

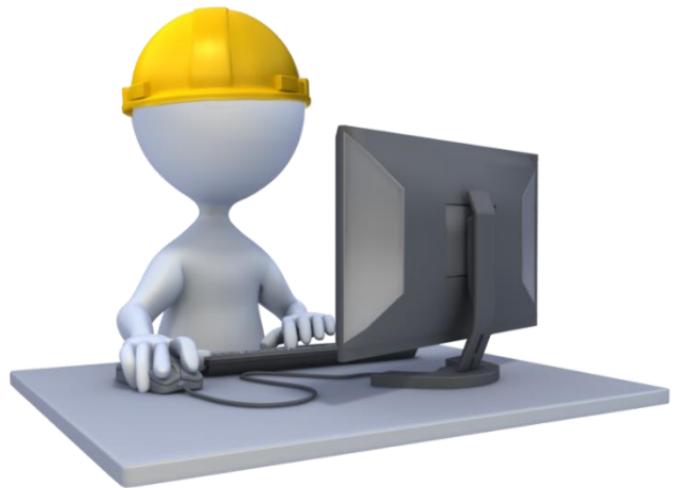
# **Computational Method (MATLAB Programming)**

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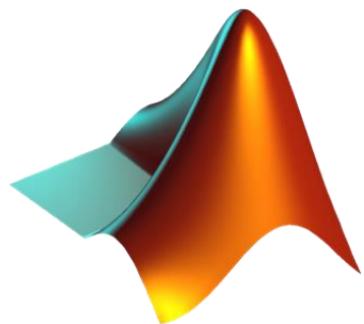
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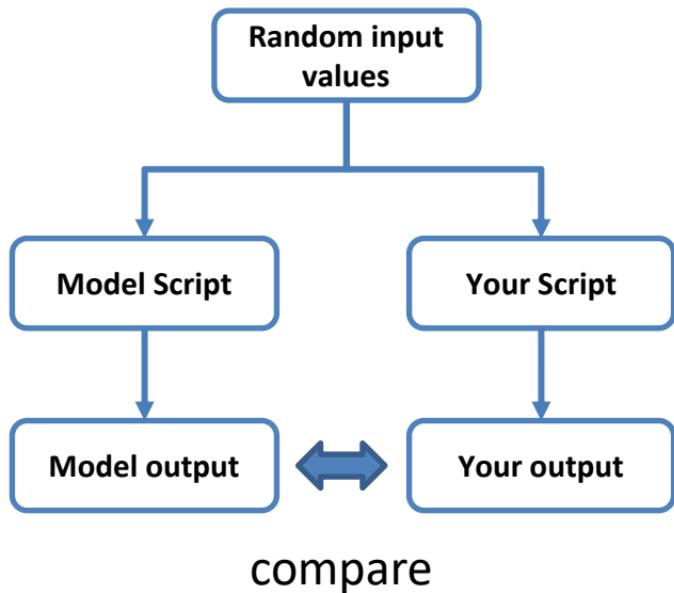
# What & Why is MATLAB?

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation.

- Very powerful software package
- Many mathematical and graphical applications
- Has programming constructs
- Also has many built-in functions
- Can use interactively in the Command Window, or write your own programs
- Easy to debug your program
- Built-in Command Window
  - At the prompt, enter a command or expression
  - MATLAB will respond with a result



# MATLAB Grader



The random number generator is to avoid your hard-coding in your assignments.

MATLAB® Grader™ is a browser-based environment for creating and sharing MATLAB coding problems and assessments. It's an auto-grading system.

An instructor designs several testers (assessments) to check your script if

- Correct outputs are generated from the given random inputs;
- Variables are properly defined;
- Keywords (e.g., built-in function) are present or absent.

# Conventions Used in This Course Material

- **bold, Italic, Red**  
Used for highlighting or introducing a new concept, terms, or structure
- Constant width  
Refer to program elements such as variable or functions names used in MATLAB scripts

: This element indicates a warning or caution.

: This element signifies a tip or suggestion.

: This element signifies a general note.

**Topic** (placed at next to a slide title)

- Remind  
**Math formula or concept**
- Optional  
**Optional topic or tip**
- Challenging  
**Challenging subjects**

# Conventions Used in This Course Material (Continue)

## Editor or Script Window

```
% variable = expression  
a1 = 3  
a2 = 5
```

|   |                         |
|---|-------------------------|
| 1 | % variable = expression |
| 2 | a1 = 3                  |
| 3 | a2 = 5                  |
| 4 |                         |

## Example level



: Easy



: Moderate



: Difficult

## Workspace

| Name | Value |
|------|-------|
| a1   | 3     |
| a2   | 5     |

## Command window

```
>> a  
  
a =  
  
1
```

The above script is simplified as:

|   |   |
|---|---|
| a | 1 |
|---|---|

## Navigating This Course Material

- This course material will be distributed as “images” in a PDF format so that students cannot copy scripts. Typing and running scripts yourself in MATLAB is a crucial process to learn programming. Do not skim the code.
- Solve problems by yourself first and then review model solutions.
- Please do not jump into future modules because each module is built up from the prior module(s).

## References

- Stormy Attaway, 2018, Matlab: A Practical Introduction to Programming and Problem Solving, 5th edition
- Lecture slides for “Matlab: A Practical Introduction to Programming and Problem Solving”
- Holly Moore, 2018, MATLAB for Engineers, 5th edition

## Acknowledgement

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# Module 01: Basic MATLAB Programming

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## Module 1: Intended Learning Outcomes

- Write an assignment statement to define a variable and assign value(s).
- Define a valid variable name acceptable in MATLAB
- Describe data types and a typecasting process.
- Explain numeric, logical operator, relational operators and compose expression using these operators
- Evaluate the expression with multiple operators following to an operator precedence in MATLAB
- Assess some basic math built-in functions (e.g., `round(x)` , `sign(x)` , or `abs(x)` )
- Generate random number(s) using a built-in random number function

# Variables and Assignments

- To store a value, use a ***variable***
- A way to put a value in a variable is with an **assignment statement**
- General form:

***variable = expression***

- The order is important:
  - *variable* name on the left
  - the assignment operator “=”
  - *expression* on the right

**⚠**: Here, = is not meant to an equality.

**⚠**: Make sure that the variable name is always on the left.

```
% variable = expression  
a1 = 3  
a2 = 5
```

| Name | Value |
|------|-------|
| a1   | 3     |
| a2   | 5     |

## Variable Names

- Names must begin with a letter of the alphabet.
- After that names can only contain letters, digits, and **the underscore character(\_)**.
- Variable names must not have a space.
- You cannot use other characters except for '\_'.
- MATLAB is **case-sensitive**.
- Names should be **mnemonic**: You and others know what are stored in your variables through its name.
- **clear** is a function to clear out variables and also functions.

## Example: Variable Names

```
val = 10; % error: must begin with a letter of the alphabet  
  
_col = 0 ; % error: must begin with a letter of the alphabet  
  
row_3_ = 1; % no error  
  
row@3 = 10; % error: cannot contain characters other than underscore  
  
col-03 = 10; % error: cannot contain characters other than underscore  
  
% Following scripts have no error but the names should be mnemonic  
  
asdf1 = 100; % no error  
love = 10; % no error  
aaaa3 = 10; % no error
```



: Recommend mnemonic variable names

```
% define a variable of 'gal'  
gal = 100
```

Q. What value is in 'Ga1' ?



## Example: Question in S19 Midterm

Q. Which of the following scripts have errors?

|     |              |
|-----|--------------|
| (1) | Val1 = 10    |
| (2) | 4val = 5     |
| (3) | new@data = 8 |
| (4) | val*2 = 3    |
| (5) | Jason = 10+2 |

1. (1), (2), and (4)
2. (2), (3), and (5)
3. (2), (3), and (4)
4. (1), (2), and (5)

# Constants

- In programming, variables, as the name suggests, store the values that **could be changed**.
- **Constants** are used when the value is **pre-defined** and not updated in the program.
- Examples in MATLAB
  - **pi**      3.14159....
  - **i, j**      imaginary number
  - **inf**      infinity
  - **NaN**      stands for “not a number”; e.g. the result of 0/0

**⚠:** However, the constants are also variables so you can overwrite values to the constants, but I **do not** recommend the use of constants as variables. For example: `pi = 3` % no error

# Modifying Variables

```
myvar = 10; % initialize a variable  
myvar = myvar + 3; % increment by 3
```

| Name  | Value |
|-------|-------|
| myvar | 13    |

```
myvar = 10; % initialize a variable  
val = 3; % initialize a variable  
  
% identical operations  
myvar1 = myvar + val;  
myvar2 = 10 + 3;
```

| Name   | Value |
|--------|-------|
| myvar  | 10    |
| val    | 3     |
| myvar1 | 13    |
| myvar2 | 13    |

## Swap two values

```
myvar1 = 10; % initialize a var.  
myvar2 = 5; % initialize a var.  
  
tmp = myvar1;  
myvar1 = myvar2;  
myvar2 = tmp;
```

| Name   | Value |
|--------|-------|
| myvar1 | 5     |
| myvar2 | 10    |
| tmp    | 10    |

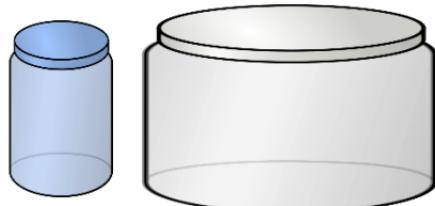
# Data Types

- Every expression and variable has an associated *type* or *class*
  - Real numbers: *single*, *double* (**default type for numbers**)
  - Integer types: numbers in the names are the number of bits used to store a value of that type
    - Signed integers: *int8*, *int16*, *int32*, *int64*
    - Unsigned integers: *uint8*, *uint16*, *uint32*, *uint64*
  - Single characters and character vectors: *char*
  - Strings of characters: *string*
  - True/false: *logical (represented as 1 or 0)*



The same value can be defined as a different type.

## Container



char

double

logical

int

## Examples

- 2.145, 0.15893, 3.0, 2.45
- 10, 11, 24, 30, 400
- 'a', 'b', 'A', 'c'
- "sam"
- true, false

# Data Types (Continue)

## Example

- double : 2.145, 0.15893, 3.0,
- integer type: 10, 11, 24, 30
- char: 'a', 'b', 'A', 'c'
- string: "sam"
- logical: true, false

**class** is a function of determining a class of variables or values.

```
>> class("sam")  
ans =  
    'string'
```

```
>> class('a')  
  
ans =  
    'char'  
  
>> class(true)  
  
ans =  
    'logical'  
  
>> class(2.145)  
  
ans =  
    'double'  
  
>> class(10)  
  
ans =  
    'double'
```

**⚠:** The default type of numbers is 'double'. Integers like 10, 11, .. are also defined as 'double'. If you want to define these number as integer, you should do type-casting.

## Type Cast

## Challenging

There are many functions that convert values from one type to another. The names of these functions are the same as the names of the types. The names can be used as functions to convert a value to that type. This is called casting the value to a different type or type casting.

```
>> a = logical(1);
>> class(a)

ans =
    'logical'

>> b = double(a);
>> class(b)

ans =
    'double'
```

```
>> a = logical(1);
>> b = a + 2;
>> class(b)

ans =
    'double'
>> c = logical(b)
c =
    logical
    1
```

 In the second line in red, the type of a is converted to double and arithmetic operation is conducted with 2. In the fourth line, b is double but the logical type only carries 0 or 1 so non-zero double (or other numeric type) values becomes 1, otherwise 0. This is a very important concept for logical operations.



## Example: Type Cast (logical and double Types)

Q. What value is assigned to each variable? What is its type?

```
a = 3;  
b = logical(a);  
c = logical(1);  
d = logical(0);  
  
e = 1 + a;  
f = 1 + double(b);  
g = a - b;  
h = logical(3 - a);  
k = b - c;
```

For the variable of k, you cannot add or subtract values with a logical type. To conduct the operation, their types are implicitly changed to double types.

| Name | Value | Class   |
|------|-------|---------|
| a    | 3     | double  |
| b    | 1     | logical |
| c    | 1     | logical |
| d    | 0     | logical |
| e    | 4     | double  |
| f    | 2     | double  |
| g    | 2     | double  |
| h    | 0     | logical |
| k    | 0     | double  |

# Operators

- There are in general two kinds of operators: *unary* operators, which operate on a single value and *binary* operators, which operate on two values.
- Operators include:
  - + addition
  - subtraction or negation
  - \* multiplication
  - / division
  - ^ exponentiation (e.g.,  $5^2$  is 25)

```
val1 = 5 + 1;  
val2 = 10*2;  
val3 = 10^2;  
val4 = 100/5;  
val5 = 10 + 2 + 3;
```

| Name | Value |
|------|-------|
| val1 | 6     |
| val2 | 20    |
| val3 | 100   |
| val4 | 20    |
| val5 | 15    |

# Operator Precedence Rules

- Some operators have precedence over others.
- Within given precedence, the expressions are evaluated from **left to right**.
- Precedence list (highest to lowest) :

|                          |                                 |
|--------------------------|---------------------------------|
| ( )                      | parentheses                     |
| $\wedge$                 | exponentiation                  |
| -                        | negation                        |
| $*$ , $/$ , $\backslash$ | all multiplication and division |
| $+$ , $-$                | addition and subtraction        |

- Nested parentheses: expressions in inner parentheses are evaluated first

```
val1 = (5 + 1)*2;  
val2 = 10^2*3;  
val3 = 10^(2+3);  
val4 = 4-3*2;  
val5 = 3*((4+3)*2);  
val6 = -10^2;
```



A good practice is to use parentheses to clarify your operation:  $-(10^2)$  or  $(-10)^2$ .

| Name | Value  |
|------|--------|
| val1 | 12     |
| val2 | 300    |
| val3 | 100000 |
| val4 | -2     |
| val5 | 42     |
| val6 | -100   |



## Example: Operator Precedence Rules

Q. What values are assigned to the variables?

```
val1 = 3*2+3-2*3  
val2 = -10^4*3  
val3 = (-10)^4*3  
val4 = 5-3*2;  
val5 = (3+3)^(2-1);
```

| Name | Value  |
|------|--------|
| val1 | 3      |
| val2 | -30000 |
| val3 | 30000  |
| val4 | -1     |
| val5 | 6      |

## Relational Operator

- The relational operators in MATLAB are:

|    |                        |
|----|------------------------|
| >  | greater than           |
| <  | less than              |
| >= | greater than or equals |
| <= | less than or equals    |
| == | equality               |
| ~= | inequality             |



⚠: Here, == is meant to an equality. Not =.

