Introduction to MATLAB

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Outline

- Overview
- Start-up
- Matrix
- Programming
- Plotting figures
- Solve problems:
  - Polynomial regression
  - Numerical integration
Overview

- Matlab is a high-level language and interactive environment for numerical computation, visualization, and programming.
  - Analyze data.
  - Develop algorithms.
  - Create models and applications.

- Millions of engineers and scientists in industry and academia use Matlab.
- The language of technical computing.
Matlab graphical interface

- Command window
- Workspace
- Navigator
- Toolstrip
M-file

- An m-file, or script file, is a text file where you can place MATLAB commands.
- Save your work.
- Convenient for debugging.
- Run directly. No explicit compilation.
Matrix and vectors

- Matlab = Matirx laboratory
- Objects (e.g. data, text, color) in Matlab can be represented by matrices.

- **Scalar:**  
  \[ s = 5 \]

- **Vector:**  
  \[ a = [1 \ 2 \ 3] \quad \% \text{row vector} \]
  \[ a = [1, \ 2, \ 3] \quad \% \text{row vector} \]
  \[ a = 1:5 \quad \% \text{row vector} \]
  \[ b = [4; \ 5; \ 6] \quad \% \text{column vector} \]

**Matrix:**  
\[ A = [1 \ 2 \ 3; \ 4 \ 5 \ 6; \ 7 \ 8 \ 9] \]
\% Use the percent mark for comments.
\% Suppress output by adding a semicolon at the end of a command line.
- **Functions to create matrices**
  - `zeros(5,5)` % All zeros
  - `ones(5,5)` % All ones
  - `I=eye(5)` % Unit matrix
  - `rand(5,5)` % Uniformly distributed random elements, between 0 and 1.
  - `randn(5,5)` % Normally distributed random elements, with mean 0 and variance 1.
Vector operations:

- a+3  % add a scalar to a vector
- a+b  % element-by-element addition
- a-b  % element-by-element subtraction
- a*3  % multiply a vector and a scalar
- a.*b % element-by-element multiplication
- a*c  % dot product
- dot(a,c) % dot product
- a'   % transpose
Vector operations (continued)

- cross(a,b)  % cross product (only for vectors with 3 elements)
- pinv(a)     % Moore-Penrose pseudoinverse of a vector: a*pinv(a)=1
- a./b        % element-by-element division
- a/b         % equivalent to a*pinv(b)
- norm(b)     % norm
Matrix operations

- A+3 % a matrix plus a scalar
- A*3 % a matrix multiply a scalar
- A*a % a matrix multiplies a vector
- sin(A) % element-by-element sine of a matrix
- exp(A) % element-by-element exponential of a matrix
- A + B % matrix addition
- A*B % matrix multiplication
- A.*B % element-by-element multiplication.
Matrix operations (continued)

- A.^3  % element-by-element power
- A'    % transpose or complex conjugate transpose of a matrix
- inv(A) % inverse of a square matrix
- pinv(A) % Pseudoinverse of a non-square matrix, A*pinv(A)=eye or pinv(A)*A=eye
- A./B  % element-by-element division.
- A/B   % equivalent to A*inv(B)
- A\B  % backslash operator, returns inv(A)*B, with better performance.
- det(A) % determinant of a matrix
- isequal(A,B) % return 1 if A=B or 0 if otherwise.
Matrix indexing

Index starts from 1 (not from 0).

Column-major convention.

- $A(3,2)$  \hspace{1cm} \% the element of $3^{\text{rd}}$ row and $2^{\text{nd}}$ column
- $A(:,1)$  \hspace{1cm} \% the $1^{\text{st}}$ column
- $A(2,2:3)$  \hspace{1cm} \% through $2^{\text{nd}}$ to $3^{\text{rd}}$ elements of $2^{\text{nd}}$ row
- $\text{sum}(A(2,:))$  \hspace{1cm} \% sum all elements of the $2^{\text{nd}}$ row
- $\text{max}(A(3,:))$  \hspace{1cm} \% maximum element of the $3^{\text{rd}}$ row
- $\text{find}(\text{isprime}(A))$  \hspace{1cm} \% return the indexes of prime numbers among all elements
Cell array

- **Create a Cell Array**
  - `cell(size1, size2, ...)`  % Create a multidimensional cell array
  - `myCell = {2, [7 8 9], [1 2 3; 4 5 6]; 'text', rand(5,5), {11; 22; 33}}`  % Initialize a 2*3 cell array
  % The elements in a cell array can be of different types, for example, the element can be a number, a vector, a matrix, text, or itself can be a cell array too.

