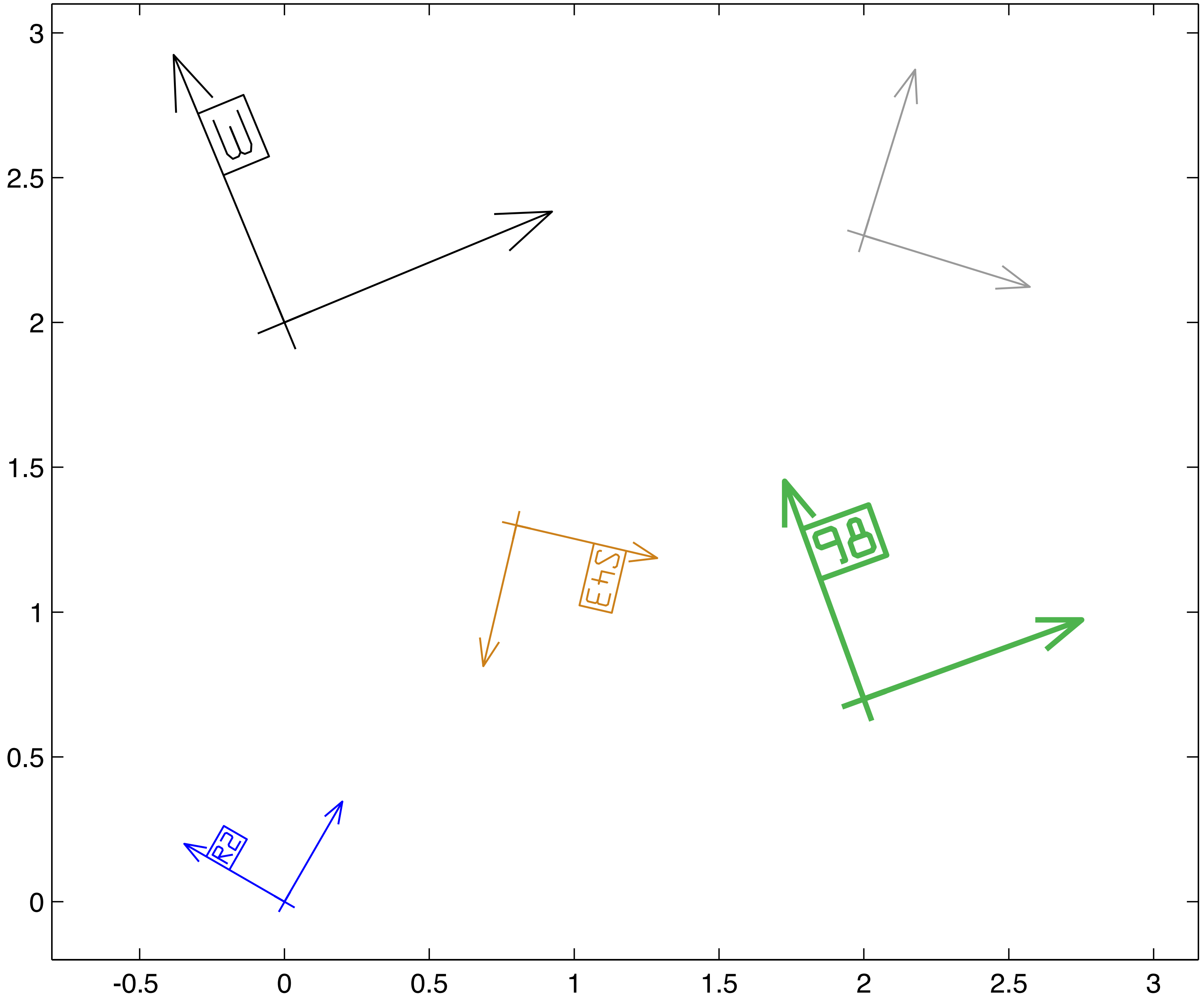
- **librobotics** is a small library with frequently used Octave/Matlab