- It is also called *Boolean* expressions or *logical* expressions.
- The resulting type is logical 1 for true or 0 for false**

📖: “true” is represented by the logical value 1, and “false” is represented by the logical value 0. A logical type only contain one value, either 0 or 1.

## Relational Operator (Continue)

```
% relation operator  
ro1 = 3 < 4;  
ro2 = 3 > 5;  
ro3 = 3 == 5;  
ro4 = 3 ~= 7;  
ro5 = 3 <= 3;  
ro6 = 3 >= 3;  
ro7 = 3 > 3;
```

 In the second line, the code is first running the expression ( $3 < 4$ ) and computing its value. This expression means “3 less than 4”, which is a true. Thus, true (or logical 1) is assigned to ro1.

| Name | Value |
|------|-------|
| ro1  | 1     |
| ro2  | 0     |
| ro3  | 0     |
| ro4  | 1     |
| ro5  | 1     |
| ro6  | 1     |
| ro7  | 0     |

 Here, the values are all *logical* values, 0 or 1, not *double*.

# Logical Operator

## Challenging

- The logical operators are:

|    |     |
|----|-----|
|    | or  |
| && | and |
| ~  | not |

- Note that the logical operators are **commutative**
  - (e.g.,  $x \mid\mid y$  is equivalent to  $y \mid\mid x$ )
- The resulting type is **logical 1** for true or 0 for false

| x     | y     | $\sim x$ | $x \mid\mid y$ | $x \&\& y$ |
|-------|-------|----------|----------------|------------|
| true  | true  | false    | true           | true       |
| true  | false | false    | true           | false      |
| false | false | true     | false          | false      |

 For example, logical (1) && logical (1) becomes 1. This is the same with true && true.

# Logical Operator (Continue)

```
% relation operator  
lo1 = true && false  
lo2 = 1 || 0  
lo3 = 0 || 0  
lo4 = true && true  
lo5 = 0 || ~false  
lo6 = ~false && true  
lo7 = ~true || false
```

| Name | Value |
|------|-------|
| lo1  | 0     |
| lo2  | 1     |
| lo3  | 0     |
| lo4  | 1     |
| lo5  | 1     |
| lo6  | 1     |
| lo7  | 0     |

| x     | y     |
|-------|-------|
| true  | true  |
| true  | false |
| false | false |



| $\sim x$ | $x \text{    } y$ | $x \text{ && } y$ |
|----------|-------------------|-------------------|
| false    | true              | true              |
| false    | true              | false             |
| true     | false             | false             |

# General Operator Precedence

## Challenging

Parentheses ()

Highest

Power: ^

Unary: negation (-), not (~)

Multiplication or division: \*, /, \

Addition, subtraction: +, -

Relational: <, <=, >, ==, ~=

And: &&

Or: ||



Lowest

```
val1 = 3 < (1 + 3)  
val2 = (3 < 1) + 3  
val3 = 3 < 1 + 3
```

**⚠:** Although there is no error for computing val3, this syntax is not recommended to avoid a potential mistake.

I know it's bit hard but, it might be easy if you consider relational and logical operators as common operators like +, -, and compute the values with this precedence order.

Remember ! 0 is false otherwise true.

| Name | Value | Class   |
|------|-------|---------|
| val1 | 1     | double  |
| val2 | 3     | logical |
| val3 | 1     | logical |

## Example: Operator Precedence



```
lg1 = (3 < 4) < 4;  
lg2 = 3 < (4 < 5);  
lg3 = (3 > 5) + 3;  
lg4 = (10 > 4) && (4 > 1);  
lg5 = (10 < 4) && (4 < 1);  
lg6 = ~((10 < 4) && (4 < 1));  
lg7 = 2 < 3 + 4;
```

|                                     |         |
|-------------------------------------|---------|
| Parentheses ()                      | Highest |
| Power: ^                            |         |
| Unary: negation (-), not (~)        |         |
| Multiplication or division: *, /, \ |         |
| Addition, subtraction: +, -         |         |
| Relational: <, <=, >, ==, ~=        |         |
| And: &&                             |         |
| Or:                                 | Lowest  |

Q. What values are assigned to the variables?

| Name | Value |
|------|-------|
| lg1  | 1     |
| lg2  | 0     |
| lg3  | 3     |
| lg4  | 1     |
| lg5  | 0     |
| lg6  | 1     |
| lg7  | 1     |



 Regardless of the operator precedence, you could use parentheses to clarify the operation order



## Example: General Operator Precedence

Q. How to write a code to check if  $x$  lies in between 5 and 10. If yes, 1 and otherwise 0.

```
x1 = 6;  
x2 = 11;  
  
lg1 = (5 < x1) && (x1<10)  
lg2 = 5 < x1 <10; % incorrect!  
lg3 = (5 < x1) <10; % incorrect!  
  
lg4 = (5 < x2) && (x2 < 10)  
lg5 = 5 < x2 < 10; % incorrect!  
lg6 = (5 < x2) < 10; % incorrect!
```

| Name | Value |
|------|-------|
| x1   | 6     |
| x2   | 11    |
| lg1  | 1     |
| lg2  | 1     |
| lg3  | 1     |
| lg4  | 0     |
| lg5  | 1     |
| lg6  | 1     |

⚠: For  $lg2$ , the first expression  $5 < x$  will be evaluated. It gives a logical value 1. Then, the rest of the expression will be evaluated,  $1 < 10$ . So, the final value to be assigned to  $lg2$  become logical 1, true.

# Using Functions: Terminology

- To use a function, you **call** it
- To call a function, give its name followed by the **argument(s)** that are **passed** to it in parentheses:

```
out = fun(arg1, arg2,...)
```

- Functions basically calculate values and **return** the results:
- For example, to find the absolute value of  $-4$

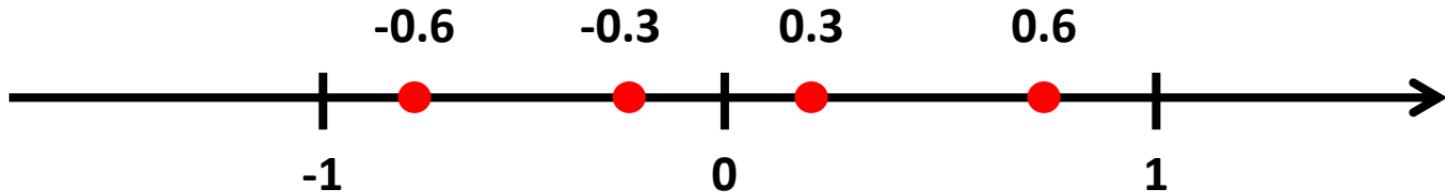
```
>> abs(-4)
ans =
    4
```

- The name of the function is “`abs`”
- One argument,  $-4$ , is passed to the `abs` function
- The `abs` function finds the absolute value of  $-4$  and returns the result,  $4$ .

# Rounding Functions

| Function              | Description   | Note  |
|-----------------------|---|---|
| <code>round(x)</code> | Rounds $x$ to the nearest integer                           |   |
| <code>fix(x)</code>   | Truncates $x$ to the nearest integer toward zero.           |  |
| <code>floor(x)</code> | Rounds $x$ to the nearest integer toward negative infinity. |  |
| <code>ceil(x)</code>  | Rounds $x$ to the nearest integer toward positive infinity. |  |

# Rounding Functions (Continue)



| Function              | Description   |
|-----------------------|---|
| <code>round(x)</code> | Rounds $x$ to the nearest integer                           |
| <code>fix(x)</code>   | Truncates $x$ to the nearest integer toward zero.           |
| <code>floor(x)</code> | Rounds $x$ to the nearest integer toward negative infinity. |
| <code>ceil(x)</code>  | Rounds $x$ to the nearest integer toward positive infinity. |

|      | round | fix | floor | ceil |
|------|-------|-----|-------|------|
| 0.3  | 0     | 0   | 0     | 1    |
| 0.6  | 1     | 0   | 0     | 1    |
| -0.3 | 0     | 0   | -1    | 0    |
| -0.6 | -1    | 0   | -1    | 0    |

# Rounding Functions (Continue)

```
x1 = 10.3;  
x2 = 12.7;  
x3 = -1.3;  
  
x1_ce = ceil(x1);  
x1_fi = fix(x1);  
x1_fl = floor(x1);  
  
x2_ce = ceil(x2);  
x2_fi = fix(x2);  
x2_fl = floor(x2);  
  
x3_ce = ceil(x3);  
x3_fi = fix(x3);  
x3_fl = floor(x3);  
x3_ro = round(x3);
```

| Name  | Value |
|-------|-------|
| x1    | 10.3  |
| x2    | 12.7  |
| x3    | -1.3  |
| x1_ce | 11    |
| x1_fi | 10    |
| x1_fl | 10    |
| x2_ce | 13    |
| x2_fi | 12    |
| x2_fl | 12    |
| x3_ce | -1    |
| x3_fi | -1    |
| x3_fl | -2    |
| x3_ro | -1    |

| Function         | Description  |
|------------------|--|
| <b>round (x)</b> | Rounds <b>x</b> to the nearest integer                           |
| <b>fix (x)</b>   | Truncates <b>x</b> to the nearest integer toward zero.           |
| <b>floor (x)</b> | Rounds <b>x</b> to the nearest integer toward negative infinity. |
| <b>ceil (x)</b>  | Rounds <b>x</b> to the nearest integer toward positive infinity. |

 You do not have to memorize the functions and their usage. You can simply search for their usage in google or type `doc round` in command window (`doc fun_name`).

# Common Math Functions

| Function           | Description   | Script  | Value        |
|--------------------|---|---|--------------|
| <b>abs (x)</b>     | Finds the absolute value of <b>x</b>  | <code>abs (-3)</code><br><code>abs (2)</code>                                     | 3<br>2       |
| <b>sqrt (x)</b>    | Finds the square root of <b>x</b>   | <code>sqrt (4)</code><br><code>sqrt (1.75)</code>                                 | 2<br>1.5     |
| <b>sign (x)</b>    | Return -1 if <b>x</b> is less than zero, a value of 0 if <b>x</b> equals zero, and a value of 1 if <b>x</b> is greater than zero. | <code>sign (-5)</code><br><code>sign (3)</code><br><code>sign (0)</code>          | -1<br>1<br>0 |
| <b>rem (x , y)</b> | Computes the remainder of <b>x/y</b>  | <code>rem (25 , 4)</code><br><code>rem (4 , 2)</code><br><code>rem (9 , 5)</code> | 1<br>0<br>4  |

# Common Math Functions (Continue)

| Function        | Description  |
|-----------------|--|
| <b>abs (x)</b>  | Finds the absolute value of <b>x</b>   |
| <b>sqrt(x)</b>  | Finds the square root of <b>x</b>  |
| <b>sign(x)</b>  | Return <b>-1</b> if <b>x</b> is less than zero, a value of <b>0</b> if <b>x</b> equals zero, and a value of <b>1</b> if <b>x</b> is greater than zero. |
| <b>rem(x,y)</b> | Computes the remainder of <b>x/y</b>   |

```
x = -4;  
y = 9;  
z = 2;  
  
x_ab = abs(x)  
x_si = sign(x)  
  
xz_r = rem(x, z)  
  
y_ab = abs(y)  
y_sq = sqrt(y)  
y_si = sign(y)  
  
yz_r = rem(y, z)
```

| Name | Value |
|------|-------|
| x    | -4    |
| y    | 9     |
| z    | 2     |
| x_ab | 4     |
| x_si | -1    |
| xz_r | 0     |
| y_ab | 9     |
| y_sq | 3     |
| y_si | 1     |
| yz_r | 1     |

# Logical Operation Functions

| Function         | Operator |
|------------------|----------|
| <b>and(A, B)</b> | A && B   |
| <b>or(A, B)</b>  | A    B   |
| <b>not(A)</b>    | $\sim A$ |

```
x1 = true;
x2 = false;

lg1a = and(x1, x2);
lg1b = x1 && x2;

lg2a = or(x1, x2);
lg2b = x1 || x2

lg3a = not(x1);
lg3b = ~x1;
```



: These functions improve readability.

For instance:

```
log1 = 3<x && x<10
```

```
log2 = and(3<x, x<10)
```

| Name | Value |
|------|-------|
| x1   | 1     |
| x2   | 0     |
| lg1a | 0     |
| lg1b | 0     |
| lg2a | 1     |
| lg2b | 1     |
| lg3a | 0     |
| lg3b | 0     |

# Random Number

# Challenging

- MATLAB generates pseudorandom numbers. These numbers are not strictly random and independent in the mathematical sense, but they pass various statistical tests of randomness and independence, and their calculation can be repeated for testing or diagnostic purposes.
  - Several built-in functions generate random numbers.
  - Random number generators start with a number called the `seed`. This is either a predetermined value or from the clock. This is considered as an “index” of a random number lookup table.