- **Access Data in a Cell Array**
  - `myCell{1,3}`  % The cell at the first row and the third column.
  - `myCell{2,1:2}`  % The first and second cells in the second row.
  - `myCell{1,:}`  % All cells in the first row.

- `iscell(myCell)`  % Determine whether input is cell array
Map Containers

- Object that maps values to unique keys. Corresponds to dictionary in Python or hash table in C.
- **Create a map container:** \( M = \text{containers.Map}(\text{keySet}, \text{valueSet}) \)

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**Example 1: uniform values**

- keys = {"Mon", "Tue", "Wed", "Thu", "Fri"};
- values = [80, 76, 71, 78, 85];
- \( M = \text{containers.Map}(\text{keys}, \text{values}) \)
- \( M.\text{Count} \% \text{Number of keywords} \)
- \( M(\text{"Wed"}) \% \text{Get value by keyword} \)
- \( M(\text{"Fri"}) = 89 \% \text{Modify value by keyword} \)
- \( M(\text{"Fri"}) \% \text{Get value by keyword} \)

**Example 2: non-uniform values**

- keys = {"key1", "key2", "key3"};
- \( v1 = 2; \% \text{Scalar} \)
- \( v2 = [1 \ 2; 3 \ 4] \% \text{Matrix} \)
- \( v3 = \text{"hello"} \% \text{Text} \)
- values = \{v1, v2, v3\} \% Use cell array as input
- \( M = \text{containers.Map}(\text{keys}, \text{values}, \ldots) \)
- 'UniformValues', false)
Exercise 1

Vector and matrix operations

i) Practice the vector operations listed above.
ii) Practice the matrix operations listed above.
iii) Practice the cell array operations listed above.
Language basics

- **Variables**
  
  No declaration of variables.

  - \( n = 25 \) \text{ % Integer}
  
  - \( a = 6.2 \) \text{ % Real number}
  
  - \text{firstword} = ‘Hello’ \text{ % Character array}
  
  - \text{secondword} = “world!” \text{ % String}

  - \text{exist name} \text{ % Check the existence of a name: 0 --- nonexistent; nonzero --- exist.}
  
  - \text{eps} \text{ % a built-in variable: Floating-point relative accuracy for double precision}
  
  - \text{realmax} \text{ % a built-in variable: Largest double-precision values}
  
  - \text{pi} \text{ % a built-in variable: the value of PI.}
- **Math expressions**
  - \( a^3 + b^2 - 3c + d/6 + 9 \)
  - \( \text{abs}(x) \quad \% \text{ absolute value} \)
  - \( \sin(x); \cos(x); \tan(x); \quad \% \text{ triangle functions} \)
  - \( \text{asin}(x); \text{acos}(x); \text{atan}(x); \text{atan2}(y, x); \quad \% \text{ inverse triangle functions} \)
  - \( \sqrt{x} \quad \% \text{ square root} \)
  - \( \exp(x) \quad \% \text{ exponential} \)
  - \( \log(x) \quad \% \text{ natural logarithm, inverse of } \exp(x) \)
  - \( \log10(x) \quad \% \text{ base-10 logarithm, inverse of } 10^x \)

- **Long statement**
  - \( s = 1 - 1/2 + 1/3 - 1/4 + 1/5 - 1/6 + 1/7 \ldots \quad \% \text{ use … to combine two lines} \)
    - \(- 1/8 + 1/9 - 1/10 + 1/11 - 1/12; \)
- **Complex number**
  - i % imaginary unit
  - j % imaginary unit
  - sqrt(-1) % imaginary unit
  - x=3+4i % complex number
  - x=complex(a,b) % real part is a, imaginary part is b
  - real(x) % real part of x
  - imag(x) % imaginary part of x
  - angle(x) % argument of x
  - abs(x) % amplitude of x
  - conj(x) % conjugate of x
  - isreal(x) % x is real or not
Condition — if, else

\[
a = \text{randi}(100, 1); \quad \% \text{ get a random integer between 1 and 100}
\]

if \(a < 30\)

\[
\text{fprintf}(\text{"\%d is smaller than 30. \n", } a); \quad \% \text{ print data in integer format}
\]

elseif \(a > 80\)

\[
\text{fprintf}(\text{"\%d is larger than 80. \n", } a);
\]

else

\[
X = \text{num2str}(a, \text{" is between 30 and 80.\'}); \quad \% \text{ a matrix with string elements}
\]

\[
\text{disp}(X) \quad \% \text{ display the matrix}
\]
end
Loop — for

% sum of an array
s=0;
b=rand(100,1)
for i = 1:1:100
    s=s+b(i); % Invalid: +=
end

s

% nested loop
m=50;
n=100;
for i = 1:1:m % stride=1
    for j = 1:2:n % stride=2
        H(i, j) = 1/(i+j);
    end
end
end
Loop — while, break