functions in Robotics, especially for visualization

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

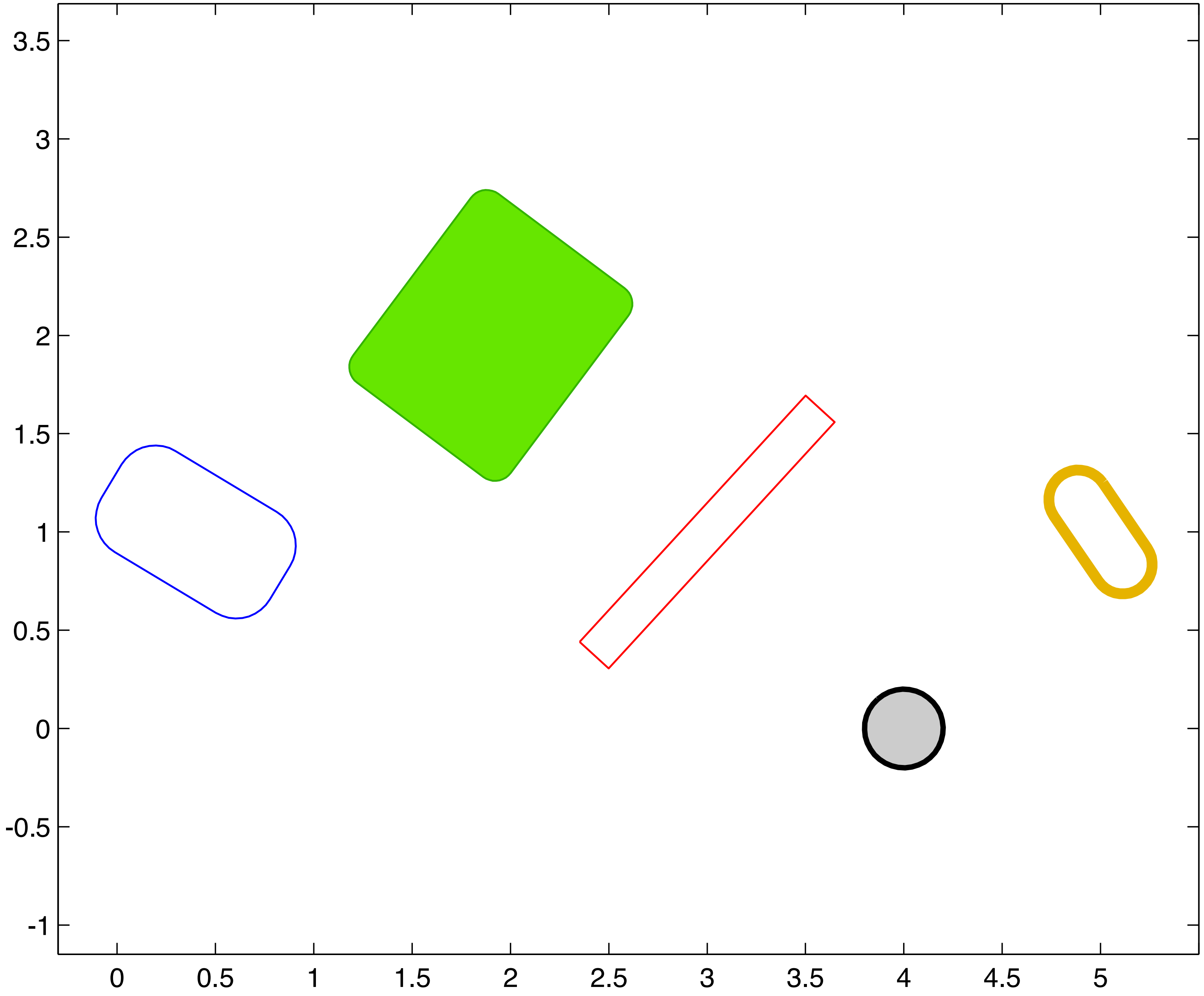
- **Download** from SRL Homepage: srl.informatik.uni-freiburg.de/downloads

librobotics