Seed: n  
Seed: 2  
Seed: 1

Seed: i

Seed: i

## Random Number (Continue)

## Challenging

- **rand(n)** creates an  $n \times n$  matrix of random reals
- **rand(n,m)** create an  $n \times m$  matrix of random reals
- **randi([range],n,m)** creates an  $n \times m$  matrix of random integers in the specified range
- **rng(seed)** specifies the seed for the random generator

```
>> rand(1)
```

ans =

0.8147

```
>> rand(1)
```

ans =

0.9058



: A seed is changed in each run of your script. Thus, different random numbers are generated

```
>> rng(10); rand(1)
```

ans =

0.7713

```
>> rng(10); rand(1)
```

ans =

0.7713



: You can specify a seed. Then, the same numbers are generated.

# Write a Numerical Expression

Optional

Suppose that you want to compute  $y$  when  $x = 10$

$$y = \frac{x^2(100x + 10) + x^3(20x^2 + 3)}{-x^{-3} + 1}$$

```
x = 10;  
y1 = (x^2*(100*x + 10) + x^3*(20*x^2 + 3)) / (-x^(-3)+1)
```

 The more terms and parentheses in your equation, the larger the probability that you may be making a mistake. In this case, I usually do it like this

```
x = 10;  
y_nom = (x^2)*(100*x + 10) + (x^3)*(20*(x^2) + 3);  
y_den = -x^(-3)+1;  
y = y_nom/y_den;
```

# Arithmetic Operation in MATLAB

Optional

Suppose that you are solving a problem: If the car has a mass of 300kg and you push the car with an acceleration of 5 inch/s<sup>2</sup>, compute the force that is generated from the car in newton

```
% MATLAB as a calculator  
300*5*0.0254
```

| Name | Value |
|------|-------|
| ans  | 38.1  |

: If you are using MATLAB as a programming tool, I would recommend writing the code below. This improves code readability and allows others to understand your code.

```
% MATLAB as programming tool  
  
inch2m = 0.0254; % inch to m  
mass = 300; % kg  
accel = 5; % inch/s/s  
  
% force = mass(kg) * acceleration (m/s/s)  
force = mass * accel * inch2m;
```

| Name   | Value  |
|--------|--------|
| inch2m | 0.0254 |
| mass   | 300    |
| accel  | 5      |
| force  | 38.1   |

# Module 02: Vectors and Matrices

Chul Min Yeum

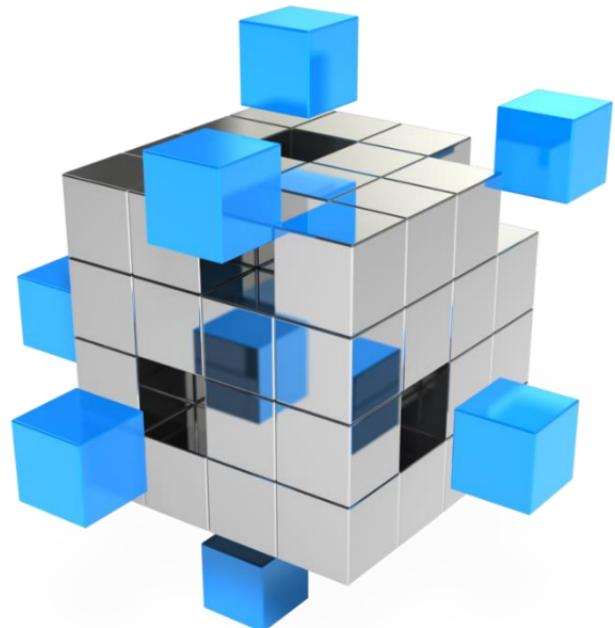
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## Module 2: Intended Learning Outcomes

- Create an array in MATLAB, which includes a scalar, vector, and matrix.
- Refer elements in an array using index or subscript.
- Modify and concatenate an array.
- Perform array operations (element-wise operation and matrix operation)
- Define and evaluate a character and character vector
- Create a 3D matrix and refer to its element.
- Understand a linear indexing method

# Matrix, Row Vector, and Column Vector

[Remind](#)

A matrix is an ordered rectangular array of numbers. A general matrix with  $m$  rows and  $n$  columns has the following structure:

$$\begin{matrix} & & \text{column, } j \\ & 1 & 2 & 3 & \cdots & n \\ \begin{matrix} 1 \\ 2 \\ \vdots \\ m \end{matrix} & \left[ \begin{matrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \cdots & \cdots & a_{mn} \end{matrix} \right]_{m \times n} \end{matrix}$$

where  $a_{ij}$  is each number in the array indexed by its row position  $i$  and column position  $j$ .

# Matrix, Row Vector, and Column Vector in MATLAB

- A ***matrix*** is used to store a set of values of the same type; every value is stored in an ***element***.
- A matrix looks like a table; it has both rows and columns
- A matrix with  $m$  rows and  $n$  columns is called  **$m \times n$** ; these are called its ***dimensions***;
- A ***vector*** is a special case of a matrix in which one of the dimensions is 1
- The term ***array*** is frequently used in MATLAB to refer generically to a matrix or a vector
  - a row vector with  $n$  elements is  $1 \times n$ , e.g.,  $1 \times 4$ :
  - a column vector with  $m$  elements is  $m \times 1$ , e.g.,  $3 \times 1$ :
- A ***scalar*** is an even more special case; it is  $1 \times 1$ , or in other words, just a single value

## Creating Row Vectors

- Direct method: put the values you want in square brackets, separated by either **commas or spaces**
- **Colon operator:** iterates through values in the form `first:step:last`
  - `2:1:4` creates the vector of `[2 3 4]`.
  - If no step is specified, the default is 1 so for example `2:4` creates the vector `[2 3 4]`
  - Can go in reverse e.g. `4:-1:1` creates `[4 3 2 1]`
  - Cannot go beyond last e.g., `1:2:6` creates `[1 3 5]`

```
rvec1 = [1 2 3 4]; % separated by space  
rvec2 = [1,2,3,4]; % separated by comma  
rvec3 = [1    2    3 4];  
rvec4 = 1:4; % use a colon operator  
rvec5 = 1:1:4; % step by 1  
rvec6 = [1:4]; % okay with putting bracket
```

| Name  | Value     |
|-------|-----------|
| rvec1 | [1 2 3 4] |
| rvec2 | [1 2 3 4] |
| rvec3 | [1 2 3 4] |
| rvec4 | [1 2 3 4] |
| rvec5 | [1 2 3 4] |
| rvec6 | [1 2 3 4] |

## Creating Row Vectors (Continue)

```
rvec1 = [1 2 3 4 5 6];  
rvec2 = [1:6];  
  
rvec3 = [1:2:6]; % step by 2  
  
rvec4 = [1:3:6]; % step by 3  
  
rvec5 = [6:-1:1]; % step by -1
```

```
my_rvec1 = [1:5:6];  
  
my_rvec2 = [5:-2:1];
```

| Name  | Value         |
|-------|---------------|
| rvec1 | [1 2 3 4 5 6] |
| rvec2 | [1 2 3 4 5 6] |
| rvec3 | [1 3 5]       |
| rvec4 | [1 4]         |
| rvec5 | [6 5 4 3 2 1] |

| Name  | Value   |
|-------|---------|
| rvec1 | [1 6]   |
| rvec2 | [5 3 1] |



: Remember ! variable = first:step:last

The **transpose** of a matrix is the operation of flipping the rows to columns and vice versa across the diagonal of the matrix. For example,

$$A = \begin{bmatrix} 1 & 4 \\ 2 & 5 \\ 3 & 6 \end{bmatrix}_{3 \times 2} \quad \text{has transpose } A^T = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix}_{2 \times 3}$$

where the power of  $T$  indicates the transpose of a matrix. Note that in the example, the dimensions of the matrix changes from  $3 \times 2$  to  $2 \times 3$  (with the same total number of elements) and diagonal elements remain the same.

## Creating Column Vectors

- A **column** vector is an  $m \times 1$  vector
- **Direct method:** can create by separating values in square brackets with ***semicolons*** (e.g., [4; 7; 2])
- You cannot directly create a column vector using methods such as the colon operator, but you can create a row vector and then ***transpose*** it to get a column vector using the transpose operator (e.g., [4 7 2]')

```
cvec1 = [1;2;3;4];  
cvec2 = [1 2 3 4]';  
rvec3 = [1:4];  
cvec4 = rvec3';
```

| Name  | Value        |
|-------|--------------|
| cvec1 | [1; 2; 3; 4] |
| cvec2 | [1; 2; 3; 4] |
| rvec3 | [1 2 3 4]    |
| cvec4 | [1; 2; 3; 4] |

## Referring to Elements

- The elements in a vector are numbered sequentially; each element number is called the ***index***, or ***subscript***:

```
myvec = [5 33 11 -4 2];
```

| Index   | 1 | 2  | 3  | 4  | 5 |
|---------|---|----|----|----|---|
| Element | 5 | 33 | 11 | -4 | 2 |

- Refer to an element using its ***index*** or ***subscript*** in parentheses, e.g. `vec(4)` is the 4<sup>th</sup> element of a vector `vec` (assuming it has at least 4 elements)
- Can also refer to a subset of a vector by using an ***index vector*** which is a vector of indices e.g. `vec([2 5])` refers to the 2<sup>nd</sup> and 5<sup>th</sup> elements of `vec`.



: The index in MATLAB starts from 1 !!

## Example: Referring to Elements

```
rvec = [5:10];  
cvec = rvec';  
  
val1 = rvec(2);  
val2 = rvec(5);  
  
vec1 = rvec([1 4]);  
vec2 = rvec([1 2 6]);  
  
vec3 = cvec([1 4]);  
vec4 = cvec([1 2 6]);
```

| Name | Value               |
|------|---------------------|
| rvec | [5 6 7 8 9 10]      |
| cvec | [5; 6; 7; 8; 9; 10] |
| val1 | 6                   |
| val2 | 9                   |
| vec1 | [5 8]               |
| vec2 | [5 6 10]            |
| vec3 | [5; 8]              |
| vec4 | [5; 6; 10]          |

Index

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|

Element

|   |   |   |   |   |    |
|---|---|---|---|---|----|
| 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|----|

rvec

# Modifying Vectors

- Elements in a vector can be changed.

***variable(index) = expression***

```
rvec = 1:4;  
rvec1 = rvec;  
rvec1(4) = 10;
```

| Name  | Value      |
|-------|------------|
| rvec  | [1 2 3 4]  |
| rvec1 | [1 2 3 10] |

 : Value(s) computed from *expression* are assigned to *variable* at *index* location(s).

```
rvec = 1:5;  
rvec1 = rvec;  
rvec2 = rvec;  
rvec3 = rvec;  
  
rvec1([1 3]) = [0 0];  
rvec2(1:3) = 4:6;  
rvec3([1 3]) = rvec3([3 1]);
```

| Name  | Value       |
|-------|-------------|
| rvec  | [1 2 3 4 5] |
| rvec1 | [0 2 0 4 5] |
| rvec2 | [4 5 6 4 5] |
| rvec3 | [3 2 1 4 5] |

## Modifying Vectors (Continue)

- A vector can be extended by referring to elements that do not yet exist
- A vector cannot be read by an index that does not yet exist

***variable(index) = expression***

```
rvec1 = 1:4;  
rvec1(5) = 5;  
  
rvec2 = 1:4;  
rvec2([5 6]) = [3 2];
```

| Name  | Value         |
|-------|---------------|
| rvec1 | [1 2 3 4 5]   |
| rvec2 | [1 2 3 4 3 2] |

```
rvec1 = 1:4;  
val1 = rvec1(5)
```

*Error: Index exceeds the number  
of array elements (4)*

```
rvec1 = 1:4;  
rvec1(1:2) = [1 2 3];
```

*Error: Unable to perform assignment  
because the left and right sides  
have a different number of elements.*

# Concatenation

- Vectors can be created by joining existing vectors together, or adding elements to existing vectors
- This is called ***concatenation***

```
rvec = [1 2];  
rvec1 = [rvec 8 9];  
rvec2 = [rvec rvec1];
```

```
cvec = [4;5];  
cvecp = [6;7]  
cvec1 = [cvec; cvecp];
```

| Name  | Value         |
|-------|---------------|
| rvec  | [1 2]         |
| rvec1 | [1 2 8 9]     |
| rvec2 | [1 2 1 2 8 9] |
| cvec  | [4; 5]        |
| cvecp | [6; 7]        |
| cvec1 | [4; 5; 6; 7]  |

```
rvec = [1 2];  
rvec1 = [rvec; 8];
```

Error: using vertcat  
Dimensions of arrays being concatenated  
are not consistent.

