Matlab variable types

- **integer**: 123, -345, 0
- **real or float**: 12.2344, 5.445454
- **engineering notation**: $4.2323 \times 10^{-9}$
- **complex**: $i = \sqrt{-1} = 1i$
  - $34.23 + 21.21i$
  - $(1+1i) \times (1-1i) = 2$
- **strings (put your words inside apostrophes)**: handy for file names and messages
  - 'programming is fun'
  - `s='Williamsburg'`

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Practical Computing
Lecture 02
Matlab variable types

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Matlab variable types

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- real or float
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    - $4.2323e^{-9} = 4.2323 \times 10^{-9}$
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- strings (put your words inside apostrophes)
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Some built in constants and functions

- \( \pi = 3.141592653589793238462643383279502 \cdots \)
  - use \( \text{pi} \)

- trigonometry functions
  - By default angle is in \textit{radians}
  - \( \sin, \cos, \tan, \cot \)
  - \( \text{asin, acos, atan, acot} \)
  - \( \sin(\pi/2) = 1 \)
  - \( \text{sind}(90) = 1 \)

- hyperbolic functions
  - \( \sinh, \cosh, \tanh, \coth \)
  - \( \text{asinh, acosh, atanh, acoth} \)

- logarithms
  - natural \( \log \)
  - base of 10 \( \log10 \)

- power
  - \( x^y \) use \( x^y \) or alternatively \( \text{power}(x, y) \)
  - \( e^y \) use \( \exp(y) \)
Assignment operator

\[ x = 1.2 + 3.4 \]

Despite the look, \( = \) is not an equality operator. \( = \) is an assignment operator. The expression above should be read as evaluate expression at the right hand side of equality symbol, assign the result of the RHS to the variable on the left hand side. Now variable \( x \) holds the value 4.6. We are free to use the value of the variable \( x \) in any further expressions.

\[ x + 4.2 \]

\[ \text{ans} = 8.8 \]
Assignment operator

\[ x = 1.2 + 3.4 \]

Despite the look, \( = \) is not an equality operator. \( = \) is an assignment operator.
Assignment operator

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x = 1.2 + 3.4
\]

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The expression above should be read as
- evaluate expression at the right hand side of equality symbol
- assign the result of the RHS to the variable on the left hand sign
- now variable \( x \) holds the value 4.6

We are free to use the value of the variable \( x \) in any further expressions

\[
> x + 4.2
\]

\[
\text{ans} = 8.8
\]
Once you typed some expressions in “Command window”

- type couple of first symbols of variable or function name
- hit tab and you will get
  - either fully typed name (if it is uniq)
  - or little chart with choices
    - use <up> or <down> arrows to choose
    - alternatively <Ctrl-p>, <Ctrl-n>
    - then hit <enter> to make your choice
Help related commands

These are the most important commands

- **docsearch word**
  - will search for *word* in the help files and show up matched help files
  - example: `docsearch trigonometry`

- **help name**
  - output short help text into “Command window” about function/method named *name*
  - example: `help sin`

- **doc name**
  - show a reference page about function/method named *name* in the help vrowser
  - usually has more information compare to `help name`
  - example: `doc sin`
Look at the following Matlab expression

\[-2^4 \times 5 + \tan(\pi/8 + \pi/8)^2\]

Guess the answer.
Operator Precedence

Look at the following Matlab expression

\[-2^4*5 + \tan(\pi/8+\pi/8)^2\]

Guess the answer.

\[- (2^4)*5 + (\tan( (\pi/8+\pi/8) ))^2\]
Look at the following Matlab expression

\[-2^4*5 + \tan(\pi/8+\pi/8)^2\]

Guess the answer.

\[-(2^4)*5 + (\tan(\pi/8+\pi/8))^2\]

\[-(16)*5 + (\tan(\pi/4))^2\]

Rule of thumb: if not sure use extra parentheses ()