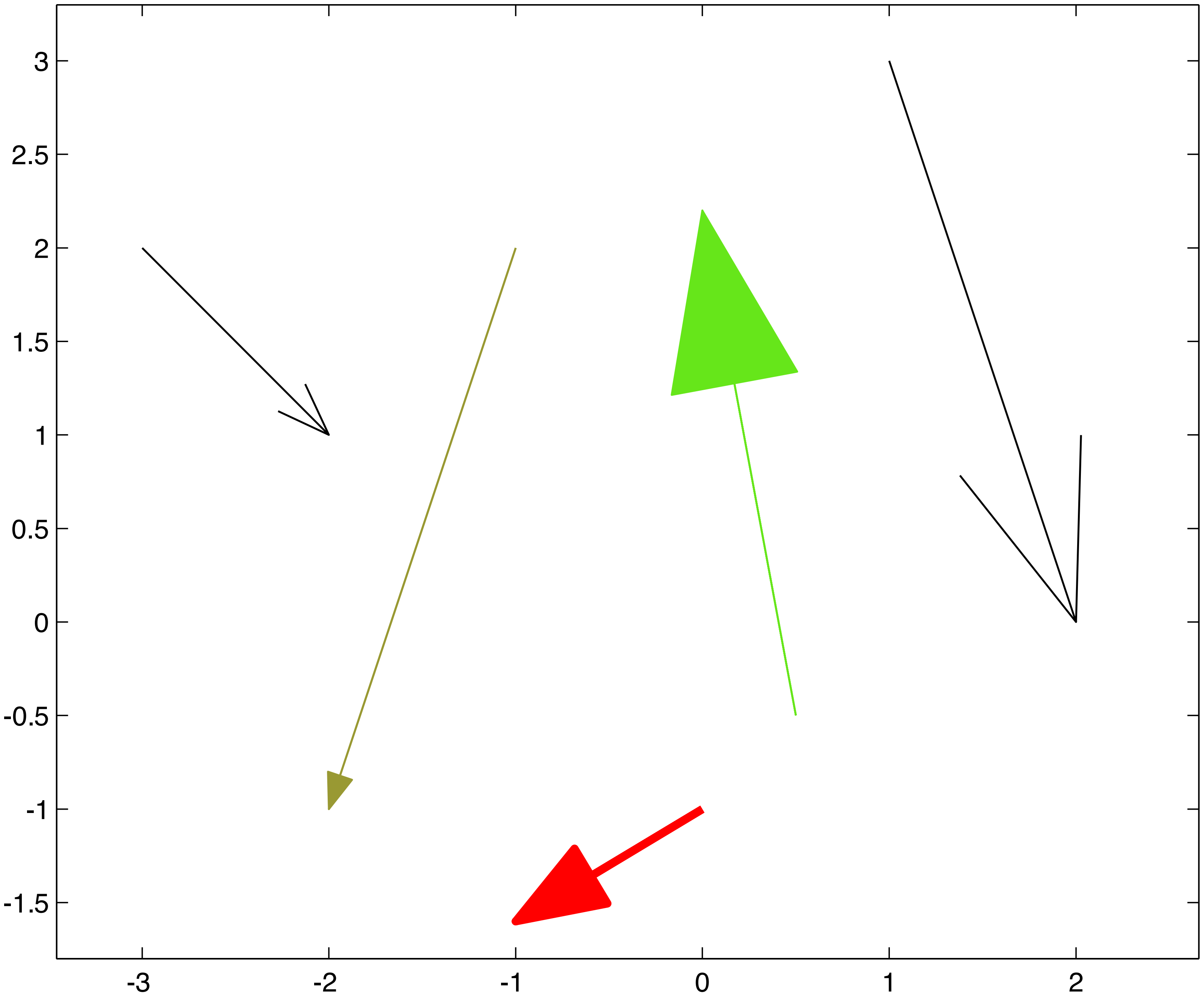
- **Command** `drawreference.m`



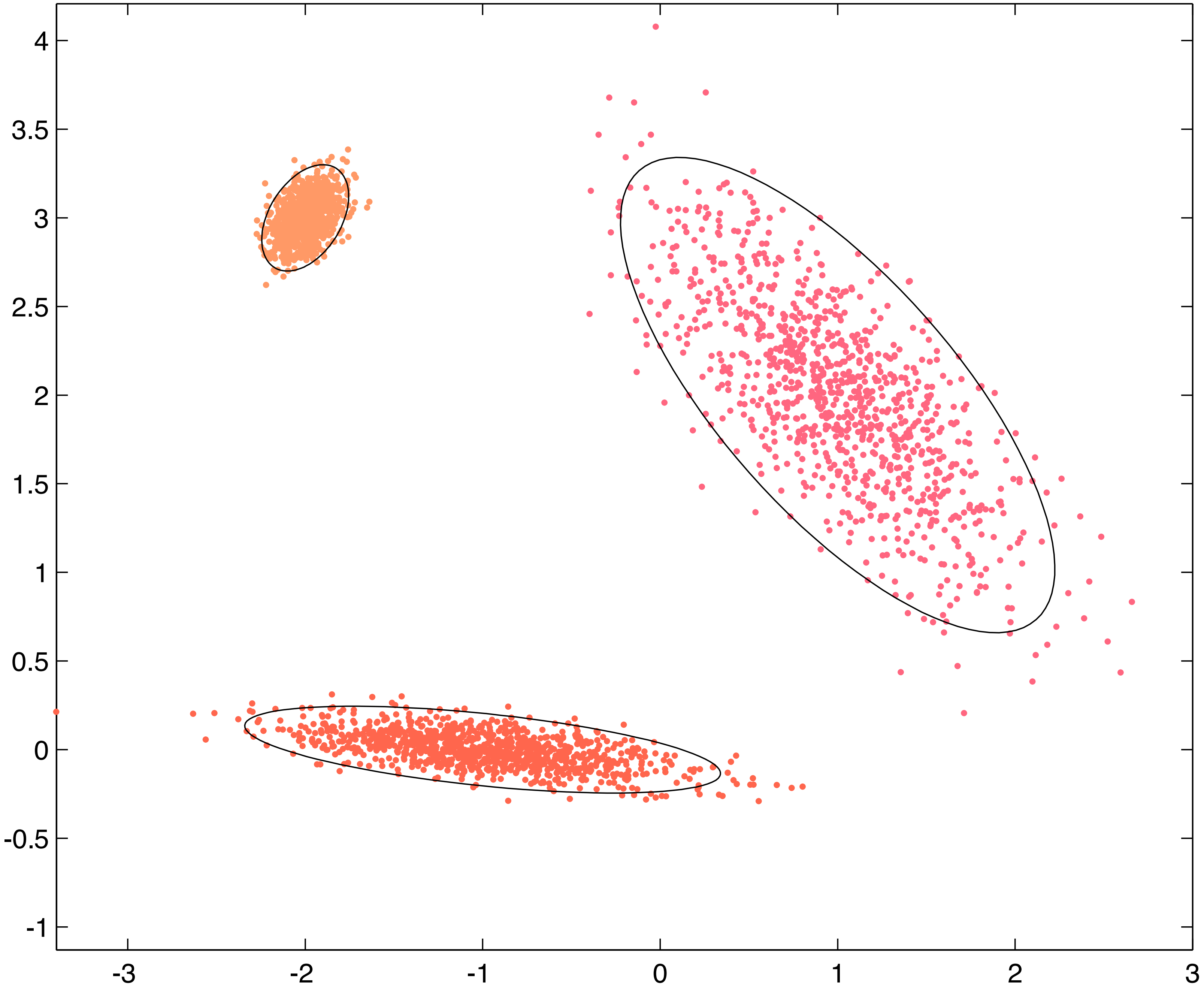