# Creating a Matrix

- Separate values within rows with **blanks** or **commas**, and separate the rows with **semicolons**
- Can use any method to get values in each row (any method to create a row vector, including colon operator)
- There must ALWAYS be the same number of values in every row!!**

```
m1 = [1 2 3;4 5 6];  
  
r1 = [1 2 3];  
r2 = [4 5 6];  
  
m2 = [r1;r2];  
m3 = [r1;4 5 6];  
% it works not recommend
```

m1, m2, m3

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |

| Name | Value         |
|------|---------------|
| m1   | [1 2 3;4 5 6] |
| r1   | [1 2 3]       |
| r2   | [4 5 6]       |
| m2   | [1 2 3;4 5 6] |
| m3   | [1 2 3;4 5 6] |

# Functions that Create Matrices

There are many built-in functions to create matrices

- **`zeros (n)`** creates an  $n \times n$  matrix of all zeros
- **`zeros (n, m)`** creates an  $n \times m$  matrix of all zeros
- **`ones (n)`** creates an  $n \times n$  matrix of all ones
- **`ones (n, m)`** creates an  $n \times m$  matrix of all ones
- **`eye (n)`** creates an  $n \times n$  identity matrix.

```
m1 = zeros(3);  
m2 = zeros(3, 2);  
  
m3 = ones(2, 1);  
m4 = eye(3);
```

$$\begin{matrix} m1 & \begin{array}{|c|c|c|} \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array} & m2 & \begin{array}{|c|c|} \hline 0 & 0 \\ \hline 0 & 0 \\ \hline 0 & 0 \\ \hline \end{array} \end{matrix}$$

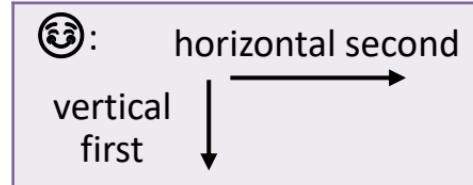
| Name | Value                 |
|------|-----------------------|
| m1   | [0 0 0; 0 0 0; 0 0 0] |
| m2   | [0 0; 0 0; 0 0]       |
| m3   | [1; 1]                |
| m4   | [1 0 0; 0 1 0; 0 0 1] |

$$\begin{matrix} m3 & \begin{array}{|c|} \hline 1 \\ \hline 1 \\ \hline \end{array} & m4 & \begin{array}{|c|c|c|} \hline 1 & 0 & 0 \\ \hline 0 & 1 & 0 \\ \hline 0 & 0 & 1 \\ \hline \end{array} \end{matrix}$$

**⚠:** `zeros (n)` or `ones (n)` is a matrix, not a column or row vector.

# Matrix Elements

- To refer to an element in a matrix, you use the matrix variable name followed by ***the index of the row, and then the index of the column***, in parentheses
- ALWAYS refer to the row first, column second
- This is called **subscripted indexing**.



**Variable (row indexes, column indexes)**

```
m1 = [1 2 3;4 5 6];
```

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |

Element

|       |       |       |
|-------|-------|-------|
| (1,1) | (1,2) | (1,3) |
| (2,1) | (2,2) | (2,3) |

Indexing

## Matrix Elements (Continue)

- You can index and refer to an entire row or column using a colon (:).
- Can also refer to any subset of a matrix
  - To refer to the entire  $m^{\text{th}}$  row:  $m1(m, :)$
- To refer to the entire  $n^{\text{th}}$  column:  $m1(:, n)$
- To refer to the last row or column use **end**, (e.g.  $m1(\text{end}, m)$  is the  $m^{\text{th}}$  value in the last row)
- Can modify an element or subset of a matrix in an assignment statement

***Variable (row indexes, column indexes)***

Used for **referring values** and **reading values**

## Example: Matrix Elements

```
m1 = [1 2 3; 4 5 6; 7 8 9];
```

```
c1 = m1(:, 1);
```

```
r1 = m1(2, :);
```

```
c2 = m1(:, end);
```

```
c3 = m1(1:3, end);
```

```
c4 = m1(1:end, end);
```

```
r2 = m1(end, :);
```

```
r3 = m1(3, :);
```

```
m2 = m1(2:3, 2:3);
```

```
m3 = m1(2:end, 2:end);
```

```
m4 = m1([1 3], [1 3]);
```

m1

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |
| 7 | 8 | 9 |

c1

|   |
|---|
| 1 |
| 4 |
| 7 |

r1

|   |   |   |
|---|---|---|
| 4 | 5 | 6 |
|---|---|---|

c2

|   |
|---|
| 3 |
| 6 |
| 9 |

c3

|   |
|---|
| 3 |
| 6 |
| 9 |

c4

|   |
|---|
| 3 |
| 6 |
| 9 |

r2

|   |   |   |
|---|---|---|
| 7 | 8 | 9 |
|---|---|---|

r3

|   |   |   |
|---|---|---|
| 7 | 8 | 9 |
|---|---|---|

m2

|   |   |
|---|---|
| 5 | 6 |
| 8 | 9 |

m3

|   |   |
|---|---|
| 5 | 6 |
| 8 | 9 |

m4

|   |   |
|---|---|
| 1 | 3 |
| 7 | 9 |

## Modifying Matrices

- An individual element in a matrix can be modified by assigning a new value to it.
- Entire rows and columns can also be modified.
- Any subset of a matrix can be modified, as long as what is being assigned has the same dimensions as the subset being modified.
- An exception to this: a scalar can be assigned to any size subset; the same scalar is assigned to every element in the subset.

***Variable (row indexes, column indexes) = Expression***

Used for **referring elements** and **reading values**

## Example: Modifying Matrices

```
>> m1 = [1 2 3; 4 5 6; 7 8 9];
```

```
>> m2 = m1
```

```
m2 =
```

```
1      2      3  
4      5      6  
7      8      9
```

```
>> m2(1,1) = 10
```

```
m2 =
```

```
10     2      3  
4      5      6  
7      8      9
```

```
>> m2(1,end) = 30
```

```
m2 =
```

```
10     2      30  
4      5      6  
7      8      9
```

*... continue ...*

```
>> m2(:,1) = [10; 10; 10];
```

```
m2 =
```

```
10      2      30  
10      5      6  
10      8      9
```

```
>> m2(end,:) = zeros(1, 3);
```

```
m2 =
```

```
10      2      30  
10      5      6  
0       0      0
```

```
>> m2(3,:) = m2(1,:)
```

```
m2 =
```

```
10      2      30  
10      5      6  
10      2      30
```

## Example: Modifying Matrices (Continue)

... continue ...

```
>> m2(:,1) = [10; 10; 10];  
m2 =
```

|    |   |    |
|----|---|----|
| 10 | 2 | 30 |
| 10 | 5 | 6  |
| 10 | 8 | 9  |

```
>> m2(end,:) = zeros(1, 3);  
m2 =
```

|    |   |    |
|----|---|----|
| 10 | 2 | 30 |
| 10 | 5 | 6  |
| 0  | 0 | 0  |

```
>> m2(2,:) = 1;  
m2 =
```

|    |   |    |
|----|---|----|
| 10 | 2 | 30 |
| 1  | 1 | 1  |
| 0  | 0 | 0  |

... continue ...

```
>> m2(:, end) = 3;  
m2 =
```

|    |   |   |
|----|---|---|
| 10 | 2 | 3 |
| 1  | 1 | 3 |
| 0  | 0 | 3 |

```
>> m2([1 3], [1 3]) = 10;  
m2 =
```

|    |   |    |
|----|---|----|
| 10 | 2 | 10 |
| 1  | 1 | 3  |
| 10 | 0 | 10 |

 Exception to this: a scalar can be assigned to any size subset; the same scalar is assigned to every element in the subset.



## Example: Modifying Matrices

Q: Swap the 2<sup>nd</sup> and 3<sup>rd</sup> columns in mat1

```
mat1 = [1 2 3; 4 5 6; 7 8 9];  
  
% write your code here  
vec = mat1(:, 2);  
  
mat1(:,2) = mat1(:,3);  
mat1(:,3) = vec;
```

```
mat1 = [1 2 3; 4 5 6; 7 8 9];  
  
mat1(:, [3 2]) = mat1(:, [2 3]);
```

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |
| 7 | 8 | 9 |

mat1



|   |   |   |
|---|---|---|
| 1 | 3 | 2 |
| 4 | 6 | 5 |
| 7 | 9 | 8 |

mat1

# Matrix Dimension

- There are several functions to determine the dimensions of a vector or matrix:
  - `size` returns the # of rows and columns for a vector or matrix
  - Important: capture both output values in an assignment statement  
`[r, c] = size(mat)`
  - `numel` returns the total # of elements in a vector or matrix

**⚠:** Very important to generalize your script: do not assume that you know the dimensions of a vector or matrix – use `size` or `numel` to find out!

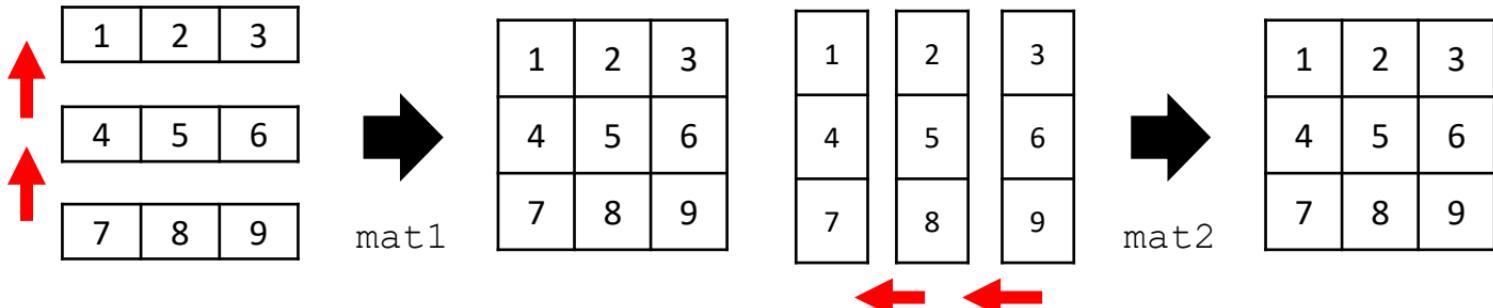
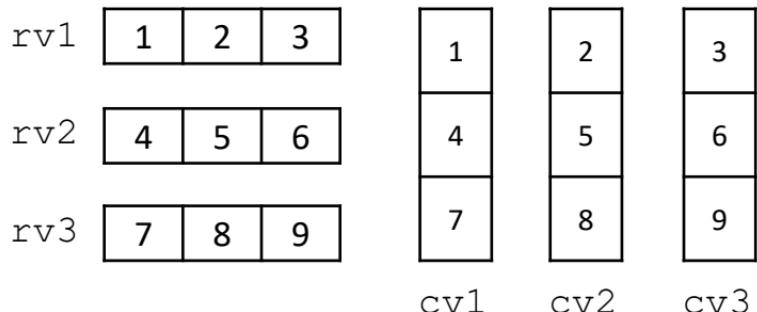
```
m1 = [1 2 3;4 5 6];  
  
[r1, c1] = size(m1);  
  
n_m1 = numel(m1);
```

| Name | Value         |
|------|---------------|
| m1   | [1 2 3;4 5 6] |
| r1   | 2             |
| c1   | 3             |
| n_m1 | 6             |

# Matrix Concatenation

```
rv1 = [1 2 3];  
rv2 = [4 5 6];  
rv3 = [7 8 9];  
  
mat1 = [rv1; rv2; rv3];  
  
cv1 = [1; 4; 7];  
cv2 = [2; 5; 8];  
cv3 = [3; 6; 9];  
  
mat2 = [cv1 cv2 cv3]
```

Matrices can be created by joining, vectors or adding elements.



## Empty Vectors and Matrices

- An ***empty vector*** is a vector with no elements; an empty vector can be created using square brackets with nothing inside [ ]
- To **delete** an element from a vector, assign an empty vector to that element
- Delete an entire row or column from a matrix by assigning [ ]
  - Note: **cannot delete an individual element from a matrix**

```
>> v1 = 2:6  
v1 =  
  
      2      3      4      5      6  
  
>> v1(3) = []  
v1 =  
  
      2      3      5      6  
  
>> v1(end) = []  
v1 =  
  
      2      3      5
```

```
>> m1 = [1 2 3;4 5 6;7 8 9]  
m1 =  
  
      1      2      3  
      4      5      6  
      7      8      9  
  
>> m1(2,:) = []  
m1 =  
  
      1      2      3  
      7      8      9
```

## Scalar Operations

- Numerical operations can be performed on every element in a vector or matrix
- For example, ***Scalar multiplication:*** multiply every element by a scalar

```
>> v1 = [4 0 11] * 3  
v1 =  
  
    12      0     33
```

- Another example: ***Scalar addition:*** add a scalar to every element

```
>> v2 = zeros(1,3) + 5  
v2 =  
  
    5      5      5
```

# Array Operations

Array operations on two matrices A and B.

- These are applied term-by-term, or element-by-element
- In MATLAB:
  - matrix addition:  $A + B$
  - matrix subtraction:  $A - B$       or     $B - A$
  - For operations that are based on multiplication (multiplication, division, and exponentiation), a dot must be placed in front of the operator
    - array (element-wise) multiplication:  $A . * B$
    - array (element-wise) division:  $A . / B, A . \backslash B$
    - array (element-wise) exponentiation  $A . ^ 2$
  - **Matrix multiplication: NOT an array operation:**  $A . * B$  is not equal to  $A * B$ .

