Matlab Introduction I:

Basic concepts, commands, and structure

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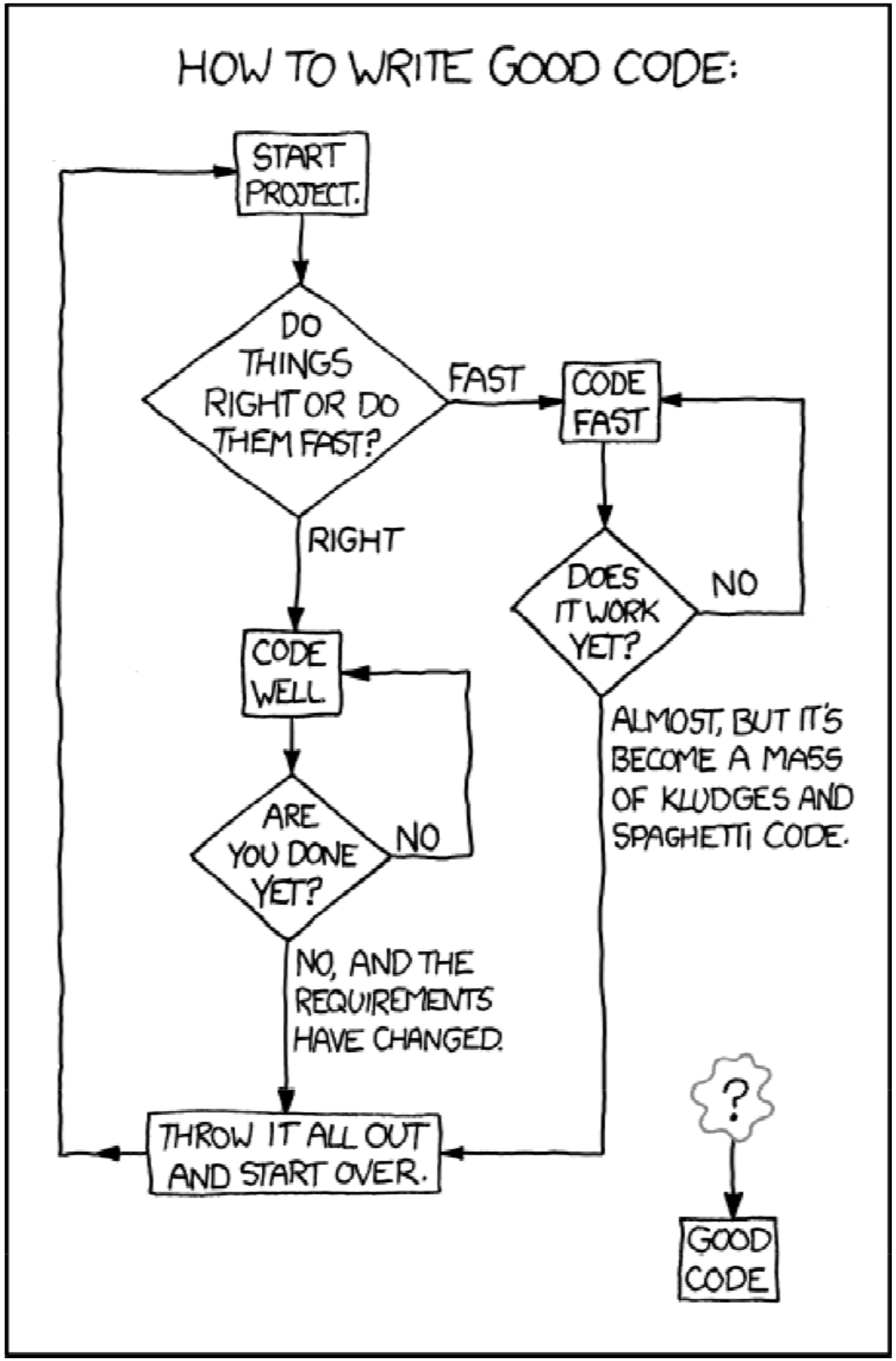


HOW TO WRITE GOOD CODE:
START PROJECT.
DO THINGS RIGHT OR DO THEM FAST?
FAST
CODE FAST
DOES IT WORK YET?
NO
ALMOST, BUT IT'S BECOME A MASS OF KLUDGES AND SPAGHETTI CODE.
RIGHT
CODE WELL
ARE YOU DONE YET?
NO
NO, AND THE REQUIREMENTS HAVE CHANGED.
THROW IT ALL OUT AND START OVER.
?
GOOD CODE

[from xkcd.com]

Outline

- Why Matlab?
- A Brief (Interactive) Introduction to Matlab
    - → Starting Matlab
    - → Path
    - → Workspace
    - → Numeric Variables
    - → Maths/Logic
    - → Strings, Cells, Structures
    - → Loops
- Scripts and Functions
    - → An Example Script
    - → An Example Function
- HELP?! (Where to get it)

* NOTE: All of this is available in: /imaging/jt03/demo

Why Matlab?

