Matlab Tutorial Code

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1 intro.m

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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Introduction to Matlab
% (adapted from http://www.stanford.edu/class/cs223b/matlabIntro.html)
%
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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% (1) Basics

% The symbol "%" is used to indicate a comment (for the remainder of
% the line).

% When writing a long Matlab statement that becomes to long for a
% single line use "..." at the end of the line to continue on the next
% line.  E.g.

A = [1, 2; ...
     3, 4];

% A semicolon at the end of a statement means that Matlab will not
% display the result of the evaluated statement. If the ";" is omitted
% then Matlab will display the result.  This is also useful for
% printing the value of variables, e.g.

A

% Matlab's command line is a little like a standard shell:
% - Use the up arrow to recall commands without retyping them (and
%   down arrow to go forward in the command history).
% - C-a moves to beginning of line (C-e for end), C-f moves forward a
%   character and C-b moves back (equivalent to the left and right
%   arrow keys), C-d deletes a character, C-k deletes the rest of the
%   line to the right of the cursor, C-p goes back through the
%   command history and C-n goes forward (equivalent to up and down
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%   arrows), Tab tries to complete a command.

% Simple debugging:
% If the command "dbstop if error" is issued before running a script
% or a function that causes a run-time error, the execution will stop
% at the point where the error occurred. Very useful for tracking down
% errors.



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% (2) Basic types in Matlab

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% (A) The basic types in Matlab are scalars (usually double-precision
% floating point), vectors, and matrices:

A = [1 2; 3 4];              % Creates a 2x2 matrix
B = [1,2; 3,4];              % The simplest way to create a matrix is
                             % to list its entries in square brackets.
                             % The ";" symbol separates rows;
                             % the (optional) "," separates columns.

N = 5                        % A scalar
v = [1 0 0]                  % A row vector
v = [1; 2; 3]                % A column vector
v = v'                       % Transpose a vector (row to column or
                             %   column to row)
v = 1:.5:3                   % A vector filled in a specified range:
v = pi*[-4:4]/4              %   [start:stepsize:end]
                             %   (brackets are optional)
v = []                       % Empty vector



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% (B) Creating special matrices: 1ST parameter is ROWS,
%   2ND parameter is COLS

m = zeros(2, 3)              % Creates a 2x3 matrix of zeros
v = ones(1, 3)               % Creates a 1x3 matrix (row vector) of ones
m = eye(3)                   % Identity matrix (3x3)
v = rand(3, 1)               % Randomly filled 3x1 matrix (column
                             % vector); see also randn

                             % But watch out:
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m = zeros(3)                  % Creates a 3x3 matrix (!) of zeros



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% (C) Indexing vectors and matrices.
% Warning: Indices always start at 1 and *NOT* at 0!

v = [1 2 3];
v(3)                          % Access a vector element


m = [1 2 3 4; 5 7 8 8; 9 10 11 12; 13 14 15 16]
m(1, 3)                       % Access a matrix element
                              %       matrix(ROW #, COLUMN #)
m(2, :)                       % Access a whole matrix row (2nd row)
m(:, 1)                       % Access a whole matrix column (1st column)

m(1, 1:3)                     % Access elements 1 through 3 of the 1st row
m(2:3, 2)                     % Access elements 2 through 3 of the
                              %   2nd column
m(2:end, 3)                   % Keyword "end" accesses the remainder of a
                              %   column or row

m = [1 2 3; 4 5 6]
size(m)                       % Returns the size of a matrix
size(m, 1)                    % Number of rows
size(m, 2)                    % Number of columns

m1 = zeros(size(m))           % Create a new matrix with the size of m

who                           % List variables in workspace
whos                          % List variables w/ info about size, type, etc.



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% (3) Simple operations on vectors and matrices

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% (A) Element-wise operations:

% These operations are done "element by element".  If two
% vectors/matrices are to be added, subtracted, or element-wise
% multiplied or divided, they must have the same size.

a = [1 2 3 4]';               % A column vector
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2 * a                        % Scalar multiplication
a / 4                        % Scalar division
b = [5 6 7 8]';              % Another column vector
a + b                        % Vector addition
a - b                        % Vector subtraction
a .^ 2                       % Element-wise squaring (note the ".")
a .* b                       % Element-wise multiplication (note the ".")
a ./ b                       % Element-wise division (note the ".")

log([1 2 3 4])               % Element-wise logarithm
round([1.5 2; 2.2 3.1])      % Element-wise rounding to nearest integer

% Other element-wise arithmetic operations include e.g. :
%   floor, ceil, ...