- **Command** `drawroundedrect.m`



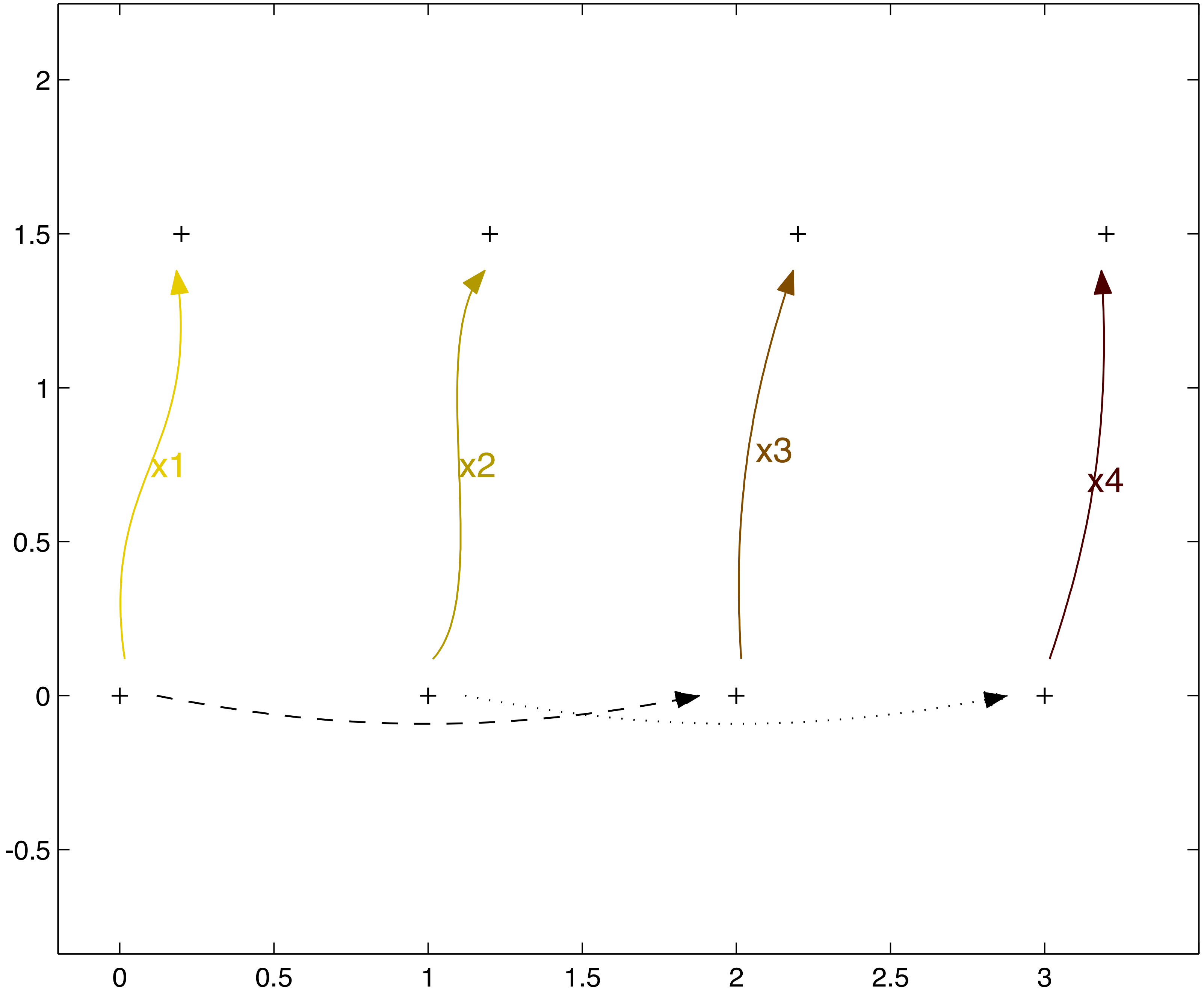
- **Command** `drawarrow.m`