...or any other command-line software

There are distinct advantages to analysing your data using scripts and functions:

- Leave data in its original format
- Retain a complete record of all processing
- Hard work for the first subject, easy sailing for the rest
- Easily modify analysis pipeline and re-run analyses

Alternatives to Matlab:

- Octave (free!) ... matlab clone
- S-Plus (not free) or R (free!) ... stats
- Yes, you can script Excel (Visual Basic) and SPSS (syntax) too, but these are less flexible / powerful

Why Matlab?

... specifically

Versatility:

- Statistics
- Image Processing
- Signal Processing
- 3D Visualisation
- Custom

  see: http://www.mathworks.com/matlabcentral/fileexchange

Neuroimaging (MRI, fMRI, DTI, M/EEG)

- SPM
- GIFT / EEGIFT
- EEGLAB / FMRLAB
- FieldTrip
- etc.

A Brief (Interactive) Introduction to Matlab

Go to demo (brief_intro_to_matlab.m)

On the following slides I've simply copied the contents of brief_intro_to_matlab.m, one cell per page. It's meant to be explored interactively and run line-by-line, so why not go open it in Matlab Editor and try it out?

(Otherwise, skip ahead to slide 22)

```
% A Brief Introduction to Matlab
%
% This script is intended to introduce novices to
%  the Matlab environment. It is meant to be executed
%  line-by-line, allowing for interactive exploration
%  of data types and whatnot.
%
% Notes:
%  - odd spaces between cells for demonstration purposes!
%  - navigate between cells using <ctrl>+<down> <ctrl>+<up>
%
% by Jason Taylor (18 Nov 2011)
%    MRC Cognition and Brain Sciences Unit
%    Cambridge, UK
%    email: <first>.<last>@mrc-cbu.cam.ac.uk
%
```

```
%% SOME TIPS:
%
% GENERAL:
%  %         indicates a comment (ignored)
%  ;         (@ end of command) means don't print result
%
% COMMAND WINDOW:
%  >>        this is the 'prompt': type commands here!
%  <up>      scrolls through command history, last-to-first
%             - all commands if you've typed nothing
%             - matching commands if you've typed something
%  <tab>     completes (e.g., mea<tab> gives 'mean'...)
%  <ctrl+c>  stop command
%  clc       clears command window
%
% EDITOR:
%  %%        begins a new 'cell' (section of code)
%  <F9>      executes a highlighted line (or set of lines)
%  <ctrl+dn> go to next cell
%  <ctrl+up> go to prev cell
```

```
%% STARTING MATLAB

% Windows: Start->Matlab or double-click icon
%  * Note: can set startup preferences in shortcut
%           e.g., starting dir, -nojvm, etc.

% Linux Machines:
%  Type 'matlab'
%  Type 'matlab <-options>'
%  Type 'spm <options>'      *wrapper script @ CBU
%  ... see demo ...
```

```
%% Matlab & Linux

% Within matlab, linux commands can be run:
%  ! <command>
% or:
%  [status,result] = unix(<command>);

% e.g.:
! hostname
[status,hname] = unix('hostname');
if ~status, fprintf(1,'You are connected to %s\n',hname); end
```

```
%% PATH
%   = search path Matlab uses to identify and execute
%     commands, functions, scripts...

% Report the contents of path:
path

% Add a directory to your path (prepend):
% >> addpath <path/to/directory>

% e.g.,
addpath /imaging/jt03/demo/scripts/
% or, append:
addpath /imaging/jt03/demo/scripts/ -END

% edit /home/<user>/matlab/startup.m

% Find the path of a particular function/script/command:
%  which <command>
which mean
```

```
%% THE WORKSPACE
%   = variables that are currently available to be used
%      by you (or by functions as input)

% Two ways to get the mean of a vector:
mean([4.1 3.3 4.8]) % <-this will give you the answer

% or,
x = [4.1 3.3 4.8]   % <- this will store the values
