MATLAB® Introduction

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Course Information

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- Getting started with MATLAB®:
  - Official user guide: https://www.mathworks.com/help/pdf_doc/matlab/getstart.pdf
  - https://matlabacademy.mathworks.com/ (Recommended Tutorial)
  - https://ubcmatlabguide.github.io/

Lecture Overview

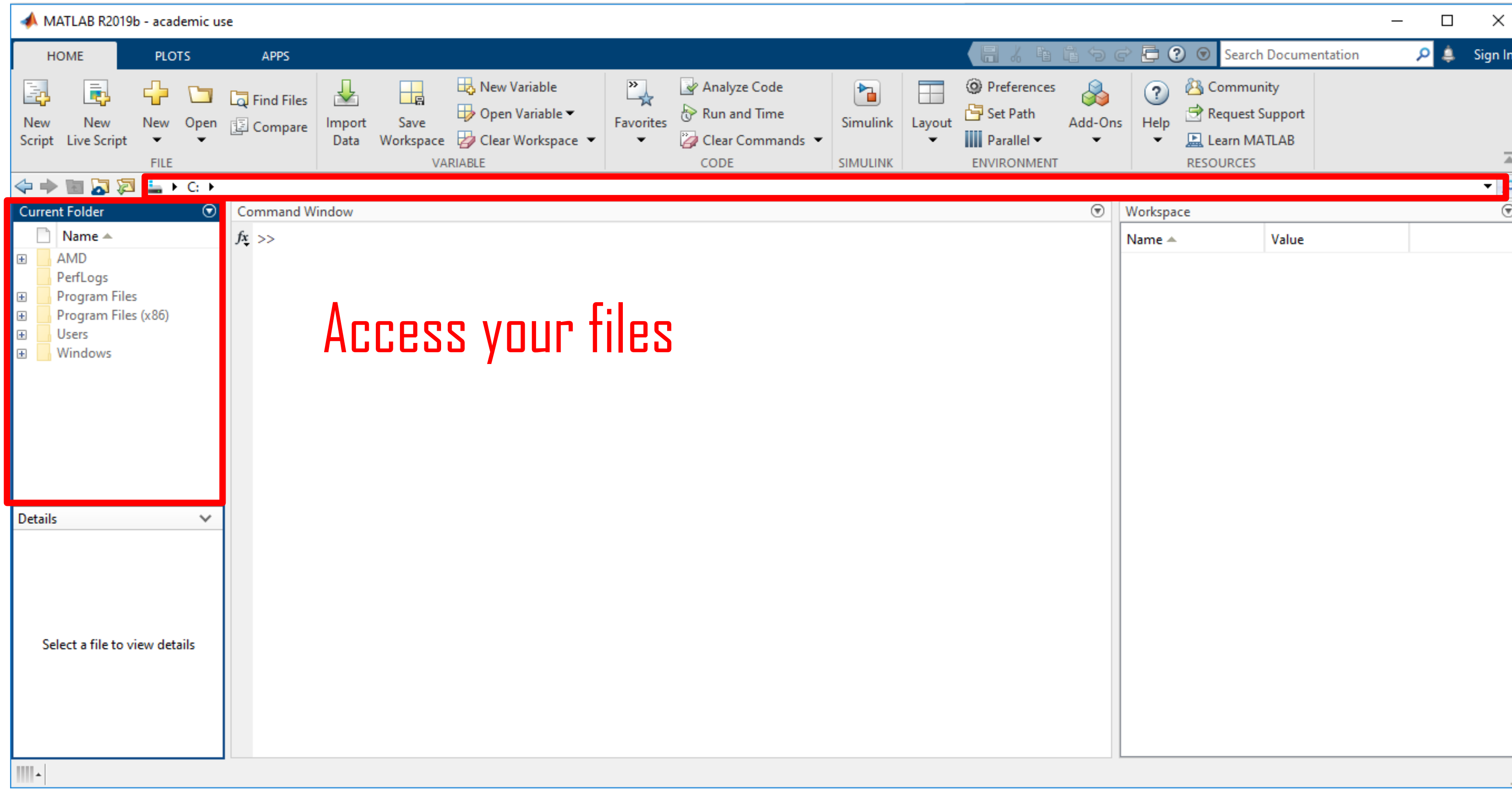
- What is MATLAB®
- MATLAB® default Layout, help and documentation
- Basic MATLAB® Commands and operations
- Basic MATLAB® functions + defining functions
- Visualizing Data
- Dynamical system simulation
  - Implementation of ode45 functions
  - Data visualization

What is MATLAB®

- Programming environment and a high-level language.
- Suitable for numerical computations, especially computations involving Matrix operations and linear algebra.
- Excellent support for data visualization.
- Comprises multiple toolkits, e.g., Optimization, Signal Processing, Image Processing, System Identification and much more.