Read more by executing `doc precedence` or searching for 'precedence' in the help browser.
Look at the following Matlab expression

\[-2^{4}\times5 + \tan(\pi/8+\pi/8)^{2}\]

Guess the answer.

\[-(2^{4})\times5 + (\tan((\pi/8+\pi/8)))^2\]

\[-(16)\times5 + (\tan((\pi/4)))^2\]

\[-80 + (1)^2\]
Look at the following Matlab expression

\[-2^{4} \times 5 + \tan(\pi/8 + \pi/8)^{2}\]

Guess the answer.

\[-(2^{4}) \times 5 + (\tan(\pi/8 + \pi/8))^2\]

\[-(16) \times 5 + (\tan(\pi/4))^2\]

\[-80 + (1)^2 = -80 + 1\]
Operator Precedence

Look at the following Matlab expression

\[-2^4 \times 5 \, + \, \tan\left(\pi/8 + \pi/8\right)^2\]

Guess the answer.

\[-\left(2^4\right) \times 5 \, + \, \left(\tan\left(\pi/8 + \pi/8\right)\right)^2\]

\[-\left(16\right) \times 5 \, + \, \left(\tan\left(\pi/4\right)\right)^2\]

\[-80 \, + \, \left(1\right)^2 \, = \, -80 \, + \, 1 \, = \, -79\]
Operator Precedence

Look at the following Matlab expression

\[-2^4 \times 5 + \tan(\pi/8 + \pi/8)^2\]

Guess the answer.

\[-(2^4) \times 5 + (\tan(\pi/8 + \pi/8))^2\]

\[-(16) \times 5 + (\tan(\pi/4))^2\]

\[-80 + (1)^2 = -80 + 1 = -79\]

Rule of thumb: if not sure use extra parentheses ()
Look at the following Matlab expression

\[-2^4 \times 5 + \tan(\pi/8+\pi/8)^2\]

Guess the answer.

\[-(2^4) \times 5 + (\tan(\pi/8+\pi/8))^2\]

\[-(16) \times 5 + (\tan(\pi/4))^2\]

\[-80 + (1)^2 = -80 + 1 = -79\]

Rule of thumb: if not sure use extra parentheses ()

- Read more by executing `doc precedence`
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Recall that Matlab stands for **Matrix Laboratory**

- So deep inside **everything** is a **matrix** (array)
- A number is the case of **1 × 1** matrix
Matrices

Recall that Matlab stands for Matrix Laboratory

- So deep inside **everything** is a **matrix** (array)
- a number is the case of $1 \times 1$ matrix

Let’s create a $3 \times 5$ matrix (3 rows and 5 columns)

```matlab
>> Mz=zeros(3,5)

Mz =
 0 0 0 0 0
 0 0 0 0 0
 0 0 0 0 0
```

This is not the only way, but it is one which make sure that matrix is filled with zeros

Note: it is possible to have more than 2 dimensional arrays.
Matrix elements assignment

>> Mz(2,4)=1 % 2nd row, 4th column

Mz =

0     0     0     0     0
0     0     0     1     0
0     0     0     1     0
0     0     0     0     0
Matrix elements assignment

>> Mz(2,4)=1  % 2nd row, 4th column

Mz =

0 0 0 0 0
0 0 0 1 0
0 0 0 0 0

>> Mz(3,5)=4  % 3rd row, 5th column

Mz =

0 0 0 0 0
0 0 0 1 0
0 0 0 0 4
Alternative way to assign a matrix

- comma separates column elements
- semicolon separates row elements

```matlab
>> Mz = [ ...
0, 0, 0, 0, 0; ...
0, 0, 0, 1, 0; ...
0, 0, 0, 0, 4]
```

Mz =

```
 0 0 0 0 0
 0 0 0 1 0
 0 0 0 0 4
```

Notice ⋯ mark, which means that input continues on the next line
Native matrix operations

\[
\begin{align*}
Mz &= \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 4 \\
\end{align*}
\]

\[
\begin{align*}
\gg Mz + 5 & \\
\text{ans} &= \\
5 & 5 & 5 & 5 & 5 \\
5 & 5 & 5 & 6 & 5 \\
5 & 5 & 5 & 5 & 9 \\
\end{align*}
\]
Native matrix operations