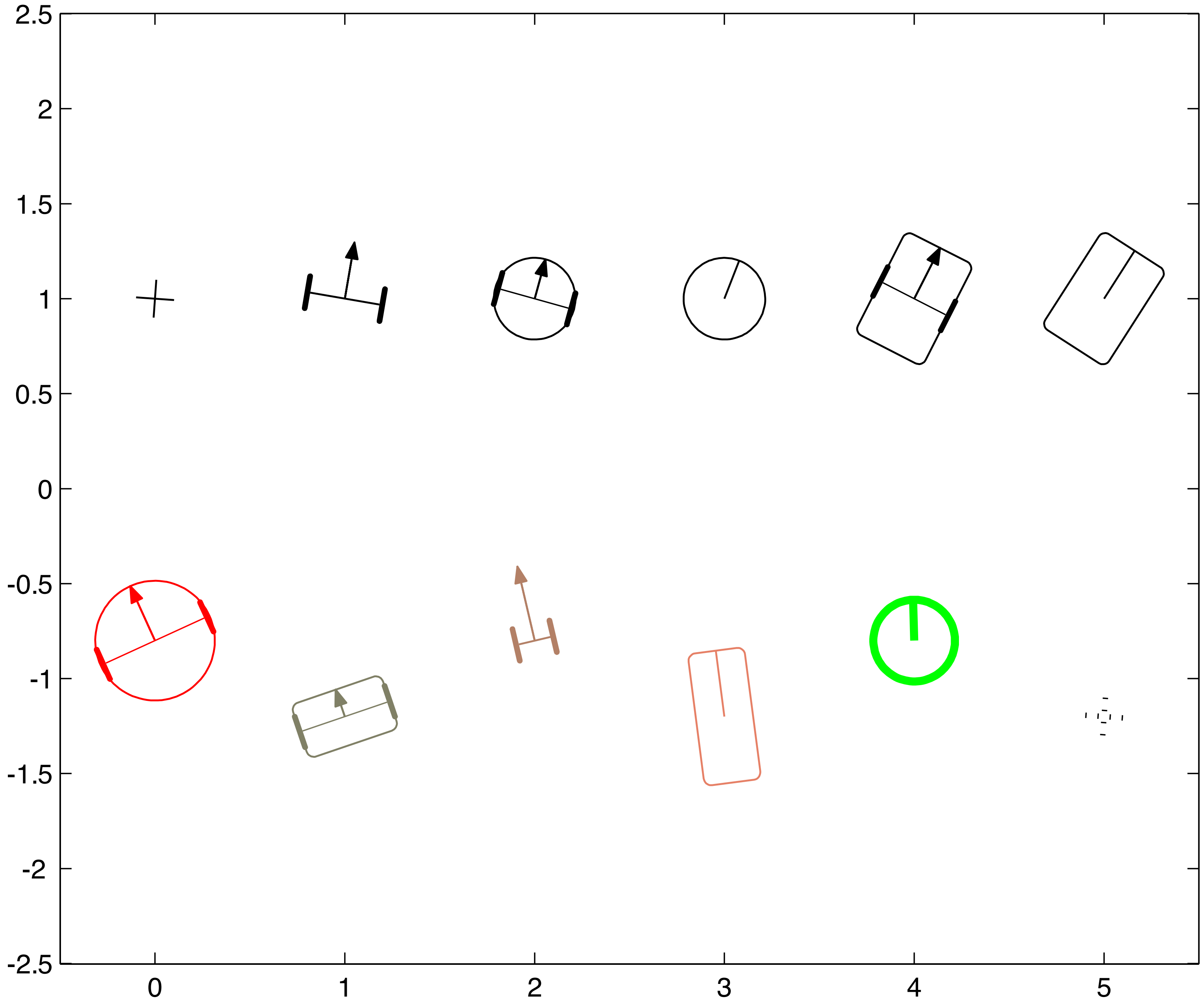
- **Command** `drawprobellipse.m`



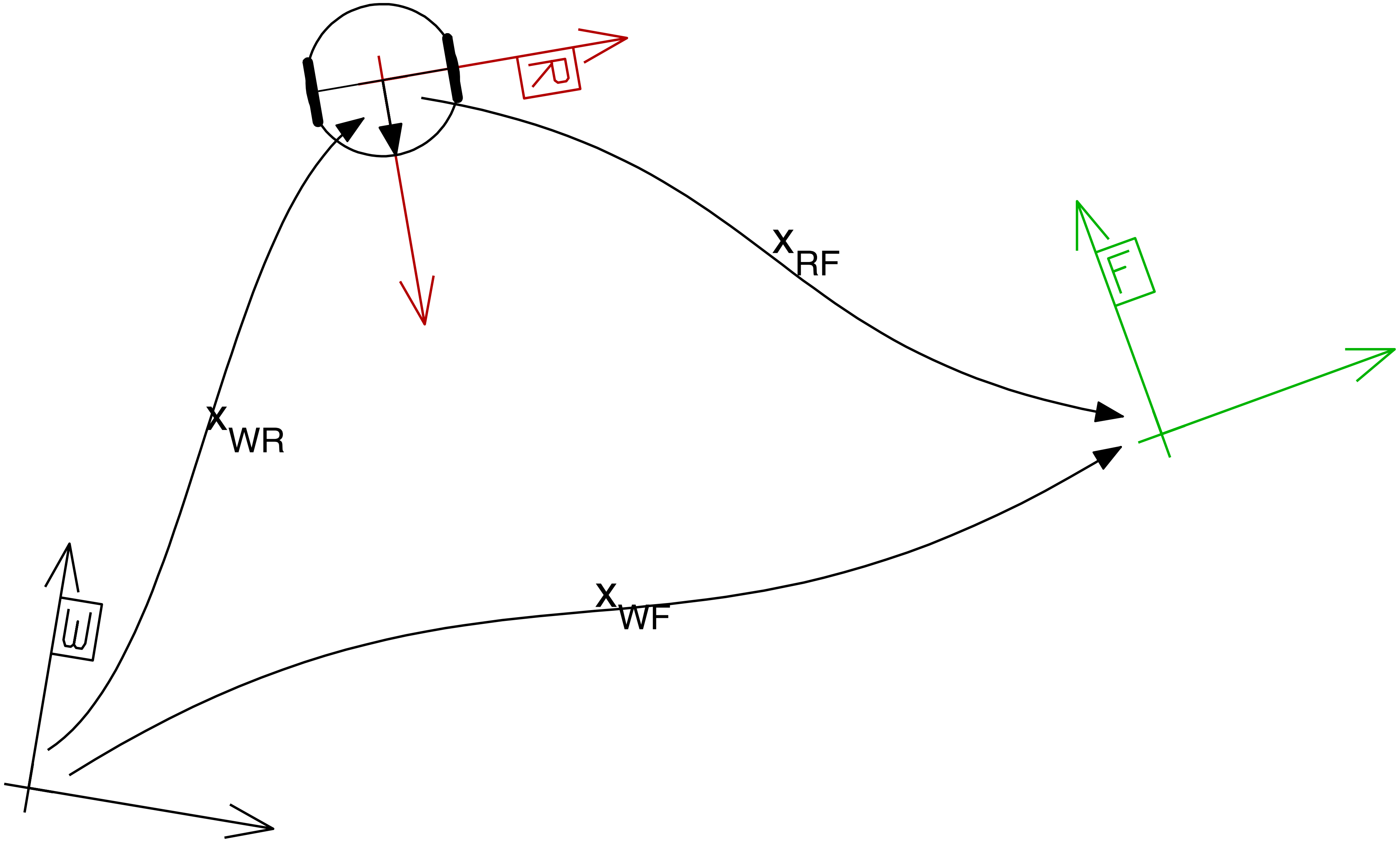
- **Command** `drawtransform.m`



- **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!

Kai Arras, Social Robotics Lab