mx = mean(x)        %     and the answer in variables
```

```matlab
%% ... and now you can:

% - get other summary statistics,
sx = std(x)
[min(x) max(x)]

% - plot
bar(x);
hold on;
plot(2,mx,'ko','MarkerFaceColor','r','MarkerSize',12);

% - write it to a text file:
dlmwrite('x.txt',x,'\t');

% - save as a .mat file
save('x.mat','x');
clear x
load('x.mat')

% - etc.
figure; imagesc(rand(64,64)*std(x));
```

```
%% Some WORKSPACE Commands:

% List names of all variables in the workspace:
who

% List names, size, class of all variables in the workspace:
whos

% List ... of a subset of variables in the workspace:
%  whos [<variablenamelist>]

% eg.,
whos x
whos *x*     % <- '*' = wildcard

% Clear (all or subset of) variables out of workspace:
clear x
```

```
%% NUMERIC VARIABLES:

% Scalar values:
x = 42

% Vectors:
xvec  = [1 2 3 4 5 6]
xvec2 = 1:6                    % equivalent

% Matrices:
xmat  = [1 2 3; 4 5 6; 7 8 9]
xmat'

% N-dimensional arrays:
x3d = cat(3,xmat,xmat+10)

% Get size of each dimension:
size(xmat)

% Indexing:
xmat(:,[2 3])  % <- all rows, columns 2 and 3
```

```
%% MATHS:

% Add/subtract
42 + 10
x + 10
y = x - 10

% Multiply/divide (scalar):
y = x * 5
y = x/2

% Multiply/divide (vector):
y = xvec .* [10 100 1000 10 100 1000]
y = xvec/(xvec(1))

% etc.:
y = sqrt(x^3)
```

```
%% LOGIC & LOGICAL INDEXING:

% Logic:
v = xvec*10
v > 30
v > 30 & v ~= 60

% Find index of 'true' (or nonzero, generally):
find(v>30 & v~=60)

% Use logical index:
v(v>30 & v~=60)
v(find(v>30 & v~=60))   % equivalent

% Use logical index on a different variable:
xvec(v>30 & v~=60)

% Valid numbers:
v(end) = NaN
v(~isnan(v))
```

```
%% STRINGS AND CELLS:

% Strings:
mystring = 'hello world'
xstr = '42'   % not the same as x = 42 (see 'isnumeric')

% String matching:
findstr('o',mystring)
findstr('world',mystring)

% Cell arrays (may mix types, sizes):
mycell = {'hello' 'world'}
xcell = {x xstr}
xcell(2)
xcell{2}

% Cell-string matching:
strmatch('world',mycell)
```

```matlab
%% STRUCTURES
%   ** SPM users take note **

% Struct:
S = struct()
S.subj = 's01'
S.sex  = 'male'
S.age  = 27
S.data = [1 2 3 4 5 6]
isfield(S,'age')

% Adding layers:
S(2).subj = 's02';
S(2).sex  = 'female';
S(2).age  = 19;
S(2).data = [11 12 13 14 15 16]

% Extracting data:
[S.age]
{S.sex}
```

```
%% LOOPS:

% For loop:
for i = 1:10
    if i>3, fprintf(1,'subject %02d\n',i); end
end

% While loop:
i = 0;
while i<3
    i = i+1;
    fprintf(1,'subject %02d\n',i);
end
```

```
%% Loops continued

% Switch ... case ... otherwise ...
switch S(1).sex
    case 'male'
        fprintf(1,'He is subject 1.\n');
    case 'female'
        fprintf(1,'She is subject 1.\n');
    otherwise
        fprintf(1,'Subject 1''s sex was not recorded.\n');
end
```

```
%% That's enough for now!

% On to scripts and functions...

% If you got here via the presentation, type 'return' +
[ENTER] at the
% command line, or highlight and <F9>:

return
```

Functions vs. (Batch) Scripts

Function:

- General

  (usually applies to any data, project)
- Run as command

  (specify input, output arguments)
- Variables do not stay in workspace

  (except input/output arguments, debugging environment)
- Can get help by typing:

  help <function name>
- First line of code MUST BE:

  [<output>] = function(<input>)

Script:

- 'Hack and Run'

  (customise to your data, project)
- Copy&Paste (<F9>) or command

  (no arguments allowed)
- Variables stay in workspace

Both are text files, which you can edit in Matlab’s editor (see edit command)
or your favourite text editor (emacs, nedit, gedit, wordpad, notepad, etc.)
NOTE: These vary in terms of debugging friendliness!