MATLAB® Layout

- Default layout



MATLAB® Layout

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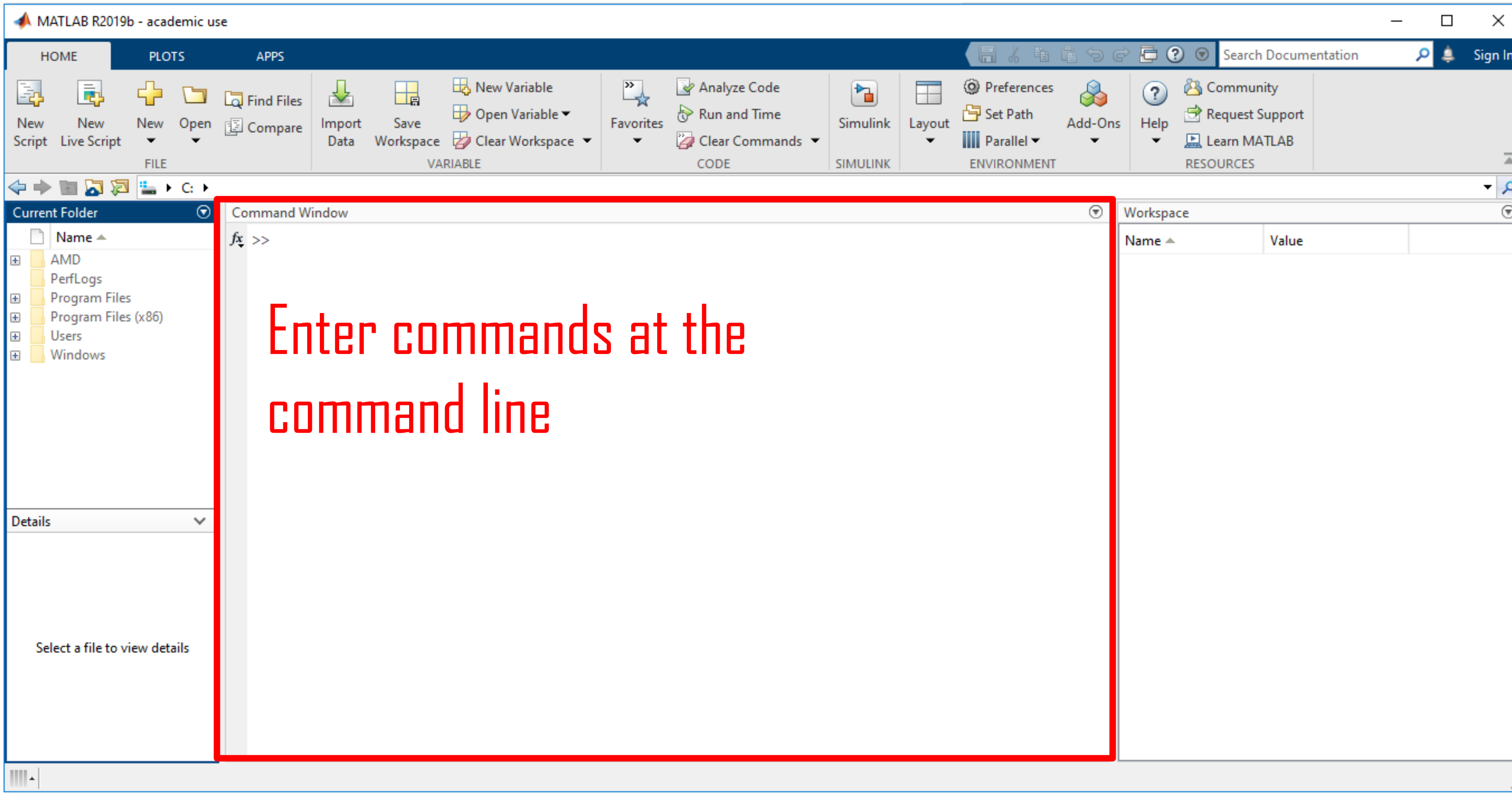

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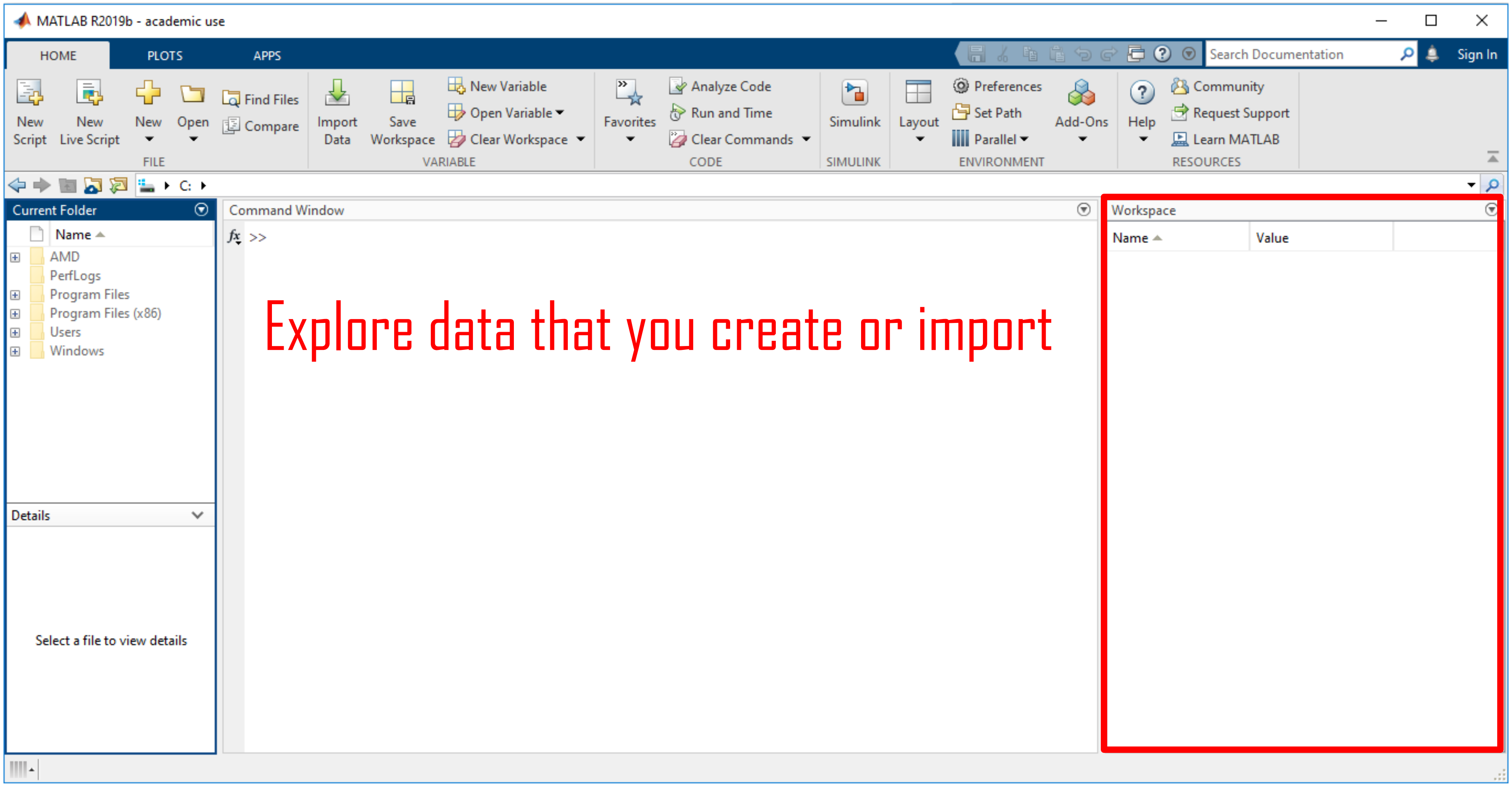