% find a root of the cubic polynomial $x^3 - 2x - 5$

a = 0; fa = -Inf;
b = 3; fb = Inf;
while b - a > eps * b
    x = (a + b) / 2;
    fx = x^3 - 2*x - 5;
    if fx == 0
        break % Already found the root, exit the loop
    elseif sign(fx) == sign(fa)
        a = x; fa = fx;
    else
        b = x; fb = fx;
    end
end
x
Programming II : Functions

- Anonymous Function: one-line expression
  
  \[ f = @(\text{arglist}) \text{ expression} \]

- One argument
  
  ```
  my_fun = @(x) x.^2 + \exp(x) + 5;
  my_fun(5)
  ```

- Two arguments
  
  ```
  my_fun = @(x,y) x.^3 + 6*\text{sqrt}(y);
  my_fun(3,4)
  ```
Function:

function y = my_fun(x)

% Code for a function. File name should be the same as function name.
function height = falling(t)
    global GRAVITY
    height = 1/2*GRAVITY*t.^2;  % Calculate the height of a freely falling object
end

% Code for main program. The main script should be in the same directory of the function script, otherwise use the function addpath to add the path to the function script.

global GRAVITY
GRAVITY = 32;
y = falling((0:.1:5)')
Programming III: Import and export files

- Import data from an external file
  
  % Matlab format
  var2 = load('filename.mat', 'var1')

  % Text format
  var2 = dlmread('filename.txt')

  % MS Excel format
  var2 = xlsread('filename.xlsx')

- Export data to an external file
  
  % Matlab format
  save('filename.mat', 'var1')

  % Text format
  dlmwrite('filename.txt', var1, delimiter)

  % MS Excel format
  xlswrite('filename.xlsx', var1)
An example: import and export data

```matlab
x=rand(10);
save('test.mat', 'x') % Export data in MATLAB format
a=load('test.mat') % Import data in MATLAB format
a.x % Print the imported data
clear x % Clear the variable
load('test.mat', 'x') % Import data in MATLAB format
x % Print the imported data

dlmwrite('test.txt', x, '\t') % Export data in text format
c=dlmread('test.txt') % Import data in text format
```
- Output data using the `fprintf` function

```matlab
x = 0:.1:1;
A = [x; exp(x)];

fileID = fopen('exp.txt', 'w');  % open a writable file
fprintf(fileID, '%6.2f %12.8f\n', A);  % print real numbers
fclose(fileID);  % close the file

B=load('exp.txt', '-ascii')  % load data from the file
```
Two ways to plot figures: mouse-operation vs. scripting.

```matlab
% plot
x = 0:pi/100:4*pi;
y = sin(x);
y2 = cos(x);
plot(x,y,'black',x,y2,'red--','linewidth',2)
xlabel('x')
ylabel('y')
axis([0 4*pi -1 1])
title('Plot of Sine and Cosine Functions', ...
'FontSize', 12)
legend('sin(x)','cos(x)')
```
Plotting three-dimensional curves

diamond `plot3`

t = 0:pi/50:10*pi; \quad % z
st = sin(t); \quad \% x
c t = cos(t); \quad \% y

figure
plot3(st,ct,t)
Contour Plot

- **contour, pcolor**

% Obtain data from peaks function
[x,y,z] = peaks;
% Create pseudocolor plot
pcolor(x,y,z)
% Smooth the colors
shading interp
% Hold the current graph
hold on
% Add the contour graph to the pcolor graph
contour(x,y,z,15,'k')  % 15-level, black line
% Return to default
hold off
Subfigures and layout

◊ subplot, mesh

\[ t = 0:\pi/10:2*\pi; \]
\% cylinder with a self-defined profile
\[ [X,Y,Z] = \text{cylinder}(4*\cos(t)); \]
subplot(2,2,1); \% left-up
mesh(X)
subplot(2,2,2); \% right-up
mesh(Y)
subplot(2,2,3); \% left-down
mesh(Z)
subplot(2,2,4); \% right-down
mesh(X,Y,Z)
Color Surface Plot

- surfc

\[ [X, Y] = \text{meshgrid}(-8:.5:8); \]
\[ R = \sqrt{X.^2 + Y.^2} + \text{eps}; \]
\[ Z = \sin(R) / R; \quad \% \text{sinc function} \]
\[ \text{surf}(X, Y, Z) \]
\[ \text{colormap hsv} \quad \% \text{color map} \]
\[ \text{colorbar} \quad \% \text{show color scaling} \]
\[ \text{view}([1 1 1]) \quad \% \text{view angle} \]
◊ Color is represented by a vector