You may start writing a batch script, then later find it useful to convert sections of it into functions.

An Example Batch Script

Go to demo (demo_script_cell_by_cell.m)

On the following slides I've simply copied the contents of demo_script_cell_by_cell.m, which shows the evolution of a simple script to analyse response time data from 15 subjects and produce a figure with a bar plot of mean RT + standard error bars. You can also view and run the resulting script – demo_script_simple.m –and the more elaborate version – demo_script_final.m –in the CBU imaging workspace.

More information is given in demo_readme.m

```
%
% This is what I showed in the demonstration. It is meant to show
%  the evolution of demo_script_simple.m:
%
%    - First, write description of what the script will do
%    - Second, write comments describing each step
%    - Third, flesh out each step with code
%
% The 'strings' at the top of each cell are annotations.
%
% Use <ctrl>+<down> and <ctrl>+<up> to navigate between cells.
%
%   by Jason Taylor (21 Nov 2011)
%
```

```
%%

'At top: What the script does, when created (updated)?'

% This is a batch script to get the median of each subject's RT data,
%  plot the grand mean and standard error for the two conditions.
%
% by Jason Taylor (17/11/2008)
% + updated (jt 17/11/2008): added error bars
%
```

```
%%
'In body: Write an outline using comments'

% (1) Define directory, filename, subject parameters


% (2) Get each subject's median RT


% (3) Compute grand mean, standard error


% (4) Plot bar graph with error bars
```

```
%%

'Then fill in with increasingly specific comments (as necessary) &
commands'


% (1) Define directory, filename, subject parameters:

% Project directory:
projdir = '/imaging/jt03/demo/rtdata/subjects';

% Working directory: * CHANGE to a dir you have permission to write to!
wkdir = '/imaging/jt03/demo/rtdata/ga15';

% Subjects:
subjects = [1:15];
```

```
%%

'...continue to fill in ...'


% (2) Get each subject's median RT:

% Initialise variable (subjects x conditions) to collect median RTs:
mdrt = zeros(length(subjects),2);

% Loop over subjects:
for i = 1:length(subjects)

    % Get current subject label:
    subj = sprintf('s%02d',subjects(i));

    % Go to subject's directory, load data:
    cd(fullfile(projdir,subj));
    load('word nonword.mat');

    % Put median RT for each condition into summary matrix:
    mdrt(i,1) = median(D.rt(D.event==1));
    mdrt(i,2) = median(D.rt(D.event==2));

end % i subjects
```

```
%%

'...continue to fill in ...'


% (3) Compute grand mean, standard error:

% Compute mean (collapsing over rows):
gm = mean(mdrt,1);

% Get standard error:
se = std(mdrt)/sqrt(size(mdrt,1));

% Save it as a .mat file in working directory:
cd(wkdir)
save rtdata.mat gm se
```

```
%%

'...continue to fill in ...'


% (4) Plot:

% Open a figure, make background white:
fig = figure;
set(fig, 'color', [1 1 1])

% Plot means:
bar(gm);

% Rescale axes:
ymax = ceil(max(gm+se));
set(gca, 'ylim', [0 ymax]);

% Plot and format error bars:
ebar1 = line([1 1],[gm(1) gm(1)+se(1)]);
ebar2 = line([2 2],[gm(2) gm(2)+se(2)]);
set([ebar1 ebar2], 'linewidth', 6);
```

```matlab
%%

'...continue to fill in ...'


% Apply title, labels, etc.:
title('Grand Mean of Median RTs');
xlabel('Stimulus Type');
ylabel('RT + SEM (ms)');
set(gca, 'xticklab', {'word', 'nonword'});

% End gracefully:
fprintf(1,'\n++ done! ++\n\n');
```

```
%%

'To run the script, type at the Command Line (or highlight and <F9>):'

demo_script_simple


'To run a version with nicer formatting, type:'

demo_script_final


'If you launched this from the presenation...'
'To return to the presentation, type:'

return
```