Matlab Layout

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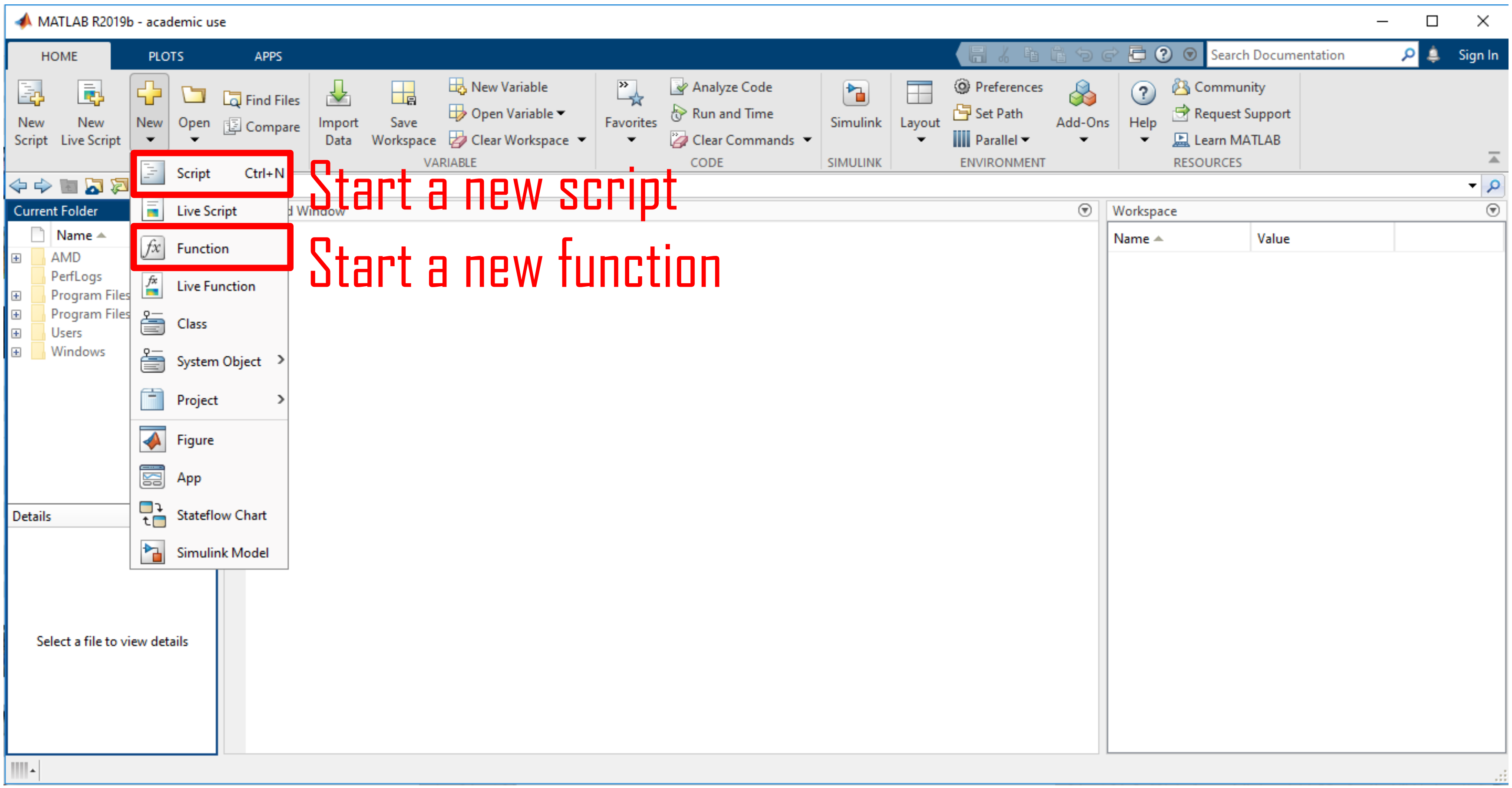