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 4
\end{bmatrix}
\]

\[
\begin{align*}
Mz + 5 \\
\text{ans} &= \\
5 & 5 & 5 & 5 & 5 \\
5 & 5 & 5 & 6 & 5 \\
5 & 5 & 5 & 5 & 9
\end{align*}
\]

\[
\begin{align*}
Mz \times 2 \\
\text{ans} &= \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2 & 0 \\
0 & 0 & 0 & 0 & 8
\end{align*}
\]
More example on matrices operations

\[
M_z =
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 4
\end{bmatrix}
\]

\[
>> M_z + M_z
\]

\[
\text{ans} =
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 2 \\
0 & 0 & 0 & 0 & 8
\end{bmatrix}
\]

Matrix multiplication according to the linear algebra rules

\[
>> M_z \cdot M_z'
\]

\[
\text{ans} =
\begin{bmatrix}
0 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 16
\end{bmatrix}
\]

Here \(M_z'\) corresponds to transposed matrix \(M_z\), i.e. \(M_z'(i, j) = M_z(j, i)\)
More example on matrices operations

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 4
\end{bmatrix}
\]

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2 & 0 \\
0 & 0 & 0 & 0 & 8
\end{bmatrix}
\]

Matrix multiplication according to the linear algebra rules

\[
\begin{bmatrix}
0 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 16
\end{bmatrix}
\]

Here \( Mz' \) corresponds to transposed matrix \( Mz \), i.e. \( Mz'(i, j) = Mz(j, i) \)
A function can take a matrix as the function argument, it will evaluate the value of the function for each matrix element.

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 4 \\
\end{bmatrix}
\]

\[
\gg \sin(Mz)
\]

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.8415 & 0 \\
0 & 0 & -0.7568 & 0 \\
\end{bmatrix}
\]
Vectors and column vector

A special case of the matrix is it has only one dimension. Such matrices generally called vectors

- $m \times 1$ column vector
- $1 \times m$ just a vector

To create a vector

```matlab
>> v = [1, 2, 3, 4, 5, 6, 7, 8]  
```

$v = 1 2 3 4 5 6 7 8$

```matlab
>> v = [1 2 3 4 5 6 7 8]  
```

```matlab
>> v = [1 2 3, 4, 5, 6 7 8]  
```

$v = 1 2 3 4 5 6 7 8$
A special case of the matrix is it has only one dimension. Such matrices generally called vectors

- \( m \times 1 \) column vector
- \( 1 \times m \) just a vector

To create a vector

```matlab
>> % use comma to separate column elements
>> v=[1, 2, 3, 4, 5, 6, 7, 8]
v =
    1 2 3 4 5 6 7 8
>> % alternatively you can use spaces
>> v=[1 2 3 4 5 6 7 8];
>> % or mix of these two notations (NOT RECOMMENDED)
>> v=[1 2 3, 4, 5, 6 7 8]
v =
    1 2 3 4 5 6 7 8
```
Column vector

Construction of column vector

```matlab
>> vc=[1; 2; 3]
% use semicolon to separate row elements

vc =

1
2
3
```
Yet one more way to create matrix

If you have prearranged vectors or column vectors you can use them

```matlab
>> vc=[1; 2; 3];
>> % note that ; after a statement suppresses output
>> Mc=[vc, vc, vc]
Mc =
    1 1 1
    2 2 2
    3 3 3
```
Yet one more way to create matrix