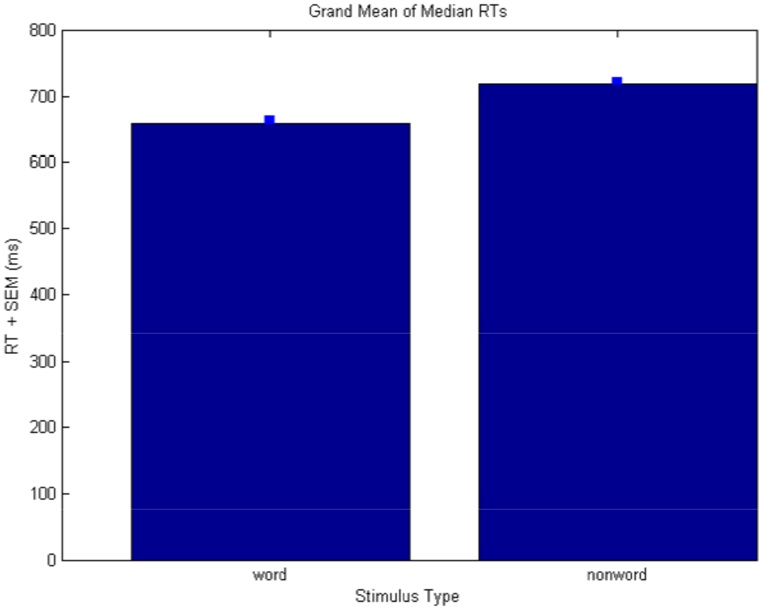
An Example Batch Script

Running the batch script demo_script_simple.m should:

- Add several variables to the workspace, including

```
gm   (grand mean of median RTs for 2 conditions)
se   (standard error of the mean for 2 conditions)
mdrt (median RTs for each subject and condition, 15x2)
```

- Open a figure window and plot M+SE for each condition



An Example Batch Script

The script demo_script_final.m shows how you might improve upon the simple batch script. Some improvements include:

'Adding (at top) some options to make the figure a bit more attractive'

```
%% (0) Define options:

% Plot format:
barcolor  = [.5 .5 .5];
ebarcolor = [0 0 0];
ebarsize  = 3;
plotfont  = 12;
```

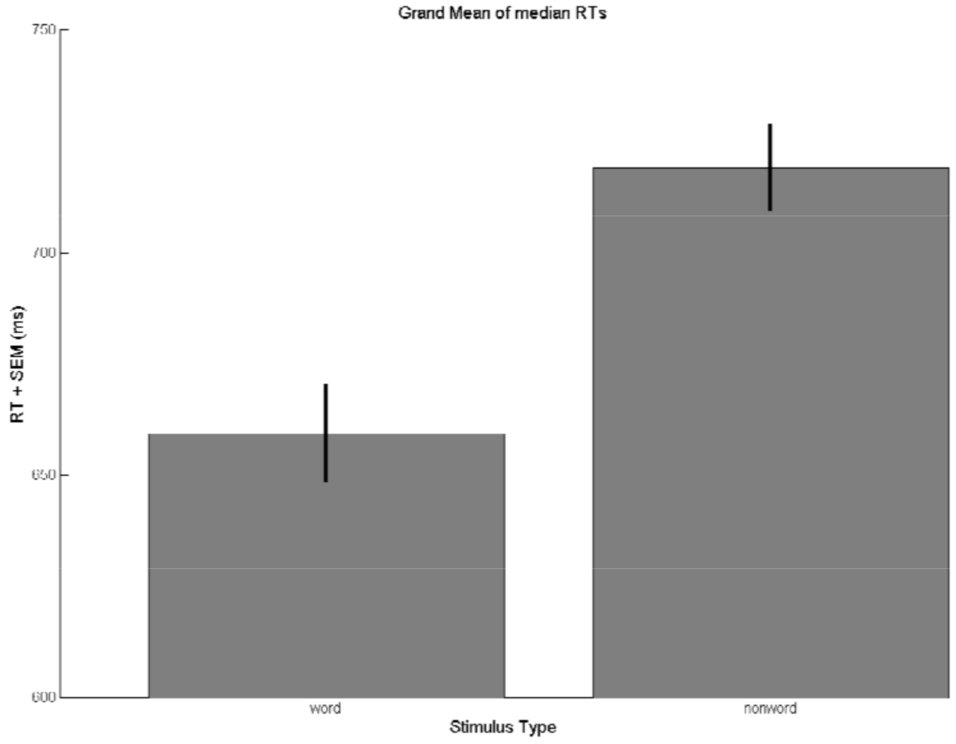
'These get called later in the call to bar (which plots the data):'

```
% Plot means:
    bar(gm, 'facecolor', barcolor);

    set([ebar1 ebar2], 'linewidth', ebarsize, 'color', ebarcolor);

    set(gca,'fontsize',plotfont);
```