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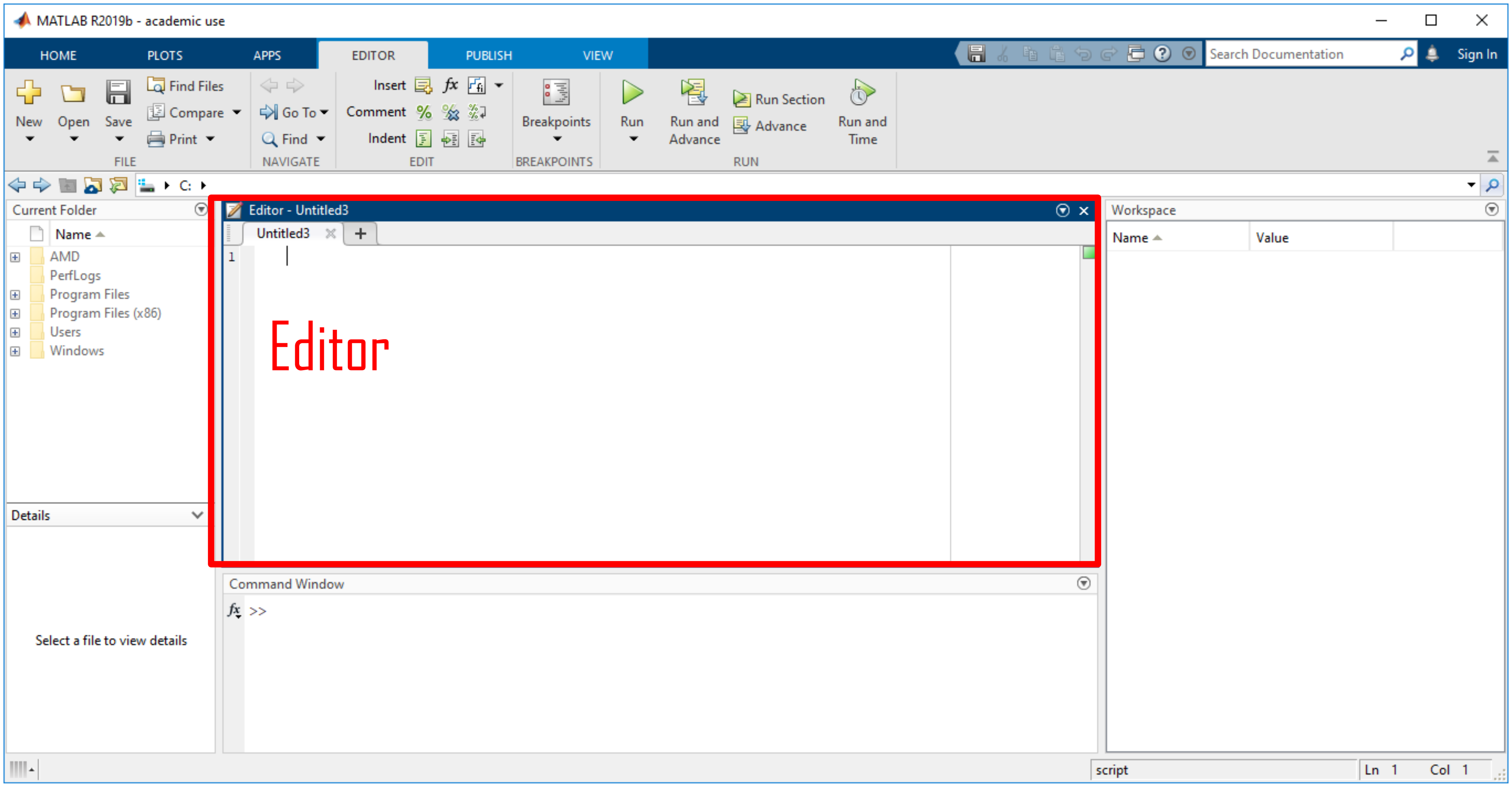
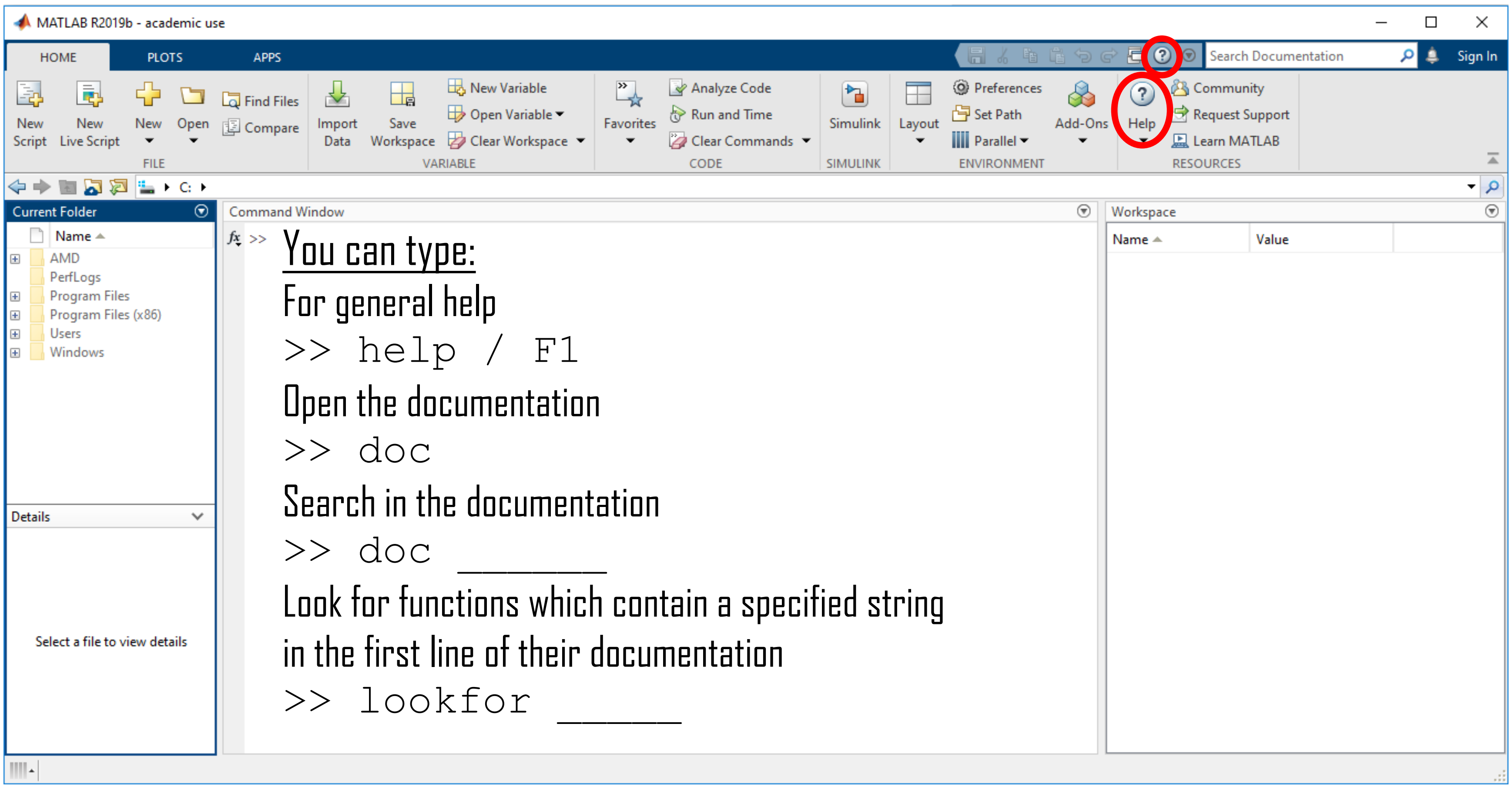
- Default layout



Help and Documentation



<u>You can type:</u>

For general help

```
>> help / F1
```

Open the documentation

```
>> doc
```

Search in the documentation

```
>> doc _______
```

Look for functions which contain a specified string in the first line of their documentation

```
>> lookfor _____
```

Basic MATLAB® Commands and operations (Command line / Editor)

- MATLAB® supports Arrays comprising real, imaginary and complex numbers.
- Mathematical operations can be used elementwise or using Tensor algebra, e.g.,:

Command Window

```
>> A = [1 2; 3+1i 7.5]

A =

   1.0000 + 0.0000i   2.0000 + 0.0000i
   3.0000 + 1.0000i   7.5000 + 0.0000i

>> B = [6 25; 7-9j -1i];
>> A.^2

ans =

   1.0000 + 0.0000i   4.0000 + 0.0000i
   8.0000 + 6.0000i  56.2500 + 0.0000i

>> A^2

ans =

   7.0000 + 2.0000i  17.0000 + 0.0000i
  25.5000 + 8.5000i  62.2500 + 2.0000i
```

Defining a matrix

Defining a matrix

Suppressing the output using a semicolon ";"

```
>> A*B

ans =

  20.0000 -18.0000i  25.0000 - 2.0000i
  70.5000 -61.5000i  75.0000 +17.5000i

>> A.*B

ans =

   6.0000 + 0.0000i  50.0000 + 0.0000i
  30.0000 -20.0000i   0.0000 - 7.5000i
```