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% (B) Vector Operations
% Built-in Matlab functions that operate on vectors

a = [1 4 6 3]                % A row vector
sum(a)                       % Sum of vector elements
mean(a)                      % Mean of vector elements
var(a)                       % Variance of elements
std(a)                       % Standard deviation
max(a)                       % Maximum
min(a)                       % Minimum

% If a matrix is given, then these functions will operate on each column
%   of the matrix and return a row vector as result
a = [1 2 3; 4 5 6]           % A matrix
mean(a)                      % Mean of each column
max(a)                       % Max of each column
max(max(a))                  % Obtaining the max of a matrix
mean(a, 2)                   % Mean of each row (second argument specifies
                             %   dimension along which operation is taken)


[1 2 3] * [4 5 6]'           % 1x3 row vector times a 3x1 column vector
                             %   results in a scalar.  Known as dot product
                             %   or inner product.  Note the absence of "."

[1 2 3]' * [4 5 6]           % 3x1 column vector times a 1x3 row vector
                             %   results in a 3x3 matrix.  Known as outer
                             %   product.  Note the absence of "."
```

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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% (C) Matrix Operations:

a = rand(3,2)                % A 3x2 matrix
b = rand(2,4)                % A 2x4 matrix
c = a * b                    % Matrix product results in a 3x4 matrix

a = [1 2; 3 4; 5 6];         % A 3x2 matrix
b = [5 6 7];                 % A 1x3 row vector
b * a                        % Vector-matrix product results in
                             %   a 1x2 row vector
c = [8; 9];                  % A 2x1 column vector
a * c                        % Matrix-vector product results in
                             %   a 3x1 column vector

a = [1 3 2; 6 5 4; 7 8 9];   % A 3x3 matrix
inv(a)                       % Matrix inverse of a
eig(a)                       % Vector of eigenvalues of a
[V, D] = eig(a)              % D matrix with eigenvalues on diagonal;
                             %   V matrix of eigenvectors
                             %   Example for multiple return values!
[U, S, V] = svd(a)           % Singular value decomposition of a.
                             %   a = U * S * V', singular values are
                             %   stored in S

% Other matrix operations: det, norm, rank, ...


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% (D) Reshaping and assembling matrices:

a = [1 2; 3 4; 5 6];         % A 3x2 matrix
b = a(:)                     % Make 6x1 column vector by stacking
                             %   up columns of a
sum(a(:))                    % Useful:  sum of all elements

a = reshape(b, 2, 3)         % Make 2x3 matrix out of vector
                             %   elements (column-wise)

a = [1 2]; b = [3 4];        % Two row vectors
c = [a b]                    % Horizontal concatenation (see horzcat)

a = [1; 2; 3];               % Column vector
c = [a; 4]                   % Vertical concatenation (see vertcat)

a = [eye(3) rand(3)]         % Concatenation for matrices
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b = [eye(3); ones(1, 3)]

b = repmat(5, 3, 2)           % Create a 3x2 matrix of fives
b = repmat([1 2; 3 4], 1, 2) % Replicate the 2x2 matrix twice in
                             %   column direction; makes 2x4 matrix
b = diag([1 2 3])            % Create 3x3 diagonal matrix with given
                             %   diagonal elements



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% (4) Control statements & vectorization

% Syntax of control flow statements:
%
% for VARIABLE = EXPR
%     STATEMENT
%      ...
%     STATEMENT
% end
%
%   EXPR is a vector here, e.g. 1:10 or -1:0.5:1 or [1 4 7]
%
%
% while EXPRESSION
%     STATEMENTS
% end
%
% if EXPRESSION
%     STATEMENTS
% elseif EXPRESSION
%     STATEMENTS
% else
%     STATEMENTS
% end
%
%   (elseif and else clauses are optional, the "end" is required)
%
%   EXPRESSIONs are usually made of relational clauses, e.g. a < b
%   The operators are <, >, <=, >=, ==, ~=  (almost like in C(++))

% Warning:
%   Loops run very slowly in Matlab, because of interpretation overhead.
%   This has gotten somewhat better in version 6.5, but you should
%   nevertheless try to avoid them by "vectorizing" the computation,
%   i.e. by rewriting the code in form of matrix operations.  This is
%   illustrated in some examples below.
```

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% Examples:
for i=1:2:7                    % Loop from 1 to 7 in steps of 2
  i                            % Print i
end

for i=[5 13 -1]                % Loop over given vector
  if (i > 10)                  % Sample if statement
    disp('Larger than 10')     % Print given string
  elseif i < 0                 % Parentheses are optional
    disp('Negative value')
  else
    disp('Something else')
  end
end


% Here is another example: given an mxn matrix A and a 1xn
% vector v, we want to subtract v from every row of A.

m = 50; n = 10; A = ones(m, n); v = 2 * rand(1, n);
%
% Implementation using loops:
for i=1:m
  A(i,:) = A(i,:) - v;
end

% We can compute the same thing using only matrix operations
A = ones(m, n) - repmat(v, m, 1);   % This version of the code runs
                                    %   much faster!!!


% We can vectorize the computation even when loops contain
%   conditional statements.
%
% Example: given an mxn matrix A, create a matrix B of the same size
%   containing all zeros, and then copy into B the elements of A that
%   are greater than zero.