An Example Batch Script

The script demo_script_final.m shows how you might improve upon the simple batch script. Some improvements include:

```
'Which results in this slightly prettier figure:'
```



An Example Batch Script

The script demo_script_final.m shows how you might improve upon the simple batch script. Some improvements include:

```
'Adding some processing options (Which summary statistic? Save? Plot?):'
  % Processing options:
  plotvar = 'median';  % 'median', 'mean', 'trim<N>' (N%-trimmed mean)
  dosave  = 0;         % save grandmean data?
  doplot  = 1;         % plot grandmean data?

'And some data options...'
  % Data options:
  conds     = [1 2];
  condlabs  = {'word', 'nonword'};
  Nevents   = [240 240];

'... which get looped over later'
  % Loop over conditions
      for j = 1:length(conds)
       ' ... '
        rt = D.rt(D.event==conds(j));
       ' ... '
      end % j in conds
```

This loop is more flexible and more powerful than typing out the same command for each condition

In demo_script_simple.m, we had:

```
mdrt(i,1) = median(D.rt(D.event==1));
mdrt(i,2) = median(D.rt(D.event==2));
```

But what if we want to add more conditions?

*** Better yet, vector / matrix operations are more efficient than loops!**

An Example Function

At some point, you may find you're often typing out the same formula or set of commands. This is annoying… and inefficient!

For example: In our script, we had to compute standard error by hand:

```
% Get standard error:
se = std(mdrt)/sqrt(size(mdrt,1));
```

By contrast, we don't compute the mean by hand (sum elements/number of elements), we just call the function mean.

So let's create a standard error function.