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>> A^2

ans =

   7.0000 + 2.0000i  17.0000 + 0.0000i
  25.5000 + 8.5000i  62.2500 + 2.0000i
```

$$A.\hat{}2 = \begin{pmatrix} a_{11}^2 & a_{12}^2 \\ a_{21}^2 & a_{22}^2 \end{pmatrix}$$

$$A\hat{}2 = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} = \begin{pmatrix} a_{11}a_{11} + a_{12}a_{21} & a_{11}a_{12} + a_{12}a_{22} \\ a_{21}a_{11} + a_{22}a_{21} & a_{21}a_{12} + a_{22}a_{22} \end{pmatrix}$$

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>> A*B

ans =

  20.0000 -18.0000i  25.0000 - 2.0000i
  70.5000 -61.5000i  75.0000 +17.5000i

>> A.*B

ans =

   6.0000 + 0.0000i  50.0000 + 0.0000i
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```

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>> B = [6 25; 7-9j -1i];
>> A.^2

ans =

   1.0000 + 0.0000i   4.0000 + 0.0000i
   8.0000 + 6.0000i  56.2500 + 0.0000i

>> A^2

ans =

   7.0000 + 2.0000i  17.0000 + 0.0000i
  25.5000 + 8.5000i  62.2500 + 2.0000i
```

```
>> A*B

ans =

  20.0000 -18.0000i  25.0000 - 2.0000i
  70.5000 -61.5000i  75.0000 +17.5000i
```

$$\mathrm{A}*\mathrm{B}=\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}\begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix}$$

```
>> A.*B

ans =

   6.0000 + 0.0000i  50.0000 + 0.0000i
  30.0000 -20.0000i   0.0000 - 7.5000i
```

$$\mathrm{A}.*\mathrm{B}=\begin{pmatrix} a_{11}b_{11} & a_{12}b_{12} \\ a_{21}b_{21} & a_{22}b_{22} \end{pmatrix}$$

Basic MATLAB® Commands and operations (Command / Editor)

- MATLAB® supports Arrays comprising real, imaginary, and complex numbers.
- Mathematical operations can be used elementwise or using Tensor algebra, e.g.,
- **Array indices in MATLAB® start with 1, not 0 as in most programming languages.**

```
C =

    16     2     3    13
     5    11    10     8
     9     7     6    12
     4    14    15     1

>> C(1,3)

ans =

     3

>> C(:,end)

ans =

    13
     8
    12
     1
```

```
>> C([1 4],[2 3])

ans =

     2     3
    14    15

>> C([1 4],2:4)

ans =

     2     3    13
    14    15     1
```

C =

	1	2	3	4/end
1	16	2	3	13
2	5	11	10	8
3	9	7	6	12
4/end	4	14	15	1

Basic MATLAB® Commands and operations (Command / Editor)

- MATLAB® supports Tensors and Arrays comprising real, imaginary and complex numbers.
- Mathematical operations can be used elementwise or using Tensor algebra, e.g.,
- Array (matrix) indices in MATLAB® starts with 1 , not 0 as in most programming languages.
- Allowed Names of variables/ functions/ files:
  - Names consist of letters, followed by any number of letters, digits, or underscores. MATLAB® is case-sensitive; it distinguishes between uppercase and lowercase letters. `A` and `a` are not the same variable.
  - Stored function names can be overridden; however, it is advised to avoid the latter.

Basic MATLAB® Commands and operations (Command / Editor)

- Generate a vector:

```
>> a = 1:10

a =

     1     2     3     4     5     6     7     8     9    10

>> a = 1:2:10

a =

     1     3     5     7     9

>> a = linspace(1,10,10)

a =

     1     2     3     4     5     6     7     8     9    10

>> a = linspace(1,10,4)

a =

     1     4     7    10
```

1 to 10, spacing: 1

1 to 10, spacing: 2

1 to 10, 10 elements

1 to 10, 4 elements

It also possible to generate logarithmic spacing using `Logspace`

Vectors of zeroes or ones using
`zeros`
`ones`

Basic MATLAB® Commands and operations (Command / Editor)

- Transpose, Hermitian transpose and matrix manipulations

```
C =

   8.0000 +17.0000i   1.0000 +24.0000i   6.0000 + 1.0000i
   3.0000 +23.0000i   5.0000 + 5.0000i   7.0000 + 7.0000i
   4.0000 + 4.0000i   9.0000 + 6.0000i   2.0000 +13.0000i

>> C'
```

Hermitian transpose = Transpose + complex conjugate

```
ans =

   8.0000 -17.0000i   3.0000 -23.0000i   4.0000 - 4.0000i
   1.0000 -24.0000i   5.0000 - 5.0000i   9.0000 - 6.0000i
   6.0000 - 1.0000i   7.0000 - 7.0000i   2.0000 -13.0000i

>> C.'

ans =
```

Transpose

```
   8.0000 +17.0000i   3.0000 +23.0000i   4.0000 + 4.0000i
   1.0000 +24.0000i   5.0000 + 5.0000i   9.0000 + 6.0000i
   6.0000 + 1.0000i   7.0000 + 7.0000i   2.0000 +13.0000i
```

Basic MATLAB® Commands and operations (Command / Editor)

- Transpose, Hermitian transpose and matrix manipulations

```
C =

   8.0000 +17.0000i   1.0000 +24.0000i   6.0000 + 1.0000i
   3.0000 +23.0000i   5.0000 + 5.0000i   7.0000 + 7.0000i
   4.0000 + 4.0000i   9.0000 + 6.0000i   2.0000 +13.0000i
```

Flip up down

```
>> flipud(C)

ans =

   4.0000 + 4.0000i   9.0000 + 6.0000i   2.0000 +13.0000i
   3.0000 +23.0000i   5.0000 + 5.0000i   7.0000 + 7.0000i
   8.0000 +17.0000i   1.0000 +24.0000i   6.0000 + 1.0000i
```

Flip left right

```
>> fliplr(C)

ans =

   6.0000 + 1.0000i   1.0000 +24.0000i   8.0000 +17.0000i
   7.0000 + 7.0000i   5.0000 + 5.0000i   3.0000 +23.0000i
   2.0000 +13.0000i   9.0000 + 6.0000i   4.0000 + 4.0000i
```

Rotate by 3*90 deg CCW

```
>> rot90(C,3)

ans =

   4.0000 + 4.0000i   3.0000 +23.0000i   8.0000 +17.0000i
   9.0000 + 6.0000i   5.0000 + 5.0000i   1.0000 +24.0000i
   2.0000 +13.0000i   7.0000 + 7.0000i   6.0000 + 1.0000i
```

Functions

- Basic useful functions
  - `clc` – clears the command window
  - `clear` – clears the workspace (i.e., delete all variables and stored data)
  - `close all` – close all Figures
  - `save _______` - saves the workspace as : ____.mat
  - `load ______` - loads a saved workspace or a data file
- For more information on a function, e.g.,

```
>> doc linspace
```

Functions

- Anonymous Functions

"An anonymous function is a function that is not stored in a program file, but is associated with a variable whose data type is function_handle. Anonymous functions can accept inputs and return outputs, just as standard functions do. However, they can contain only a single executable statement."