% Implementation using loops:
B = zeros(m,n);
for i=1:m
  for j=1:n
    if A(i,j)>0
      B(i,j) = A(i,j);
    end
  end
```

```
end

% All this can be computed w/o any loop!
B = zeros(m,n);
ind = find(A > 0);            % Find indices of positive elements of A
                              %   (see "help find" for more info)
B(ind) = A(ind);              % Copies into B only the elements of A
                              %   that are > 0



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%(5) Saving your work

save myfile                   % Saves all workspace variables into
                              %   file myfile.mat
save myfile a b               % Saves only variables a and b

clear a b                     % Removes variables a and b from the
                              %   workspace
clear                         % Clears the entire workspace

load myfile                   % Loads variable(s) from myfile.mat



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%(6) Creating scripts or functions using m-files:
%
% Matlab scripts are files with ".m" extension containing Matlab
% commands.  Variables in a script file are global and will change the
% value of variables of the same name in the environment of the current
% Matlab session.  A script with name "script1.m" can be invoked by
% typing "script1" in the command window.

% Functions are also m-files. The first line in a function file must be
% of this form:
% function [outarg_1, ..., outarg_m] = myfunction(inarg_1, ..., inarg_n)
%
% The function name should be the same as that of the file
% (i.e. function "myfunction" should be saved in file "myfunction.m").
% Have a look at myfunction.m and myotherfunction.m for examples.
%
% Functions are executed using local workspaces: there is no risk of
% conflicts with the variables in the main workspace. At the end of a
% function execution only the output arguments will be visible in the
% main workspace.
```

```
a = [1 2 3 4];                % Global variable a
b = myfunction(2 * a)         % Call myfunction which has local
                              %   variable a
a                             % Global variable a is unchanged

[c, d] = ...
  myotherfunction(a, b)       % Call myotherfunction with two return
                              % values


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%(7) Plotting

x = [0 1 2 3 4];              % Basic plotting
plot(x);                      % Plot x versus its index values
pause                         % Wait for key press
plot(x, 2*x);                 % Plot 2*x versus x
axis([0 8 0 8]);              % Adjust visible rectangle

figure;                       % Open new figure
x = pi*[-24:24]/24;
plot(x, sin(x));
xlabel('radians');            % Assign label for x-axis
ylabel('sin value');          % Assign label for y-axis
title('dummy');               % Assign plot title

figure;
subplot(1, 2, 1);             % Multiple functions in separate graphs
plot(x, sin(x));              %   (see "help subplot")
axis square;                  % Make visible area square
subplot(1, 2, 2);
plot(x, 2*cos(x));
axis square;

figure;
plot(x, sin(x));
hold on;                      % Multiple functions in single graph
plot(x, 2*cos(x), '--');      % '--' chooses different line pattern
legend('sin', 'cos');         % Assigns names to each plot
hold off;                     % Stop putting multiple figures in current
                              %   graph

figure;                       % Matrices vs. images
m = rand(64,64);
imagesc(m)                    % Plot matrix as image
colormap gray;                % Choose gray level colormap
```

```
axis image;                  % Show pixel coordinates as axes
axis off;                    % Remove axes



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%(8) Working with (gray level) images

I = imread('cit.png');        % Read a PNG image

figure
imagesc(I)                    % Display it as gray level image
colormap gray;

colorbar                      % Turn on color bar on the side
pixval                        % Display pixel values interactively
truesize                      % Display at resolution of one screen
                              %   pixel per image pixel
truesize(2*size(I))           % Display at resolution of two screen
                              %   pixels per image pixel

I2 = imresize(I, 0.5, 'bil'); % Resize to 50% using bilinear
                              %   interpolation
I3 = imrotate(I2, 45, ...textcolorcomment     % Rotate 45 degrees and crop to
              'bil', 'crop'); %   original size

I3 = double(I2);              % Convert from uint8 to double, to allow
                              %   math operations
imagesc(I3.^2)                % Display squared image (pixel-wise)
imagesc(log(I3))              % Display log of image (pixel-wise)
I3 = uint8(I3);               % Convert back to uint8 for writing
imwrite(I3, 'test.png')       % Save image as PNG

figure;
g = [1 2 1]' * [1 2 1] / 16;  % 3x3 Gaussian filter mask
I2 = double(I);               % Convert image to floating point
I3 = conv2(I2, g);            % Convolve image with filter mask
I3 = conv2(I2, g, 'same');    % Convolve image, but keep original size
subplot(1, 2, 1)              % Display original and filtered image
imagesc(I);                   %   side-by-side
axis square;
colormap gray;
subplot(1, 2, 2)
imagesc(I3);
axis square;
colormap gray;
```

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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

2 myfunction.m

```
function y = myfunction(x)
% Function of one argument with one return value

a = [-2 -1 0 1];              % Have a global variable of the same name
y = a + x;
```

3 myotherfunction.m

```
function [y, z] = myotherfunction(a, b)
% Function of two arguments with two return values

y = a + b;
z = a - b;
```