## Example: Array Operations

```
m1 = [1 2 3; 4 5 6; 7 8 9];
m2 = [1 1 1; 2 2 2; 1 1 1];
sv = 3;
```

```
mat1 = m1 + m2;
mat2 = m1 .* m2;
mat3 = m1 - m2;
mat4 = m1 ./ m2;

mat5 = m1 + sv;
mat6 = m1 * sv;
```

```
mat5 =
    [4 5 6
     7 8 9
     10 11 12]

mat6 =
    [3 6 9
     12 15 18
     21 24 27]
```

|    |   |   |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |
|----|---|---|---|---|---|---|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|----|---|---|
| m1 | <table border="1"><tr><td>1</td><td>2</td><td>3</td></tr><tr><td>4</td><td>5</td><td>6</td></tr><tr><td>7</td><td>8</td><td>9</td></tr></table> | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | m2 | <table border="1"><tr><td>1</td><td>1</td><td>1</td></tr><tr><td>2</td><td>2</td><td>2</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table> | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | sv | <table border="1"><tr><td>3</td></tr></table> | 3 |
| 1  | 2   | 3 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |
| 4  | 5   | 6 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |
| 7  | 8   | 9 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |
| 1  | 1   | 1 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |
| 2  | 2   | 2 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |
| 1  | 1   | 1 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |
| 3  |   |   |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |   |   |

|        |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
|--------|---|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|--|---|---|---|---|---|---|---|---|----|
| mat1 = | <table border="1"><tr><td>1</td><td>2</td><td>3</td></tr><tr><td>4</td><td>5</td><td>6</td></tr><tr><td>7</td><td>8</td><td>9</td></tr></table> | 1  | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | + | <table border="1"><tr><td>1</td><td>1</td><td>1</td></tr><tr><td>2</td><td>2</td><td>2</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table> | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | = | <table border="1"><tr><td>2</td><td>3</td><td>4</td></tr><tr><td>6</td><td>7</td><td>8</td></tr><tr><td>8</td><td>9</td><td>10</td></tr></table> | 2 | 3 | 4 | 6 | 7 | 8 | 8 | 9 | 10 |
| 1      | 2   | 3  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 4      | 5   | 6  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 7      | 8   | 9  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 1      | 1   | 1  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 2      | 2   | 2  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 1      | 1   | 1  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 2      | 3   | 4  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 6      | 7   | 8  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |
| 8      | 9   | 10 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |  |   |   |   |   |   |   |   |   |    |

|        |   |    |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
|--------|---|----|---|---|---|---|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|----|----|---|---|---|
| mat2 = | <table border="1"><tr><td>1</td><td>2</td><td>3</td></tr><tr><td>4</td><td>5</td><td>6</td></tr><tr><td>7</td><td>8</td><td>9</td></tr></table> | 1  | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | .* | <table border="1"><tr><td>1</td><td>1</td><td>1</td></tr><tr><td>2</td><td>2</td><td>2</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table> | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | = | <table border="1"><tr><td>1</td><td>2</td><td>3</td></tr><tr><td>8</td><td>10</td><td>12</td></tr><tr><td>7</td><td>8</td><td>9</td></tr></table> | 1 | 2 | 3 | 8 | 10 | 12 | 7 | 8 | 9 |
| 1      | 2   | 3  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 4      | 5   | 6  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 7      | 8   | 9  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 1      | 1   | 1  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 2      | 2   | 2  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 1      | 1   | 1  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 1      | 2   | 3  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 8      | 10  | 12 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |
| 7      | 8   | 9  |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |

|        |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|--------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mat3 = | <table border="1"><tr><td>1</td><td>2</td><td>3</td></tr><tr><td>4</td><td>5</td><td>6</td></tr><tr><td>7</td><td>8</td><td>9</td></tr></table> | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | - | <table border="1"><tr><td>1</td><td>1</td><td>1</td></tr><tr><td>2</td><td>2</td><td>2</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table> | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | = | <table border="1"><tr><td>0</td><td>1</td><td>2</td></tr><tr><td>2</td><td>3</td><td>4</td></tr><tr><td>6</td><td>7</td><td>8</td></tr></table> | 0 | 1 | 2 | 2 | 3 | 4 | 6 | 7 | 8 |
| 1      | 2   | 3 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 4      | 5   | 6 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 7      | 8   | 9 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1      | 1   | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 2      | 2   | 2 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1      | 1   | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 0      | 1   | 2 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 2      | 3   | 4 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 6      | 7   | 8 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

|        |   |   |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
|--------|---|---|---|---|---|---|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|---|---|---|---|
| mat4 = | <table border="1"><tr><td>1</td><td>2</td><td>3</td></tr><tr><td>4</td><td>5</td><td>6</td></tr><tr><td>7</td><td>8</td><td>9</td></tr></table> | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | ./ | <table border="1"><tr><td>1</td><td>1</td><td>1</td></tr><tr><td>2</td><td>2</td><td>2</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table> | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | = | <table border="1"><tr><td>1</td><td>2</td><td>3</td></tr><tr><td>2</td><td>2.5</td><td>3</td></tr><tr><td>7</td><td>8</td><td>9</td></tr></table> | 1 | 2 | 3 | 2 | 2.5 | 3 | 7 | 8 | 9 |
| 1      | 2   | 3 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 4      | 5   | 6 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 7      | 8   | 9 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 1      | 1   | 1 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 2      | 2   | 2 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 1      | 1   | 1 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 1      | 2   | 3 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 2      | 2.5   | 3 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |
| 7      | 8   | 9 |   |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |   |   |   |   |

## Matrix Multiplication: Dimensions

- In MATLAB, the multiplication **operator \*** performs matrix multiplication.
- To multiply a matrix A by a matrix B, the number of columns of A must be the same as the number of rows of B.
- If the matrix A has dimension of  $m \times n$ , this means that matrix B must have dimensions of  $n \times$  something;
  - In mathematical notation,  $[A]_{m \times n} [B]_{n \times p}$
  - We say that the **inner dimensions** must be the same
- The resulting matrix C has the same number of rows as A and the same number of columns as B
  - in other words, the **outer dimensions**  $m \times p$
  - In mathematical notation,  $[A]_{m \times n} [B]_{n \times p} = [C]_{m \times p}$ .

 : Matrix multiplication is NOT an array operation. It does NOT mean multiplying term by term (element by element)

## Matrix Times a Vector

[Remind](#)

A linear system of equations with coefficient matrix  $A$ , variable vector  $\vec{x}$  and constant term vector  $\vec{b}$ , can be expressed as

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \cdots & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \vdots \\ b_m \end{bmatrix}$$

matrix      vector  
 $(m \times n) (n \times 1) = (m \times 1)$

$$b_i = \sum_j^n x_j a_{ij}$$

**Compatibility** – the number of columns in the matrix **must** equal the number of rows in the vector.

## Example: Matrix Times a Vector

```
m1 = [1 1 1; 2 2 2; 3 3 3];  
v1 = [2 2 2]';  
  
c1 = m1*v1;  
  
c11 = m1(1,:)*v1;  
c21 = m1(2,:)*v1;  
c31 = m1(3,:)*v1;  
  
c2 = [c11;c21;c31];
```

$$\begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 2 & 2 & 2 \\ \hline 3 & 3 & 3 \\ \hline \end{array} * \begin{array}{|c|} \hline 2 \\ \hline 2 \\ \hline 2 \\ \hline \end{array} = \begin{array}{|c|c|} \hline 6 \\ \hline 12 \\ \hline 18 \\ \hline \end{array}$$

$$m1 * v1 = c1$$

$$\begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 2 & 2 & 2 \\ \hline 2 & 2 & 2 \\ \hline \end{array} * \begin{array}{|c|} \hline 2 \\ \hline 2 \\ \hline 2 \\ \hline \end{array} = \begin{array}{|c|c|} \hline 6 \\ \hline \end{array}$$

$$m1(1,:) * v1 = c11$$

$$\begin{array}{|c|c|c|} \hline 2 & 2 & 2 \\ \hline 2 & 2 & 2 \\ \hline 2 & 2 & 2 \\ \hline \end{array} * \begin{array}{|c|} \hline 2 \\ \hline 2 \\ \hline 2 \\ \hline \end{array} = \begin{array}{|c|c|} \hline 12 \\ \hline \end{array}$$

$$m1(2,:) * v1 = c21$$

$$\begin{array}{|c|c|c|} \hline 3 & 3 & 3 \\ \hline 2 & 2 & 2 \\ \hline 2 & 2 & 2 \\ \hline \end{array} * \begin{array}{|c|} \hline 2 \\ \hline 2 \\ \hline 2 \\ \hline \end{array} = \begin{array}{|c|c|} \hline 18 \\ \hline \end{array}$$

$$m1(3,:) * v1 = c31$$

# Matrix Times a Matrix

[Remind](#)

Matrix multiplication is an extension of matrix and vector multiplication.

Consider the product of an  $m \times n$  matrix  $A$ , and an  $n \times p$  matrix  $B$ :

$$AB = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \dots & \dots & a_{mn} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1p} \\ b_{21} & b_{22} & \dots & b_{2p} \\ b_{31} & b_{32} & \dots & b_{3p} \\ \vdots & \vdots & & \vdots \\ b_{n1} & b_{n2} & \dots & b_{np} \end{bmatrix}$$

$$(m \times n) \text{ matrix} \quad (n \times p) \text{ matrix} = (m \times p) \text{ matrix}$$

**Compatibility** – the number of columns in the first matrix **must** equal the number of rows in the second matrix.

## Example: Matrix Times a Matrix

```
m1 = [1 2; 3 4];  
m2 = [1 2; 2 1];  
  
m3 = m1*m2;
```

```
m411 = m1(1,:)*m2(:,1);  
m421 = m1(2,:)*m2(:,1);  
m412 = m1(1,:)*m2(:,2);  
m422 = m1(2,:)*m2(:,2);
```

```
m4 = [m411 m412; m421 m422];
```

$$\begin{array}{|c|c|} \hline 1 & 2 \\ \hline 3 & 4 \\ \hline \end{array} * \begin{array}{|c|c|} \hline 1 & 2 \\ \hline 2 & 1 \\ \hline \end{array} = \begin{array}{|c|c|} \hline 5 & 4 \\ \hline 11 & 10 \\ \hline \end{array}$$

m1      \*      m2      =      m3

**⚠: \* and .\* are different!**

$$\begin{array}{|c|c|} \hline 1 & 2 \\ \hline \end{array} * \begin{array}{|c|} \hline 1 \\ \hline 2 \\ \hline \end{array} = \begin{array}{|c|} \hline 5 \\ \hline \end{array}$$

m1(1,:) \* m2(:,1) = m411

$$\begin{array}{|c|c|} \hline 3 & 4 \\ \hline \end{array} * \begin{array}{|c|} \hline 1 \\ \hline 2 \\ \hline \end{array} = \begin{array}{|c|} \hline 11 \\ \hline \end{array}$$

m1(2,:) \* m2(:,1) = m421

$$\begin{array}{|c|c|} \hline 1 & 2 \\ \hline \end{array} * \begin{array}{|c|} \hline 2 \\ \hline 1 \\ \hline \end{array} = \begin{array}{|c|} \hline 4 \\ \hline \end{array}$$

m1(1,:) \* m2(:,2) = m412

$$\begin{array}{|c|c|} \hline 3 & 4 \\ \hline \end{array} * \begin{array}{|c|} \hline 2 \\ \hline 1 \\ \hline \end{array} = \begin{array}{|c|} \hline 10 \\ \hline \end{array}$$

m1(2,:) \* m2(:,2) = m422



## Example: Matrix Times a Matrix or Vector

Q. Write a script to compute A, B, C, D using m1 and v1.

$$m1 = \begin{bmatrix} 2 & 4 \\ 3 & 2 \\ 5 & 3 \end{bmatrix} \quad v1 = \begin{bmatrix} 1 \\ 3 \\ 1 \end{bmatrix}$$

$$A = [1 \ 3 \ 1] \begin{bmatrix} 2 & 4 \\ 3 & 2 \\ 5 & 3 \end{bmatrix}$$

$$B = \begin{bmatrix} 2 & 3 & 5 \\ 4 & 2 & 3 \end{bmatrix} \begin{bmatrix} 1 \\ 3 \\ 1 \end{bmatrix} \quad C = [2 \ 3 \ 5] \begin{bmatrix} 1 \\ 3 \\ 1 \end{bmatrix}$$

$$D = [1 \ 3] \begin{bmatrix} 2 & 3 & 5 \\ 4 & 2 & 3 \end{bmatrix}$$

```
m1 = [2 4; 3 2; 5 3];  
v1 = [1; 3; 1];  
  
A = v1' *m1  
  
B = m1' *v1  
  
C = m1 (:,1)' *v1  
  
D = v1(1:2)' *m1'
```



: A' is a transpose of A.

- A ***character*** is a single character in single quotes
- A character vector is sequences of characters in single quotes, e.g. ‘hello and how are you?’
- **A character vector is a vector in which every element is a single character.**

```
ch_vec = 'MATLAB';  
  
n_ch = numel(ch_vec);  
  
ch3 = ch_vec(3);  
ch4 = ch_vec(1:3);  
  
ch_vec1 = [ch_vec ' is fun.'];
```

| Name    | Value            |
|---------|------------------|
| ch_vec  | 'MATLAB'         |
| n_ch    | 6                |
| ch3     | 'T'              |
| ch4     | 'MAT'            |
| ch_vec1 | 'MATLAB is fun.' |

# Character Type Casting

## Challenging

- The numeric type cast function can also convert a character to its equivalent numeric value.
- All characters are mapped to equivalent numeric values.

```
ch1 = 'a';
ch2 = 'b';
ch3 = 'd';

ch_vec1 = 'abc';
```

 This will be very useful for character operations.

|                   |             |
|-------------------|-------------|
| double(ch1)       | 97          |
| char(97)          | 'a'         |
| char(98)          | 'b'         |
| double('d')       | 100         |
| char([97 99])     | 'ac'        |
| 'ab' + 1          | [98 99]     |
| 'cd' - 1          | [98 99]     |
| char('cd'-1)      | 'bc'        |
| ch_vec1 + 1       | [98 99 100] |
| char(ch_vec1 + 1) | 'bcd'       |

## 3D Matrices

## Challenging

- A three-dimensional matrix has dimensions of  $m \times n \times p$
- For example, we can create a  $3 \times 4 \times 2$  matrix of random integers; there are 2 layers, each of which is a  $3 \times 4$  matrix

```
mat3D = zeros(3, 4, 2);

mat1 = [1 2 3 4; 5 6 7 8; 9 10 11 12];
mat2 = [13 14 15 16; 17 18 19 20; 21 22 23 24];

mat3D(:,:,:,1) = mat1;
mat3D(:,:,:,2) = mat2;
```

|   |    |    |    |
|---|----|----|----|
| 1 | 2  | 3  | 4  |
| 5 | 6  | 7  | 8  |
| 9 | 10 | 11 | 12 |

mat1

|    |    |    |    |
|----|----|----|----|
| 13 | 14 | 15 | 16 |
| 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 |

mat2

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

mat3D

# 3D Matrices (Continue)

## Challenging

```
val1 = mat3D(1, 3, 1);  
  
val2 = mat3D(1, 1, 2);  
  
mats = mat3D(1:2, 1:2, 1);
```

| Name  | Value        |
|-------|--------------|
| mat3D | 3x4x2 double |
| val1  | 3            |
| val2  | 13           |
| mats  | [1 2; 5 6]   |