- Syntax:

```
function_handle = @(input1, input2, …) expression;
```

- `function_handle:` Variable that holds the reference to the anonymous function.
- `@(input1, input2,…):` Defines the input parameters to the anonymous function.
- `expression:` Mathematical expression or operation that the function performs.

Functions

For example, single variable:

```
a = 1.3;
b = .2;
c = 30;
parabola = @(x) a*x.^2 + b*x + c;
>> parabola(1)
ans = 31.5000
```

For example, multiple variables (Pay attention to elementwise vs. matrix algebra):

```
x = 1:3;
y = 10:12;
myFuncEW = @(x,y) a*x.^2 + b*x.*y + c*y;
myFuncMA = @(x,y) a*(x*y).^2 + b*(x*y) + c;

>> myFuncEW(x,y)
ans = 303.3000  339.6000  378.9000

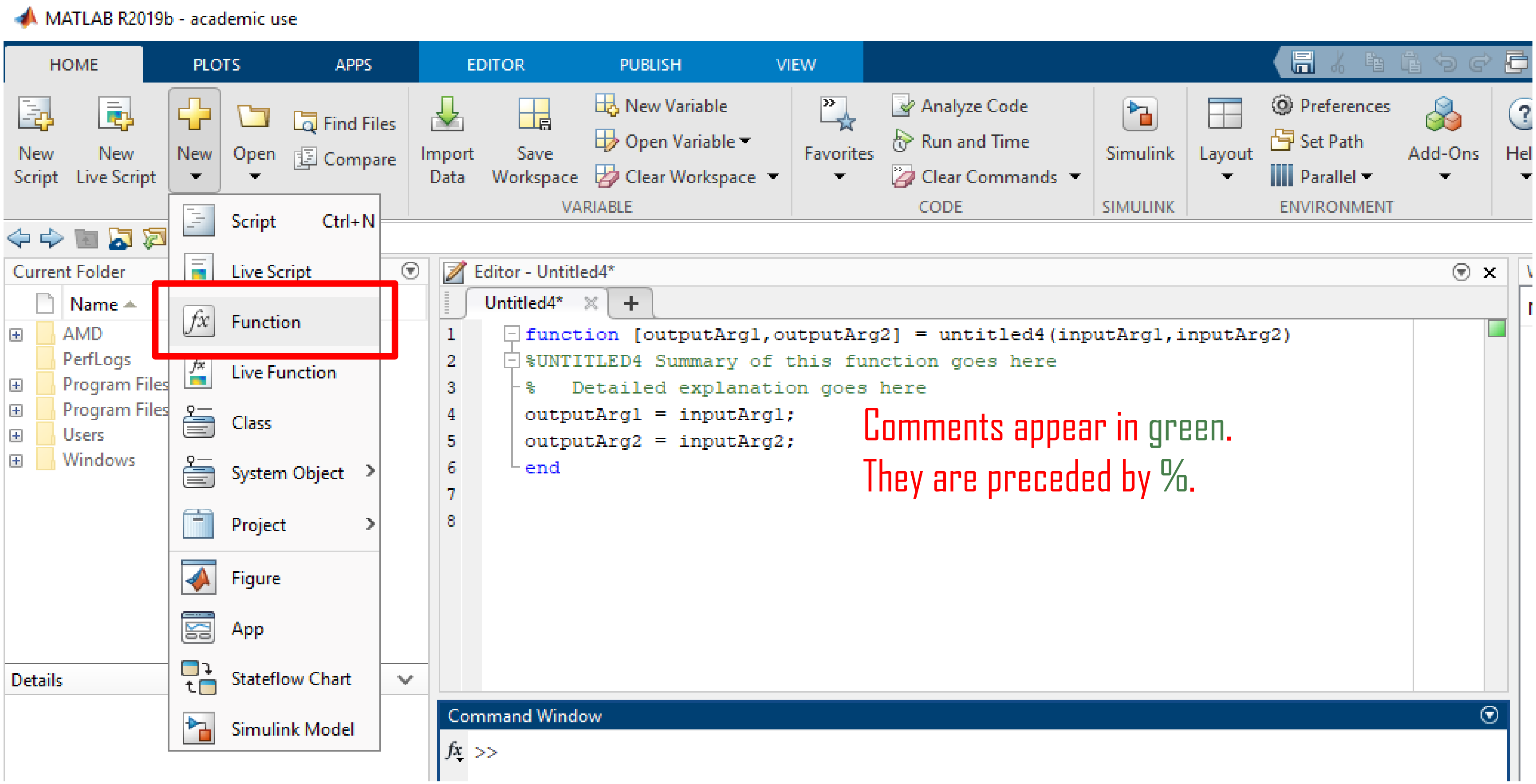
>> myFuncMA(x,y.')
ans = 6.0548e+03
```

```
>> myFuncMA(x.',y)
ans =
1.0e+03 *

    0.1620    0.1895    0.2196
    0.5540    0.6636    0.7836
    1.2060    1.4523    1.7220
```