Red \[1 \ 0 \ 0\]
Green \[0 \ 1 \ 0\]
Blue \[0 \ 0 \ 1\]
Black \[0 \ 0 \ 0\]
White \[1 \ 1 \ 1\]

A user-defined color \[0.2 \ 0.3 \ 0.5\]

◊ View angle is represented by a vector

From x axis \[1 \ 0 \ 0\]
From y axis \[0 \ 1 \ 0\]
From z axis \[0 \ 0 \ 1\]
From diagonal line \[1 \ 1 \ 1\]
Use Matlab to solve mathematical problems

✓ Polynomial regression (statistics)
✓ Numerical integration (calculus)
Polynomial Regression

- Given a set of data $x$ and $y$, predict $p$ coefficients $b_0$, $b_1$, $b_2$, ..., $b_p$, to best fit the data set with the $p$-th order polynomial $y = b_0 + b_1 \cdot x + b_2 \cdot x^2 + ... + b_p \cdot x^p$.
- Least squares fitting

$$b = \text{regress}(y, X)$$

% Return the predicted values of the coefficients $b_0$, $b_1$, $b_2$, ..., $b_p$.
% $y$ and $X$ are input data.
% $y$ is a length-$n$ vector
% $X$ is an $n$-by-$p$ matrix: [ones, $x$, $x$.^2, ..., $x$.^p].

lsline % Plot the predicted (linear least-squares) line.
Linear regression

Create a set of raw data $x$ and $y$, then predict the slope $b_1$ and the intercept $b_0$ to fit the data set with the linear equation $y = b_0 + b_1 \cdot x$.

n=100; % Problem size
x = rand(n,1)*10; % Create random data x between 0 and 10
beta0 = 4.; % Give an intercept value to create data y
beta1 = 2.5; % Give a slope value to create data y
noise = randn(n,1); % Create normally distributed noise for data y
y = beta0 + beta1 * x + noise; % Create raw data points that are in the vicinity of a straight line.
plot(x,y,'.') % Plot the raw data
lsline % Plot the predicted (least-squares) line.
X = [ones(size(x)) x]; % Prepare the input matrix for the regress function. Add ones to obtain $b_0$.
b = regress(y, X) % Return the predicted values of the intercept $b_0$ and the slope $b_1$. 
Exercise 2

- Quadratic polynomial regression
  i) Create random x-y data that are in the vicinity of a quadratic curve.
  ii) Predict coefficients $b_0$, $b_1$, and $b_2$ to fit the data set with the quadratic polynomial $y = b_0 + b_1 \times x + b_2 \times x^2$. (Hint: use the `regress` function)
  iii) Plot the x-y data points and the fitting curve. (Hint: use the `plot` function)
Numerical integration

◊ One-dimensional integration

\[ q = \text{integral}(\text{fun}, \text{xmin}, \text{ xmax}) \]

% approximates the integral of function from \text{xmin} to \text{ xmax} using global adaptive quadrature and default error tolerances.

\[ \text{fun} = @(x) \exp(-x.^2) \times \log(x).^2; \quad \% \text{define a function} \quad f(x) = e^{-x^2} [\ln(x)]^2 \]

\[ p = \text{integral}(\text{fun}, 0, 0.5) \quad \% \text{proper integral} \]

\[ q = \text{integral}(\text{fun}, 0, \text{Inf}) \quad \% \text{improper integral} \]

\[ \text{fun} = @(x) \log(x); \quad \% \text{logarithm function} \]

\% output long digits

\[ \text{format long} \]

\[ q = \text{integral}(\text{fun}, 0, 1) \quad \% \text{integral with singularity at the lower limit} \]
Exercise 3

◊ Plot a 3D curve and compute the length of the curve

Consider the curve parameterized by the following equations:

\[ x(t) = \sin(2t), \quad y(t) = \cos(t), \quad z(t) = t, \]

where \( t \in [0, 3\pi] \).

i) Create a three-dimensional plot of this curve. (Hints: use the `plot3` function.)

ii) Compute the arc length of this curve. (Hints: Use the following arc length formula.)

\[
\int_{0}^{3\pi} \sqrt{4 \cos(2t)^2 + \sin(t)^2 + 1} \, dt.
\]
References

- Matlab: Primer
- Matlab: Programming Fundamentals
- Matlab: Mathematics
- Matlab basics on BU Research Computing Services (RCS) web site:
  http://www.bu.edu/tech/support/research/software-and-programming/common-languages/matlab/
- RCS help: help@scc.bu.edu, shaohao@bu.edu