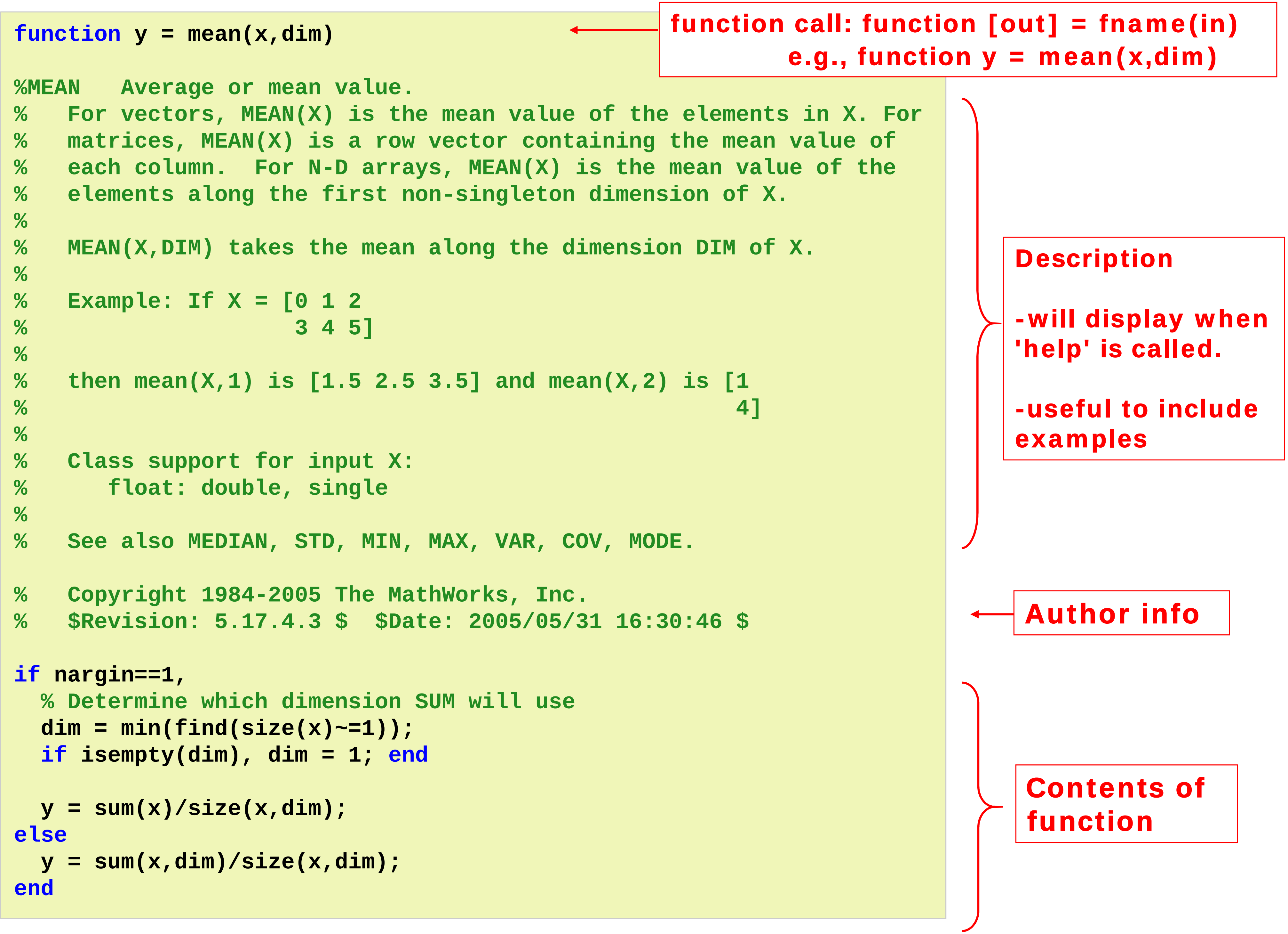
An Example Function

First … what does a function look like?

To look at a function’s contents, you can:

```
edit mean    % open the function's m-file in Matlab Editor

type mean    % dump the function's contents to screen

which mean    % find the function's m-file

unix(sprintf('nedit %s',which('mean'))); % edit in another editor
```

The main elements of a function are … (next slide)



```
function y = mean(x,dim)

%MEAN   Average or mean value.
%   For vectors, MEAN(X) is the mean value of the elements in X. For
%   matrices, MEAN(X) is a row vector containing the mean value of
%   each column.  For N-D arrays, MEAN(X) is the mean value of the
%   elements along the first non-singleton dimension of X.
%
%   MEAN(X,DIM) takes the mean along the dimension DIM of X.
%
%   Example: If X = [0 1 2
%                    3 4 5]
%
%   then mean(X,1) is [1.5 2.5 3.5] and mean(X,2) is [1
%                                                      4]
%
%   Class support for input X:
%      float: double, single
%
%   See also MEDIAN, STD, MIN, MAX, VAR, COV, MODE.

%   Copyright 1984-2005 The MathWorks, Inc.
%   $Revision: 5.17.4.3 $  $Date: 2005/05/31 16:30:46 $

if nargin==1,
  % Determine which dimension SUM will use
  dim = min(find(size(x)~=1));
  if isempty(dim), dim = 1; end

  y = sum(x)/size(x,dim);
else
  y = sum(x,dim)/size(x,dim);
end
```

function call: function [out] = fname(in)
e.g., function y = mean(x,dim)

Description

-will display when 'help' is called.

-useful to include examples

Author info

Contents of function

An Example Function

So, have a crack at a standard error function, sem:

```
function y = sem(x)

% Computes standard error (standard deviation divided by
%  square root of N) of a vector.
%
% by Jason Taylor (18/11/2008)
% note: should be modified to handle matrices
%

% Check that input is a vector:
if nargin~=1
  help sem
  error('No input!')
elseif sum(size(x)>1)>1
  help sem
  error('Input must be a vector!')
end

% Compute SEM:
y = std(x)/sqrt(length(x));

return
```

Give it a unique name; first try:
which sem

Describe it

Take credit / blame

Note modifications, limitations, bugs

Check for proper input (here must be a vector)

Do it!

Save in your path (e.g., /home/<user>/matlab/sem.m)
(see sem.m in /imaging/jt03/demo/scripts)

HELP?!

(where to find it)

Obviously:

```
   help <funcname>
```

For pretty, hypertext, browser-based help:

```
   doc <funcname>
```

Look at the function!

```
   edit <funcname>
   type <funcname>
```

Online: Matlab Central:

```
 http://www.mathworks.com/matlabcentral/
```

And the user file exchange:

```
 http://www.mathworks.com/matlabcentral/fileexchange/
```

On the imaging wiki:

```
 http://imaging.mrc-cbu.cam.ac.uk/imaging/LearningMatlab
```

Email lists (e.g., imagers+, imagerstech)