 Large matrices are not printed out in *Workspace*.

mat3D

|   |    |    |    |    |    |    |    |
|---|----|----|----|----|----|----|----|
|   |    |    |    | 13 | 14 | 15 | 16 |
| 1 | 2  | 3  | 4  | 17 | 18 | 19 | 20 |
| 5 | 6  | 7  | 8  | 21 | 22 | 23 | 24 |
| 9 | 10 | 11 | 12 |    |    |    |    |

Element

|         |         |         |         |         |
|---------|---------|---------|---------|---------|
|         | (1,1,2) | (1,2,2) | (1,3,2) | (1,4,2) |
|         | (2,1,2) | (2,2,2) | (2,3,2) | (2,4,2) |
| (1,1,1) | (1,2,1) | (1,3,1) | (1,4,1) |         |
| (2,1,1) | (2,2,1) | (2,3,1) | (2,4,1) |         |
| (3,1,1) | (3,2,1) | (3,3,1) | (3,4,1) |         |

Subindex

# Linear Indexing

# Challenging

- Linear indexing: only using one index into a matrix
- MATLAB will unwind it column-by column going from top to bottom.

```
mat1 = [1 5 3 7;3 2 2 4;4 2 8 9];  
val1 = mat1(2, 1)  
val2 = mat1(2)  
val3 = mat1(3, 4)  
val4 = mat1(12)  
  
vec1 = mat1(3:5)
```

| Name | Value   |
|------|---------|
| val1 | 3       |
| val2 | 3       |
| val3 | 9       |
| val4 | 9       |
| vec1 | [4 5 2] |

|   |   |   |   |
|---|---|---|---|
| 1 | 5 | 3 | 7 |
| 3 | 2 | 2 | 4 |
| 4 | 2 | 8 | 9 |

Element

|       |       |       |       |
|-------|-------|-------|-------|
| (1,1) | (1,2) | (1,3) | (1,4) |
| (2,1) | (2,2) | (2,3) | (2,4) |
| (3,1) | (3,2) | (3,3) | (3,4) |

Subscripted indexing

|   |   |   |    |
|---|---|---|----|
| 1 | 4 | 7 | 10 |
| 2 | 5 | 8 | 11 |
| 3 | 6 | 9 | 12 |

Linear indexing

## Function: **reshape** (x, sz)

## Challenging

B = reshape (A, sz) reshapes A using the size vector, sz, to define size (B). sz must contain at least 2 elements, product of elements in sz must be the same as numel (A).

```
vec = 3:14; % 12 elements
```

```
mat0 = reshape(vec, [2 6]);
mat1 = reshape(vec, [3 4]);
mat2 = reshape(mat1, [6 2]);
```

mat1

|   |   |    |    |
|---|---|----|----|
| 3 | 6 | 9  | 12 |
| 4 | 7 | 10 | 13 |
| 5 | 8 | 11 | 14 |

vec

|   |   |   |   |   |   |   |    |    |    |    |    |
|---|---|---|---|---|---|---|----|----|----|----|----|
| 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|----|----|----|----|----|

mat0

|   |   |   |    |    |    |
|---|---|---|----|----|----|
| 3 | 5 | 7 | 9  | 11 | 13 |
| 4 | 6 | 8 | 10 | 12 | 14 |

mat2

|   |    |
|---|----|
| 3 | 9  |
| 4 | 10 |
| 5 | 11 |
| 6 | 12 |
| 7 | 13 |
| 8 | 14 |

# Types of Errors

## Syntax error

```
a1 = [1 2 3];  
3 = a1 + 2;
```

Error: Incorrect use of '=' operator. To assign a value to a variable, use '='. To compare values for equality, use '=='.

```
a@2 = [1 2 3];
```

Error: Invalid expression. Check for missing multiplication operator, missing or unbalanced delimiters, or other syntax error.

## Runtime error

```
a2 =[11 2 3];  
b2 = a2(4) + 1;
```

Index exceeds the number of array elements (3).

```
A = [1 2;3 4];  
val1 = A(3,4);
```

Index in position 1 exceeds array bounds (must not exceed 2).

## Logical error

```
A = [1 2;3 4];  
B = [3 4;5 6];  
  
m1 = A.*B;  
m2 = A*B;
```



## Example: Types of Errors

Q. Which of the following scripts occur run-time or syntax error?

|     |  |
|-----|--|
| (1) | <code>mat1 = ones(10,10);<br/>mat1(1:2, 5:10) = [];</code> |
| (2) | <code>mat1 = ones(10,10);<br/>mat1(1, 5) = [];</code>      |
| (3) | <code>mat1 = ones(10,10);<br/>mat1(1, 1:2) = 3;</code>     |
| (4) | <code>mat1 = ones(10,10);<br/>mat1 = [1 2; 3 4];</code>    |

1. (1), (2)
2. (1), (2), (3)
3. (1), (2), (4)
4. (3), (4)
5. (1), (3), (4)



## Example (Midterm in S19)

Q. Write a code to compute val1, val2, and mat1 using A,B,r, and c

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \\ a_{41} & a_{42} & a_{43} \end{bmatrix} \quad B = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \end{bmatrix} \quad c = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} \quad r = [r_1 \quad r_2 \quad r_3 \quad r_4]$$

$$val1 = c_1 r_1 + c_2 r_2 + c_3 r_3$$

$$val2 = [c_1 r_1 \quad c_2 r_2 \quad c_3 r_3 \quad c_4 r_4]$$

$$mat1 = \begin{bmatrix} b_{11}r_1 & b_{12}r_2 & b_{13}r_3 & b_{14}r_4 \\ b_{21}r_1 & b_{22}r_2 & b_{23}r_3 & b_{24}r_4 \\ b_{31}r_1 & b_{32}r_2 & b_{33}r_3 & b_{34}r_4 \end{bmatrix}$$

```
val1 = r(1:3)*c(1:3);
```

```
val2 = r.*c';
```

```
mat1 = B.*[r; r; r];
```

# Module 03: Selection Statement

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## **Module 3: Intended Learning Outcomes**

- Describe a problem that requires if statement
- Construct an if-else statement and explain its operation
- Compare an if-else statement and its variants
- Create a script using a switch statement

## If-Statement

- The **if** statement is used to determine whether or not a statement or group of statements is to be executed
- General form:

```
if condition  
    action  
end
```

- the *condition* is any relational expression (True or False)
- the *action* is any number of valid statements (including, possibly, just one)

If the condition is true, the action is executed – otherwise, it is skipped entirely.



## Example: Relational Operator

Q. How to write a code to check if  $x$  lies in between 5 and 10. If yes, assign true to lg1 and otherwise false.

```
1 x1 = 6;  
2  
3 lg1 = (5 < x1) && (x1<10)
```

```
1 x1 = 6;  
2 lg1 = false;  
3  
4 if (5 < x1) && (x1<10)  
5     lg1 = true  
6 end
```

Q. How to write a code to check if  $x$  lies in between 5 and 10. If yes, assign 10 to val and otherwise 5.

```
1 x1 = 6;  
2  
3 val = 5;  
4  
5 if (5 < x1) && (x1<10)  
6     val = 10;  
7 end
```



## Example: Write a Code for Computing $\text{abs}(x)$

**abs (x)**

Finds the absolute value of **x**

**abs (-3)**

**3**

**abs (2)**

**2**

```
1 x1 = -3  
2  
3 if x1>=0  
4     xabs = x1;  
5 end  
6  
7 if x1<0  
8     xabs = x1*-1;  
9 end  
10
```

At line 4,  $x1$  is not more than 0, and thus, the if-statement is skipped (move to line 8). At line 8, since  $x1$  is less than 0, the action (line 9) is executed.  $x1 * -1$  is assigned to  $xabs$ .

| Name | Value |
|------|-------|
| x1   | -3    |
| xabs | 3     |

```
x1 = -3  
xabs = x1  
  
if x1<0  
    xabs = x1*-1;  
end
```

This code  
also works.



## Example: Write a Code for Computing sign (x)

**sign(x)**

Return **-1** if **x** is less than zero, a value of **0** if **x** equals zero, and a value of **1** if **x** is greater than zero.

sign(-5)  
sign(3)  
sign(0)

-1  
1  
0

```
x1 = -3

if x1 == 0
    xsign = 0 ;
end

if x1<0
    xsign = -1;
end

if x1>0
    xsign = 1;
end
```

```
x1 = -3
xsign = 0;

if x1<0
    xsign = -1;
end

if x1>0
    xsign = 1;
end
```

| Name  | Value |
|-------|-------|
| x1    | -3    |
| xsign | -1    |



## Example: Bulls and Cows

Bulls and Cows is a mind game played by two players.

In the game, a random, 4-digit number is chosen and its values are compared to those of another trial number. **All four digits of the number are different.** If any digit in the chosen number is the exact same value and in the exact same position as any digit in the trial number, this is called a bull. If the digit is present in both the trial number and chosen number, but is not in the same location, this is called a cow.



*In this figure, A: Bulls, B: Cows*



## Example: Bulls and Cows (Continue)

```
1 x_true = [1 2 3 4]; % true
2 x_test = [3 2 5 6]; % test
3
4 numb = 0; % number of Bull
5
6 if x_true(1) == x_test(1)
7     numb = numb + 1;
8 end
9
10 if x_true(2) == x_test(2)
11     numb = numb + 1;
12 end
13
14 if x_true(3) == x_test(3)
15     numb = numb + 1;
16 end
17
18 if x_true(4) == x_test(4)
19     numb = numb + 1;
end
```

Q: Write a script to compute “Bull” and assign its value to numb. The true and test sequence are in x\_true and x\_test, respectively.

| Name | Value     |
|------|-----------|
| x1   | [1 2 3 4] |
| x2   | [3 2 5 6] |
| numb | 1         |



We will keep revisiting these examples later!!

## If-else Statement

- The **if-else** statement chooses between two actions
- General form:

```
if condition  
    action1  
else  
    action2  
end
```

- ***Only one action is executed;*** which one depends on the value of the condition. In the above statement, execute action1 if condition is true **or** action2 if condition is not true (false).



## Example: If-else Statement

**abs (x)**

Finds the absolute value of **x**

**abs (-3)**

**3**

**abs (2)**

**2**

```
x1 = -3  
  
if x1>=0  
    xabs = x1;  
end  
  
if x1<0  
    xabs = x1*-1;  
end
```

```
x1 = -3  
xabs = 0  
  
if x1>0  
    xabs = x1;  
else  
    xabs = x1*-1;  
end
```

⌚: In this example, there is no difference in the final result. However, I recommend if-else statement because **abs (x)** is an obvious logical (binary) operation, meaning that if action1 is performed, action2 will not be executed.

| Name | Value |
|------|-------|
| x1   | -3    |
| xabs | 3     |

| Name | Value |
|------|-------|
| x1   | -3    |
| xabs | 3     |

# Nested if-else Statements

- To choose from more than two actions, ***nested if-else*** statements can be used (an **if** or **if-else** statement as the action of another)
- General form:

```
if condition1
    action1
else
    if condition2
        action2
    else
        action3
    end
end
```

 In this statement, only one action statement is executed!!

Recall the if-else statement:

```
if condition
    action1
else
    action2
end
```



## Example: Nested if-else Statements

Q: If 'scalar1' is larger than 0 and less than 50, assign 10 to 'out1'. Otherwise, assign 5 to 'out1'.

```
scalar1 = 20;

if scalar1 > 0
    if scalar1<50
        out1 = 10;
    else
        out1 = 5;
    end
else
    out1 = 5;
end
```

```
scalar1 = 20;

if (scalar1 > 0) && (scalar1 < 50)
    out1 = 10;
else
    out1 = 5;
end
```

In general, I avoid multiple levels of nested if-else statement. The script on the right is more readable and avoids potential mistakes.

## if-else and elseif Statements

- MATLAB also has an `elseif` clause which shortens the code (and cuts down on the number of `ends`)
- General form:

```
1 if condition1  
2     action1  
3 elseif condition2  
4     action2  
5 elseif condition3  
6     action3  
7 else  
8     action4  
9 end
```

 Again, in this statement, only one action statement must be executed!!

If `condition1` is true, `action1` is executed and go to `end` at line9. If `condition1` is false, go to `condition2` and execute `action2` if `condition2` is true. The same operation is performed for `condition3` and `action3`. If none of `condition1, 2, 3` is true, `action4` is executed.



## Example: if-else and elseif Statements

Q: Write a script to determine a grade based on a score named `score`: A:  $score \geq 90$ , B:  $80 \leq score < 90$ , C:  $70 \leq score < 80$ , D:  $score < 70$ . A character grade should be assigned to a variable named `grade`.

```
score = 81;

if score>= 90
    grade = 'A';
end
if score>=80 && score < 90
    grade = 'B';
end
if score>=70 && score < 80
    grade = 'C';
end
if score < 70
    grade = 'D';
end
```

Option 1

```
score = 81;

if score>= 90
    grade = 'A';
else
    if score >=80
        grade = 'B';
    else
        if score >=70
            grade = 'C';
        else
            grade = 'D';
        end
    end
end
```

Option 1



## Example: if-else and elseif Statements (Continue)

Q: Write a script to determine a grade based on a score named `score`: A: `score >=90`, B: `80 <= score < 90`, C:`70 <= score < 80`, D: `score < 70`. A character grade should be assigned to a variable named `grade`.

```
score = 81;  
  
if score>= 90  
    grade = 'A';  
end  
if score>=80 && score < 90  
    grade = 'B';  
end  
if score>=70 && score < 80  
    grade = 'C';  
end  
if score < 70  
    grade = 'D';  
end
```

Option 1

```
score =81;  
  
if score>= 90  
    grade = 'A';  
elseif score >=80  
    grade = 'B';  
elseif score >=70  
    grade = 'C';  
else  
    grade = 'D';  
end
```

Option 3

☺: Option 3 is simpler and more readable.