If you have prearranged vectors or column vectors you can use them

```matlab
>> vc=[1; 2; 3];
>> % note that ; after a statement suppresses output
>> Mc=[vc, vc, vc]
Mc =
1 1 1
2 2 2
3 3 3
```

```matlab
v =
1 2 3 4 5 6 7 8
>> Mv=[v; 2*v; 3*v]
Mv =
1 2 3 4 5 6 7 8
2 4 6 8 10 12 14 16
3 6 9 12 15 18 21 24
```
Colon (:) operator

The : operator is extremely useful to create vectors or matrix indexes. It usually take form \texttt{start:increment:stop} and creates a vector with following values:

\[
[\text{start}, \text{start}+\text{increment}, \ldots, \text{start}+m\times\text{increment}]
\]

where

\[
\min(\text{start}, \text{stop}) \leq m\times\text{increment} \leq \max(\text{start}, \text{stop})
\]
Colon (:) operator

The : operator is extremely useful to create vectors or matrix indexes. It usually takes the form `start:increment:stop` and creates a vector with the following values:

\[ \begin{bmatrix} \text{start}, \text{start}+\text{increment}, \ldots, \text{start}+m\times\text{increment} \end{bmatrix} \]

where

\[ \min(\text{start, stop}) \leq m\times\text{increment} \leq \max(\text{start, stop}) \]

```matlab
>> v=5:2:11

v =
5   7   9  11
```
Colon (:) operator

The : operator is extremely useful to create vectors or matrix indexes. It usually take form `start:increment:stop` and creates a vector with the following values:

\[
[ \text{start, start+increment, ... , start+m*increment} ]
\]

where

\[
\min(\text{start,stop}) \leq m\times\text{increment} \leq \max(\text{start,stop})
\]

```
>> v=5:2:11

v =
    5   7   9  11
```

It is also possible to have negative `increment`:

```
>> v2=12:-3:1

v2 =
     12    9    6    3
```
Another form $\texttt{start:stop}$ in this case $\texttt{increment} = 1$

```matlab
>> v1=1:5
v1 =
    1  2  3  4  5
```
Another form \texttt{start:stop} in this case \texttt{increment = 1}

\begin{verbatim}
>> v1=1:5
v1 =
   1   2   3   4   5
\end{verbatim}

Notice that

\begin{verbatim}
>> v3=5:1
v3 =
     Empty matrix: 1-by-0
\end{verbatim}

Produce somewhat unexpected result, since default increment is positive
Slicing matrices

It is handy to choose a subset (block) from the matrix. We have a matrix $M_v$ with size $3 \times 8$ and we want to choose all elements from columns 2, 5, 6.

```
>> Mv
Mv =
1   2   3   4   5   6   7   8
2   4   6   8  10  12  14  16
3   6   9  12  15  18  21  24
>> Mv(:,[2,5,6])
ans =
2   5   6
4  10  12
6  15  18
```

The meaning of the `:` now is **choose all**. Notice also that we use vector to specify desired columns.
Plotting

Suppose you have a vector with values of $x$ coordinates and we want to plot $\sin(x)$.

```matlab
>> x=linspace(0,2*pi,10)
x =
0 0.6981 1.3963 2.0944 2.7925 3.4907 4.1888 4.8869 5.5851 6.2832
>> y=sin(x)
y =
0 0.6428 0.9848 0.8660 0.3420 -0.3420 -0.8660 -0.9848 -0.6428 -0.0000
>> plot(x,y,'o') % alternatively plot(x,sin(x),'o')
>> % every plot MUST have title, x and y labels
>> xlabel('x (radians)')
>> ylabel('sin(x)')
>> title('Plot of sin(x)')
```
Now we want to save the figure, use `print`

```python
>> print('-dpdf', 'sin_of_x')
```

This will generate file `sin_of_x.pdf` notice automatic file extension addition.

The `-d` switch stands for output format (`'pdf'`, `'ps'`, `'eps'`, `'png'`...)

To generate 'png' file

```python
>> print('-dpng', '-r100', 'sin_of_x')
```

By default figure size is 8 x 6 inches, the `-r` switch tells the figure resolution in dpi (dots per inch). In this case it is 100 dpi so resulting image will be 800 x 600 pixels.