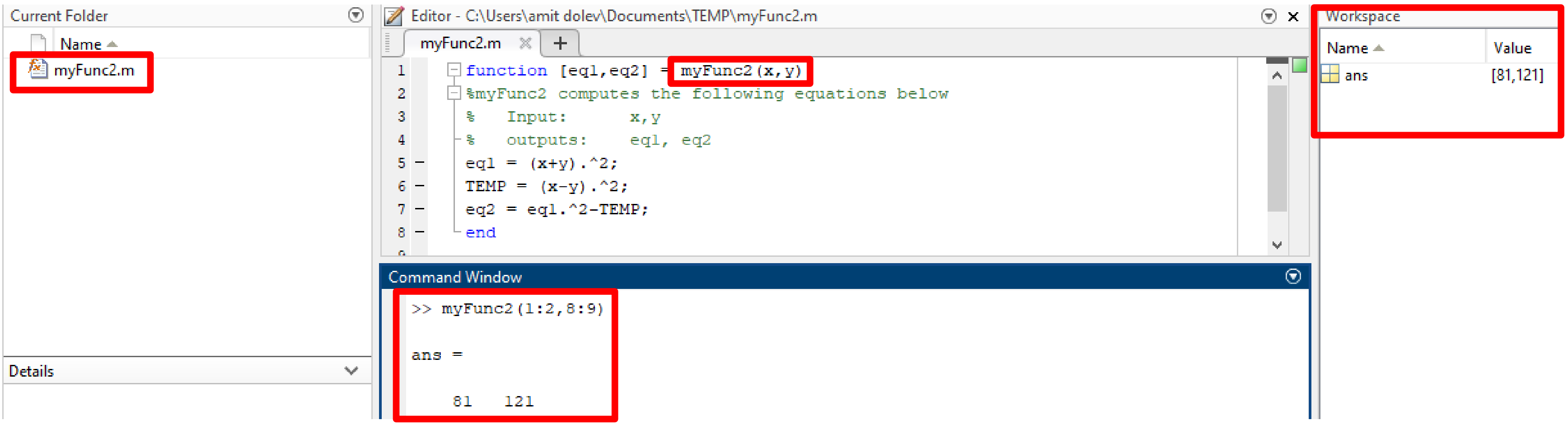
Functions

- Function



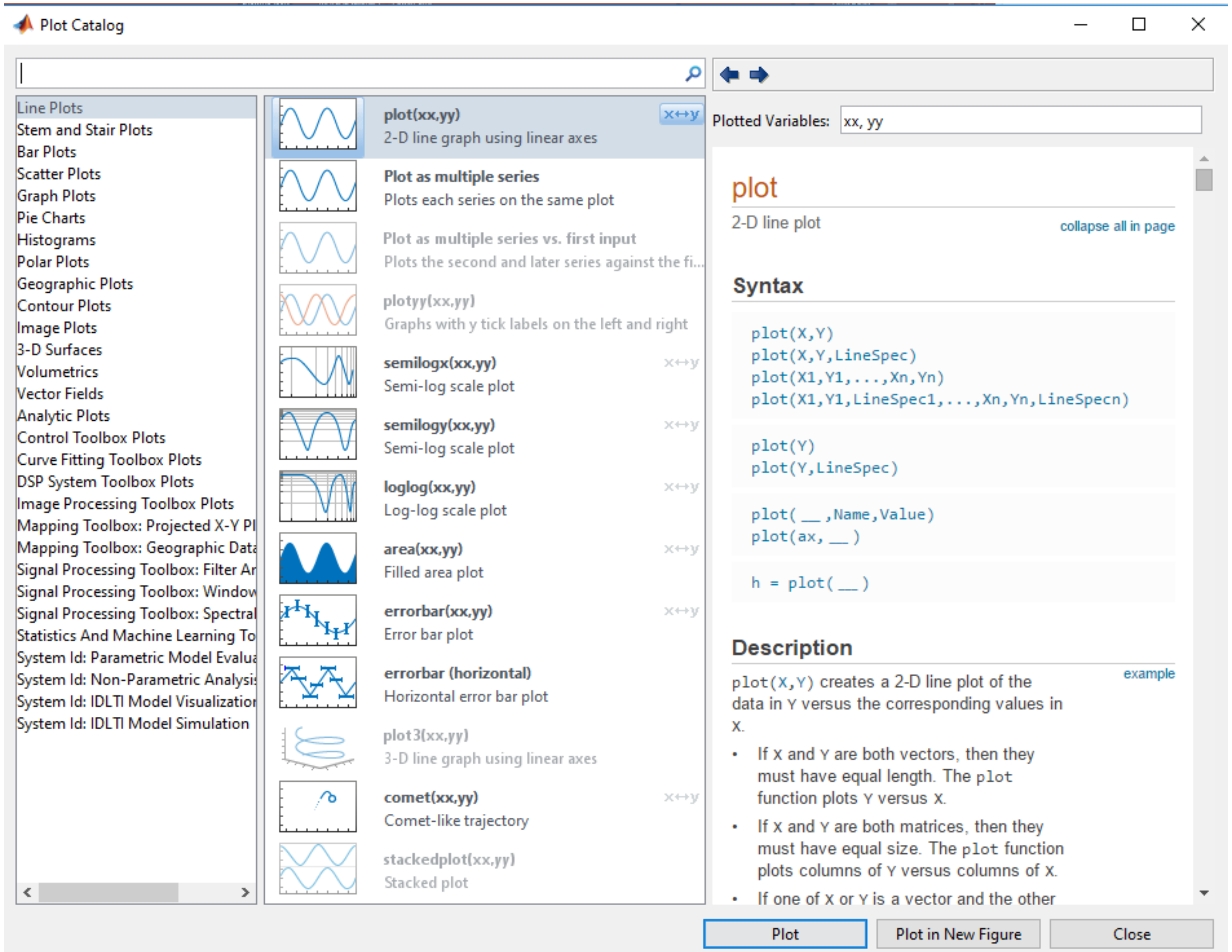
Functions

- Function



Visualizing data

- There are many built in MATLAB® functions for data visualization



Visualizing data

- Stage 1: open a figure

```
>> figure(1)
```

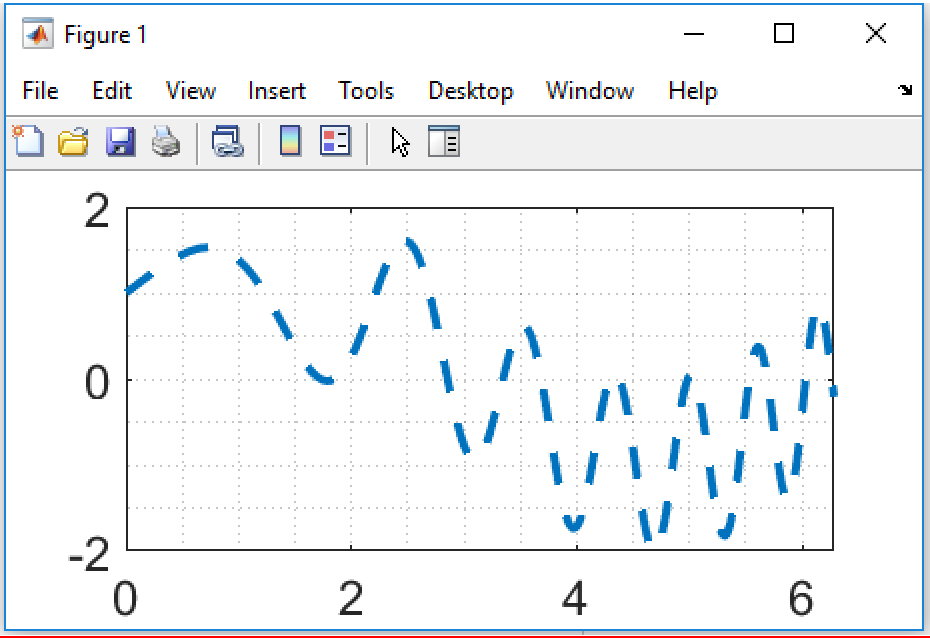
- Stage 2: plot the data (h is a plot handle)

```
>>  h = plot(xx,yy)
```