# Correct Use of if-else-elseif Statement

```
score =81;  
  
if score>= 90  
    grade = 'A';  
elseif score >=70  
    grade = 'C';  
elseif score >=80  
    grade = 'B';  
else  
    grade = 'D';  
end
```

Option 3

```
score =81;  
  
if score>= 90  
    grade = 'A';  
elseif and(score < 90, score>=80)  
    grade = 'B';  
elseif and(score < 80, score>=70)  
    grade = 'C';  
else  
    grade = 'D';  
end
```

Option 4

: If the order of the condition statements is changed, a total wrong result will be obtained.

Here, grade become 'C' , not 'B' . Again, only one action is executed!

: You can also define a clear condition statement to avoid confusion.

## Correct Use of if-else-elseif Statement (Another Example)

Write a code if the value named 'val' is a multiples of 2, add 1 to 'num'. If 'val' is multiples of 3, add additional 1 to 'num'.

```
num = 0;  
val = 6;  
  
if rem(val, 2) == 0  
    num = num + 1;  
end  
  
if rem(val, 3) == 0  
    num = num + 1;  
end
```

Correct

```
num = 0;  
val = 6;  
  
if rem(val, 2) == 0  
    num = num + 1;  
elseif rem(val, 3) == 0  
    num = num + 1;  
end
```

Wrong

| Name | Value |
|------|-------|
| num  | 2     |

| Name | Value |
|------|-------|
| num  | 1     |

## Summary: if, if-else, if-elseif, if-elseif-else

```
if condition1  
    action1  
end
```

```
if condition1  
    action1  
else  
    action2  
end
```

```
if condition1  
    action1  
elseif condition2  
    action2  
end
```

```
if condition1  
    action1  
elseif condition2  
    action2  
else  
    action3  
end
```

# How to Write a Formatted Script

- Use indentation to show the structure of a script or function for readability.  
Four empty spaces are indented in an action statement.
- The best way to format your script is to apply smart indenting while writing your script. Select your script and press ***Ctrl + I***.

```
x1 = -3
xabs = 0

if x1>0
    xabs = x1;
else
    xabs = x1*-1;
end
```

```
x1 = -3
xabs = 0
if x1>0
    xabs = x1;
else
    xabs = x1*-1;
end
```

 Both are the same and working scripts. Which do you prefer?

# Shorten Your Scripts

## Optional, Challenge

```
x1 = -3  
xabs = 0
```

```
if x1>=0  
    xabs = x1;  
end
```

```
if x1<0  
    xabs = x1*-1;  
end
```

**Option 1**

```
x1 = -3;  
xabs = 0;  
  
if x1>=0  
    xabs = x1;  
else  
    xabs = x1*-1;  
end
```

**Option 2**

**abs (x)**

Finds the absolute value of **x**

```
x1 = -3
```

```
xabs = (x1>=0)*x1 + -1*(x1<0)*x1
```

**Option 3**

 Here,  $x1$  is negative. Thus,  $(x1>=0)$  becomes logical 0. Due to intrinsic typecasting, this will be numeric 0 (type: double). Thus, the first term becomes 0. In the next term,  $(x1<0)$  becomes logical 1. Then,  $-1 * (x1<0) * x1$  becomes  $-1 * x1$ . Finally,  $-1 * x1$  is assigned to  $xabs$ , which is the same operation using if-statement.

## Switch-case Statement

- The **switch-case** statement can frequently be used in place of a nested **if-else** or **if-elseif** statement.
- This can be used when comparing the `switch_expression` to see if it is equal to the values on the case labels (the **otherwise** clause handles all other possible values)

General form:

```
switch switch_expression
  case caseexp1
    action1
  case caseexp2
    action2
  case caseexp3
    action3
  % etc: there can be many of these n actions
  otherwise
    actionn
end
```



In practice, switch-case statement is used more with character values (or character vectors).



## Example: switch-case Statements

```
grade = 'A';

if grade == 'A'
    disp('Your score is in the range of 90-100.');
elseif grade == 'B'
    disp('Your score is in the range of 80-90.');
elseif grade == 'C'
    disp('Your score is in the range of 70-80.');
elseif grade == 'D'
    disp('Your score is below 70.');
else
    disp('We do not have such grade.')
end
```

Q: Write a script to tell you the score range when your input is a grade. `disp()` is a function to print out text in a command window.

```
grade = 'A';

switch grade
    case 'A'
        disp('Your score is in the range of 90-100.');
    case 'B'
        disp('Your score is in the range of 80-90.');
    case 'C'
        disp('Your score is in the range of 70-80.');
    case 'D'
        disp('Your score is below 70.');
    otherwise
        disp('We do not have such grade.')
end
```

## Throwing an Error

Optional

- MATLAB has `error` functions that can be used to display an error message in red, similar to the error messages generated by MATLAB or generated by MATLAB grader.
- When an error is thrown in a script, the script stops executing

```
if your_var ~= model_var
    error('Sorry: your value is not correct');
else
    disp('Pass the test');
end
```

- `assert(cond, msg)` throws an error if `cond` is false.

```
assert(your_var == model_var, 'Sorry: your value is not correct');
```

# Module 04: Loop Statement

Chul Min Yeum

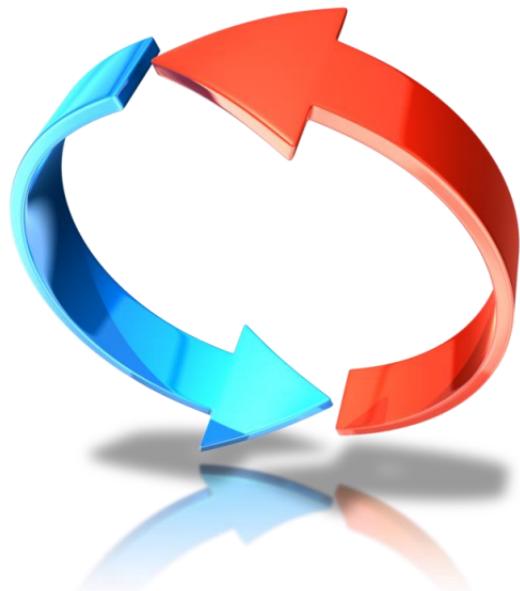
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## Module 4: Learning Outcomes

- Describe a problem that requires a loop statement
- Explain how a for-loop structure is operated
- Identify a break command and its operation
- Illustrate the difference between for-loop and while statement
- Solve and design problems using a loop statement and if-statement

## For-Loop Statement

- Used as a **counted** loop (We know how many times are repeated)
- **Repeat** an action a specified number of times
- An *iterator* or loop variable specifies how many times to repeat the action
- General form:

```
for loopvar = range  
    action  
end
```

- The range is specified by a **vector**.
- The action is repeated for every value in the specified range and it is assigned to loopvar.
- If it is desired to repeat reading input a specified number of times (N), a for loop is used:

```
for ii = 1:N  
    % do something with it!  
end
```



## Example: Summation of Values

Q. Sum 1 to 3 and assign the value to 'sumv'

```

1 sumv = 0;
2 for ii=1:3
3     sumv = sumv + ii;
4 end
5

```

| Step | Operation  | Workspace        |
|------|--|------------------|
| 1    | line1: assign 0 to sumv                            | sumv → 0         |
| 2    | line2: ii becomes 1                                | sumv → 0, ii → 1 |
| 3    | line3: add ii to sumv and assign the value to sumv | sumv → 1, ii → 1 |
| 4    | line4: end   | sumv → 1, ii → 1 |
| 5    | go back to line2 and ii becomes 2                  | sumv → 1, ii → 2 |
| 6    | line3: add ii to sumv and assign the value to sumv | sumv → 3, ii → 2 |
| 7    | line4: end   | sumv → 3, ii → 2 |
| 8    | go back to line2 and ii becomes 3                  | sumv → 3, ii → 3 |
| 9    | line3: add ii to sumv and assign the value to sumv | sumv → 6, ii → 3 |
| 10   | line4: end   | sumv → 6, ii → 3 |
| 11   | no more value in range and go to line5             | sumv → 6, ii → 3 |

## Example: Summations of Values in a Vector

Q. Sum all values in a vector named 'vec' and assign the value to 'sumv'

```
1 vec = [2 3 7 11];  
2 sumv = 0;  
3 for ii=1:4  
4     sumv = sumv + vec(ii);  
5 end
```

| Step | Operation  | Workspace                  |
|------|--|----------------------------|
| 1    | line 1 and 2: assign [2 3 7 11] to vec and 0 to sumv     | vec → [1 3 7 11], sumv → 0 |
| 2    | line 3: ii becomes 1                                     | sumv → 0, ii → 1           |
| 3    | line 4: add vec(ii) to sumv and assign the value to sumv | sumv → 2, ii → 1           |
| 4    | line 5: end  | sumv → 2, ii → 1           |
| 5    | line 3: ii becomes 2                                     | sumv → 2, ii → 2           |
| 6    | line 4: add vec(ii) to sumv and assign the value to sumv | sumv → 5, ii → 2           |
| 7    | line 5: end  | sumv → 5, ii → 2           |
| :    | continue to run until ii becomes 4.                      |                            |
| 9    | line 5: end  | sumv → 23, ii → 4          |

## Example: Summations of Values in a Vector (Continue)

Two different ways of designing a loop statement.

```
1 vec = [2 3 7 11];
2 sumv = 0;
3 nvec = numel(vec);
4 for ii=1:nvec
    sumv = sumv + vec(ii);
5 end
```

```
for ii = 1:N
    % do something!
end
```

```
1 vec = [2 3 7 11];
2 sumv = 0;
3 for val=vec
    sumv = sumv + val;
5 end
```

```
for loopvar = range
    % do something!
end
```

## Nested For-Loop Statement

- A nested for-loop is one inside of ( as the action of) another for loop
- General form of a nested **for** loop:

```
for loopvar1 = range1
    action1
    for loopvar2 = range2
        action2
    end
end
```

- The inner loop action is executed in its entirety for every value of the outer loop variable.



# Example: Summation of Values in a Matrix

Q. Sum all values in a matrix named 'mat1' and assign the value to 'sumv'

mat1

|   |   |   |
|---|---|---|
| 2 | 8 | 7 |
| 1 | 5 | 6 |

```

1 mat1 = [2 8 7; 1 5 6];
2 sumv = 0;
3 for ii=1:2
4     for jj=1:3
5         sumv = sumv + mat1(ii,jj);
6     end
7 end

```

| Step | Operation  | Workspace                       |
|------|--|---------------------------------|
| 1    | line1: assign values to mat1   | mat1 → [2 8 7; 1 5 6]           |
| 2    | line2: assign 0 to sumv  | mat1 → [2 8 7; 1 5 6], sumv → 0 |
| 3    | line3: ii becomes 1  | sumv → 0, ii → 1                |
| 4    | line4: jj becomes 1  | sumv → 0, ii → 1, jj → 1        |
| 5    | line5: Read a value at the 1st row and 1st column in mat1 and add the value to sumv and assign the value to sumv | sumv → 2, ii → 1, jj → 1        |
| 6    | line6: end   | sumv → 2, ii → 1, jj → 1        |
| 7    | line4: go back to line 4 and jj becomes 2  | sumv → 2, ii → 1, jj → 2        |

Omit mat1  
after Step 2  
in Workspace

## Example: Summation of Values in a Matrix (Continue)

Q. Sum all values in a matrix named 'mat1' and assign the value to 'sumv'

mat1

|   |   |   |
|---|---|---|
| 2 | 8 | 7 |
| 1 | 5 | 6 |

```
1 mat1 = [2 8 7; 1 5 6];
2 sumv = 0;
3 for ii=1:2
4     for jj=1:3
5         sumv = sumv + mat1(ii,jj);
6     end
7 end
```

| Step | Operation  | Workspace                 |
|------|--|---------------------------|
| 7    | line4: jj becomes 2  | sumv → 2, ii → 1, jj → 2  |
| 8    | line5: Read a value at the 1st row and 2nd column in mat1 and add the value to sumv and assign the value to sumv | sumv → 10, ii → 1, jj → 2 |
| 9    | line6: end   | sumv → 10, ii → 1, jj → 2 |
| 10   | line4: jj becomes 3  | sumv → 10, ii → 1, jj → 3 |
| 11   | line5: Read a value at the 1st row and 3rd column in mat1 and add the value to sumv and assign the value to sumv | sumv → 17, ii → 1, jj → 3 |
| 12   | line6: end   | sumv → 17, ii → 1, jj → 3 |