For 3D plots, please see help files for `plot3`, `mesh`, `surf`
Saving plots

Now we want to save the figure, use "print"

```python
>> print('-dpdf', 'sin_of_x')
```

This will generate file `sin_of_x.pdf` notice automatic file extension addition.
The ’-d’ switch stands for output format (‘pdf’, ’ps’, ’eps’, ’png”…)

Eugeniy Mikhailov (W&M)
Saving plots

Now we want to save the figure, use \texttt{print}

\begin{verbatim}
>> print('-dpdf', 'sin_of_x')
\end{verbatim}

This will generate file \texttt{sin\_of\_x.pdf} notice automatic file extension addition.
The ’-d’ switch stands for output format (’pdf’, ’ps’, ’eps’, ’png”…)
To generate ’png’ file

\begin{verbatim}
>> print('-dpng', '-r100', 'sin_of_x')
\end{verbatim}

By default figure size is $8 \times 6$ inches, the ’-r’ switch tells the figure resolution in dpi (dots per inch). In this case it is 100 dpi so resulting image will be $800 \times 600$ pixels.

For 3D plots, please see help files for \texttt{plot3, mesh, surf}
Special array arithmetic operators

There are special arithmetic operators which applied to the elements of matrices (disregard linear algebra rules), they start with .

.!*

```
>> x=1:3
x = 1 2 3
>> x*x % will generate an error
>> x.*x % equivalent to x.^2 (see below)
ans = 1 4 9
```
There are special arithmetic operators which applied to the elements of matrices (disregard linear algebra rules), they start with .

- \( .* \)

```matlab
>> x=1:3
x = 1 2 3
>> x*x \% will generate an error
>> x.*x \% equivalent to x.^2 (see below)
ans = 1 4 9
```

- \( .^\)  

```matlab
>> x.^2
ans = 1 4 9
```
Special array arithmetic operators

There are special arithmetic operators which applied to the elements of matrices (disregard linear algebra rules), they start with `. `.

- `.*`

```plaintext
>> x=1:3
x = 1  2  3
>> x*x  \% will generate an error
>> x.*x  \% equivalent to x.^2 (see below)
an = 1  4  9
```

- `.^`

```plaintext
>> x.^2
ans = 1  4  9
```

- `./`

```plaintext
>> x./x
ans = 1  1  1
```
Special array arithmetic operators continued

\[
\begin{bmatrix}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9 \\
\end{bmatrix}
\]

Linear algebra rules

\[
\begin{bmatrix}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9 \\
\end{bmatrix} \times \begin{bmatrix}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9 \\
\end{bmatrix} = \\
\begin{bmatrix}
30 & 36 & 42 \\
66 & 81 & 96 \\
102 & 126 & 150 \\
\end{bmatrix}
\]

Element wise operation

\[
\begin{bmatrix}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9 \\
\end{bmatrix} \odot \begin{bmatrix}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9 \\
\end{bmatrix} = \\
\begin{bmatrix}
1 & 4 & 9 \\
16 & 25 & 36 \\
49 & 64 & 81 \\
\end{bmatrix}
\]
Special array arithmetic operator .^ 

```matlab
>> m=[1,2,3;4,5,6;7,8,9]
m =
1  2  3
4  5  6
7  8  9
```

Linear algebra rules

```matlab
>> m^m % undefined
```

Element wise operation

```matlab
>> m.^m
ans =
1   4  27
256 3125 46656
823543 16777216 387420489
```
Special array arithmetic operator ./

```matlab
>> m = [1,2,3;4,5,6;7,8,9]
ans =
1 2 3
4 5 6
7 8 9
```

Linear algebra rules

```matlab
>> m/m % unity matrix
ans =
1 0 0
0 1 0
0 0 1
```

Element wise operation

```matlab
>> m./m %matrix of ones
ans =
1 1 1
1 1 1
1 1 1
```