- Edit the plot and axes

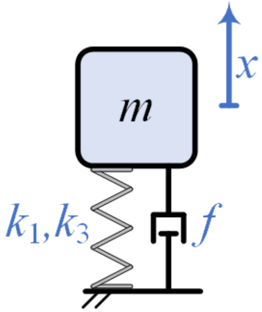
```
xx = linspace(0,2*pi,1e3);
yy = sin(xx)+cos(xx.^2);

figure(1)
h = plot(xx,yy);
set(h,'linewidth',3,'linestyle','--');
grid minor
set(gcf,'color','w')
set(gca,'fontsize',18)
```



Dynamic simulations

- A dynamical system can be represented as an ordinary differential equation (ODE). For example a damped nonlinear spring, mass system:



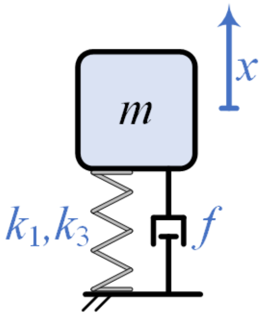
$$m\ddot{x} + f\dot{x} + k_1 x + k_3 x^3 = 0$$

- There are various ode solvers in MATLAB®. Throughout the course the function `ode45`, which implements Runge-Kutta will be used.
- Compute the system's response to the initial conditions:
  - A) $x(0) = 0.001, \dot{x}(0) = 0$
  - B) $x(0) = 10, \dot{x}(0) = 0$
- For the parameters:

$$m = 1, \quad f = 0.6, \quad k_1 = 100, \quad k_3 = 5.$$

Dynamic simulations

- Stage 1: Prepare the equation for implementation in MATLAB®
  - MATLAB ODE solvers only solve first-order equations.
  - Re-write higher-order ODEs as an equivalent system of first-order equations using the following substitutions:



$$z_1 = x$$
$$z_2 = \dot{x}$$
$$z_3 = \ddot{x}$$
$$\vdots$$
$$z_n = x^{(n-1)}$$

  - We get for our example:

$$m\ddot{x} + f\dot{x} + k_1 x + k_3 x^3 = 0$$

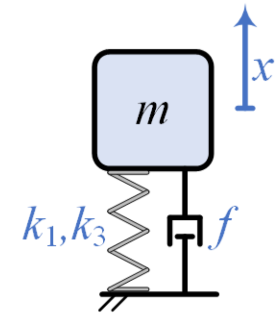
$$\mathbf{z} = \begin{pmatrix} z_1 \\ z_2 \end{pmatrix} = \begin{pmatrix} x \\ \dot{x} \end{pmatrix}, \quad \dot{\mathbf{z}} = \begin{pmatrix} \dot{z}_1 \\ \dot{z}_2 \end{pmatrix} = \begin{pmatrix} z_2 \\ -\left(f z_2 + k_1 z_1 + k_3 z_1^3 \right) / m \end{pmatrix}$$

Dynamic simulations

- Stage 1: Prepare the equation for implementation in MATLAB®

$$m\ddot{x} + f\dot{x} + k_1 x + k_3 x^3 = 0$$

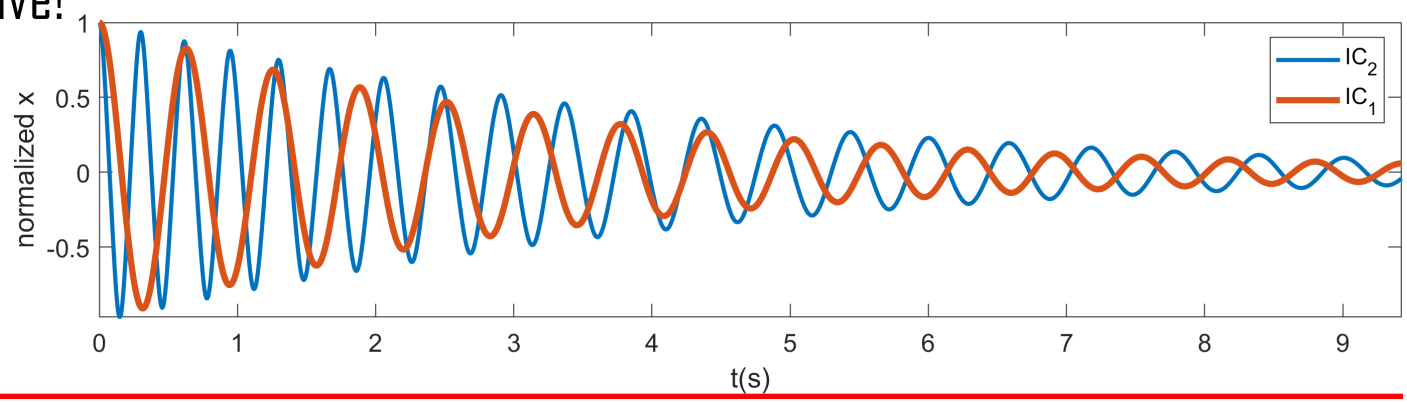
$$\mathbf{z} = \begin{pmatrix} z_1 \\ z_2 \end{pmatrix} = \begin{pmatrix} x \\ \dot{x} \end{pmatrix}, \quad \dot{\mathbf{z}} = \begin{pmatrix} \dot{z}_1 \\ \dot{z}_2 \end{pmatrix} = \begin{pmatrix} z_2 \\ -\left(f z_2 + k_1 z_1 + k_3 z_1^3 \right) / m \end{pmatrix}$$



- Stage 2: write a MATLAB® function to compute the derivatives

```
function dzdt = Damped_nonlin_sys(t,z,m,f,k1,k3)
%Damped_nonlin_sys computes the derivative of the states z
dzdt(1,1) = z(2);
dzdt(2,1) = -(f*z(2)+k1*z(1)+k3*z(1)^3)/m;
end
```

- Stage 3: Solve!



Recommended tutorial

- Complete the first MATLAB® training: MATLAB Onramp (approx. 2 hours)
  - Go to https://matlabacademy.mathworks.com/
  - Click: Launch

  - You may be asked to create a MATLAB® account (it's free and useful!)