## Example: Summation of Values in a Matrix (Continue)

Q. Sum all values in a matrix named 'mat1' and assign the value to 'sumv'

mat1

|   |   |   |
|---|---|---|
| 2 | 8 | 7 |
| 1 | 5 | 6 |

```
1 mat1 = [2 8 7; 1 5 6];
2 sumv = 0;
3 for ii=1:2
4     for jj=1:3
5         sumv = sumv + mat1(ii,jj);
6     end
7 end
```

| Step | Operation  | Workspace                 |
|------|--|---------------------------|
| 12   | line6: end   | sumv → 17, ii → 1, jj → 3 |
| 13   | line7: end   | sumv → 17, ii → 1, jj → 3 |
| 14   | line3: ii becomes 2  | sumv → 17, ii → 2, jj → 3 |
| 15   | line4: jj becomes 1  | sumv → 17, ii → 2, jj → 1 |
| 16   | line5: Read a value at the 2nd row and 1st column in mat1 and add the value to sumv and assign the value to sumv | sumv → 18, ii → 2, jj → 1 |
| 17   | line6: end   | sumv → 18, ii → 2, jj → 1 |

## Example: Summation of Values in a Matrix (Continue)

Q. Sum all values in a matrix named 'mat1' and assign the value to 'sumv'

mat1

|   |   |   |
|---|---|---|
| 2 | 8 | 7 |
| 1 | 5 | 6 |

```
1 mat1 = [2 8 7; 1 5 6];
2 sumv = 0;
3 for ii=1:2
4     for jj=1:3
5         sumv = sumv + mat1(ii,jj);
6     end
7 end
```

| Step | Operation  | Workspace                 |
|------|--|---------------------------|
| 17   | line6: end   | sumv → 18, ii → 2, jj → 1 |
| 18   | line4: jj becomes 2  | sumv → 18, ii → 2, jj → 2 |
| 19   | line5: Read a value at the 2nd row and 2st column in mat1 and add the value to sumv and assign the value to sumv | sumv → 23, ii → 2, jj → 2 |
| 20   | line6: end   | sumv → 23, ii → 2, jj → 2 |
| 21   | line4: jj becomes 3  | sumv → 23, ii → 2, jj → 3 |
| 22   | line5: Read a value at the 2nd row and 3rd column in mat1 and add the value to sumv and assign the value to sumv | sumv → 29, ii → 2, jj → 3 |
| 23   | line6: end, line7: end   | sumv → 29, ii → 2, jj → 3 |

# Summation of Values using Linear Indexing

Challenging

Q. Sum all values in a matrix named 'mat1' and assign the value to 'sumv'

```
mat1 = [2 8 7; 1 5 6];
sumv = 0;
for ii=1:2
    for jj=1:3
        sumv = sumv + mat1(ii,jj);
    end
end
```

```
mat1 = [2 8 7; 1 5 6];
sumv = 0;
n_val = numel(mat1);
for ii=1:n_val
    sumv = sumv + mat1(ii);
end
```

mat1

|   |   |   |
|---|---|---|
| 2 | 8 | 7 |
| 1 | 5 | 6 |

Element

|       |       |       |
|-------|-------|-------|
| (1,1) | (1,2) | (1,3) |
| (2,1) | (2,2) | (2,3) |

Subscripted indexing

|   |   |   |
|---|---|---|
| 1 | 3 | 5 |
| 2 | 4 | 6 |

Linear indexing

## Pre-allocating a Vector

- Pre-allocation is to set aside enough memory for a vector to be stored
- The alternative, extending a vector, is very inefficient because it requires finding new memory and copying values every time
- Many functions can be used to pre-allocation like zeros, ones, eyes
- For example, to pre-allocate a vector `vec` to have `N` elements:
- `vec = zeros(1, N);`
- (Highly recommended) if you knew the array size that you allocate values computed from a loop !!!



## Example: Summation of Values in Each Row of a Matrix

Q. Sum all values in each row of the matrix named 'mat1' and assign the value to the corresponding row of a row vector named 'rvec'.

```
mat1 = [2 8; 1 3; 2 3];
rvec = zeros(1,3);
for ii=1:3
    sumr = 0;
    for jj=1:2
        sumr = sumr + mat1(ii,jj);
    end
    rvec(ii) = sumr; % identical with rvec(ii,1)
end
```

| Name | Value           |
|------|-----------------|
| mat1 | [2 8; 1 3; 2 3] |
| rvec | [10 4 5]        |

```
mat1 = [2 8; 1 3; 2 3];
for ii=1:3
    sumr = 0;
    for jj=1:2
        sumr = sumr + mat1(ii,jj);
    end
    rvec(ii) = sumr;
end
```

⚠: rvec is not pre-allocated. Thus, in each iteration, the size of rvec will be changed

Working but not recommended

## Example: Summation of Values in Each Row of a Matrix (Continue) ★

Q. Sum all values in each row of the matrix named 'mat1' and assign the value to the corresponding row of a row vector named 'rvec'.

```
mat1 = [2 8; 1 3; 2 3];
rvec = zeros(1,3);
for ii=1:3
    sumr = 0;
    for jj=1:2
        sumr = sumr + mat1(ii,jj);
    end
    rvec(ii) = sumr; % identical with rvec(ii,1)
end
```

| Name | Value           |
|------|-----------------|
| mat1 | [2 8; 1 3; 2 3] |
| rvec | [10 4 5]        |

```
mat1 = [2 8; 1 3; 2 3];
rvec = zeros(1,3);

for ii=1:3
    for jj=1:2
        rvec(ii) = rvec(ii) + mat1(ii,jj);
    end
end
```

# Combining for-loop and if-else Statements

- **for-loop** and **if-else** statements can be combined
  - the action of a loop can include an **if-else** statement
  - the action of an **if-else** statement can include a **for-loop**
- This is also true for the nested **for-loops**; **if-else** statements can be part of the action(s) of the outer and/or inner loops
- This is done if an action is required on an element (of a vector or matrix) only if a condition is met.

```
for loopvar1 = range1
    if condition
        action
    end
end
```

 Again, action is only executed if condition is true. This form is to execute action using selective values in range1.



## Example: Combining for-loop and If-elseif Statement

Q. Change 1 to 5, 2 to 7, and the rest to 10 in a given vector named 'vec'

```
vec = [1 1 2 1 3 1 6 7 5];  
  
n_vec = numel(vec);  
for ii=1:n_vec  
    if vec(ii) == 1  
        vec(ii) = 5;  
    elseif vec(ii) == 2  
        vec(ii) = 7;  
    else  
        vec(ii) = 10;  
    end  
end
```

| Name  | Value                   |
|-------|-------------------------|
| vec   | [5 5 7 5 10 5 10 10 10] |
| n_vec | 9                       |

```
for loopvar1 = range1  
    if condition  
        action  
    end  
end
```

⌚: We will revisit this examples later!!



## Example: Value Replacement

Q. If values in 'vec1' are larger than and equal to 0 and less than 50, replace the values to 10. Otherwise, replace them to 5.

```
vec = [1 10 70 80 2];  
  
n_vec = numel(vec);  
  
for ii=1:n_vec  
    t_val = vec(ii);  
    if (t_val >= 0) && (t_val < 50)  
        vec(ii) = 10;  
    else  
        vec(ii) = 5;  
    end  
end
```

| Name  | Value          |
|-------|----------------|
| vec   | [1 10 70 80 2] |
| n_vec | [10 10 5 5 10] |



## Example: Find a Value

Q. Find index(es) of a vector where 5 is located. The vector named as 'vec' is given. The resulting indexes are assigned to 'loc'.

```
vec = [1 5 6 4 8 5 3 7 5];  
  
n_vec = numel(vec);  
loc = [];  
for ii=1:n_vec  
    if vec(ii) == 5  
        loc = [loc ii];  
    end  
end
```

Option 1

```
vec = [1 5 6 4 8 5 3 7 5];  
  
n_vec = numel(vec);  
loc = [];  
for ii=1:n_vec  
    if vec(ii) == 5  
        loc(end+1) = ii;  
    end  
end
```

Option 2

```
vec = [1 5 6 4 8 5 3 7 5];  
  
n_vec = numel(vec);  
loc = 0;  
count = 1;  
for ii=1:n_vec  
    if vec(ii) == 5  
        loc(count) = ii;  
        count = count + 1;  
    end  
end
```

Option 3

| Name | Value   |
|------|---------|
| loc  | [2 6 9] |



## Example: Find a Value (Continue)

Q. Find index(es) of a vector where 5 is located. The vector named as 'vec' is given and the indexes are assigned to 'loc'.

```
vec = [1 5 6 4 8 5 3 7 5];  
  
n_vec = numel(vec);  
loc = [];  
for ii=1:n_vec  
    if vec(ii) == 5  
        loc = [loc ii];  
    end  
end
```

Option 1

Since you do not know the size of loc in advance, you can pre-allocate the variable with its maximum size and delete the “unused” elements.

```
vec = [1 5 6 4 8 5 3 7 5];  
  
n_vec = numel(vec);  
loc = zeros(1, n_vec);  
  
count = 0;  
for ii=1:n_vec  
    if vec(ii) == 5  
        count = count + 1;  
        loc(count) = ii;  
    end  
end  
  
loc = loc(1:count);
```

Option 4



## Example: Bulls and Cows

Bulls and Cows is a mind game played by two players.

In the game, a random, 4-digit number is chosen and its values are compared to those of another trial number. **All four digits of the number are different.** If any digit in the chosen number is the exact same value and in the exact same position as any digit in the trial number, this is called a bull. If the digit is present in both the trial number and chosen number, but is not in the same location, this is called a cow.





## Example: Bulls and Cows

```
x_true = [1 2 3 4]; % true
x_test = [3 2 5 6]; % test

numb = 0; % number of Bull
if x_true(1) == x_test(1)
    numb = numb + 1;
end

if x_true(2) == x_test(2)
    numb = numb + 1;
end

if x_true(3) == x_test(3)
    numb = numb + 1;
end

if x_true(4) == x_test(4)
    numb = numb + 1;
end
```

Q: Write a script to compute “Bull” and assign its value to num\_b. The true and test sequence is in x\_true and x\_test, respectively.

```
x_true = [1 2 3 4]; % true
x_test = [3 2 5 6]; % test

numb = 0; % number of Bull
for ii=1:4
    if x_true(ii) == x_test(ii)
        numb = numb + 1;
    end
end
```



Much simple and readable.

## Example: Bulls and Cows (Continue)



Q: Write a script to compute “Cows” + “Bulls” and assign its value to `num_c`. In other word, you need to compute how many same digits are present in both sequences. The true and test sequence is in `x_true` and `x_test`, respectively.

```
x_true = [1 2 3 4]; % true
x_test = [3 2 5 6]; % test

numc = 0;
for ii=1:4
    for jj=1:4
        if x_true(ii) == x_test(jj)
            numc = numc + 1;
        end
    end
end
```

| Name | Value     |
|------|-----------|
| x1   | [1 2 3 4] |
| x2   | [3 2 5 6] |
| numc | 2         |

: “Cows” becomes “numc” – “numb” obtained from the previous code.

# Break

- **break** command can be used to terminate a loop prematurely (while the comparison in the first line is still true).
- A **break** statement will cause termination of the smallest (closest) enclosing while or for loop.

```
1 vec = zeros(1,5);  
2  
3 for ii=1:5  
4  
5     if ii == 3  
6         break;  
7     end  
8     vec(ii) = ii;  
9  
10 end
```

| Name | Value       |
|------|-------------|
| vec  | [1 2 0 0 0] |
| ii   | 3           |

 When `ii` is equal to 3, condition in line 5 is true so `break` command is executed. Then, the code directly goes to `end` at line 10 (skip a script inside a loop that includes the `break` command).



## Example: Use Break

Q: Find the first appearance location of 'a' in a character vector named as 'char\_seq' and assign its location (index) to 'loc'.

```
char_seq = 'Hello I am Matlab';  
  
num_char = numel(char_seq);  
loc = 0;  
for ii=1:num_char  
    if char_seq(ii) == 'a'  
        loc = ii;  
        break;  
    end  
end
```

| Name     | Value               |
|----------|---------------------|
| char_seq | 'Hello I am Matlab' |
| loc      | 9                   |
| num_char | 17                  |
| ii       | 9                   |

**Q1.** Think about an advantage of the use of `break` in this problem

**Q2.** Think about what value is assigned to `loc` if `break` command is deleted in the script.

## While Loop

- used as a **conditional** loop
- used to **repeat** an action when ahead of time it is not known how many times the action will be repeated
- general form:

```
while condition  
    action  
end
```

 : condition is an exist condition for the loop.

- *the action is repeated as long as the condition is true*
- Note: since the condition comes before the action, it is possible that the condition will be false the first time and then, the action will not be executed at all

 : If action cannot make condition true, an infinite loop can occur.  
Use **Ctrl-C** to break out of the infinite loop.

# Example: Summation

Q. Summation of 1 to 10 using a while loop

```
1 num = 1;  
2 val = 0;  
3  
4 while num < 11  
5     val = val + num;  
6     num = num+ 1;  
7 end
```

| Step | Operation   | Workspace          |
|------|---|--------------------|
| 1    | lines 1 & 2: assign 0 to num and assign 1 to val                                  | num → 1, val → 0   |
| 2    | line 4: since num is less than 11, condition is true and action is executed.      | num → 1, val → 0   |
| 3    | lines 5 & 6: add num to val and add 1 to num                                      | num → 2, val → 1   |
| 4    | line 7: end, and go back to line 4  | num → 2, val → 1   |
| 5    | line 4: since num is less than 11, condition is true, and action is executed.     | num → 2, val → 1   |
| 6    | lines 5 & 6: add num to val and add 1 to num                                      | num → 3, val → 3   |
| :    | continue to run until num becomes 10.   | num → 10, val → 45 |
| 8    | line 4: since num is less than 11, condition is true, and action is executed.     | num → 10, val → 45 |
| 9    | lines 5 & 6: add num to val and add 1 to num                                      | num → 10, val → 55 |
| 10   | line 7: end, and go back to line 4  | num → 11, val → 55 |
| 11   | line 4: since num is <b>NOT</b> less than 11, action is skipped and go to line 7. | num → 11, val → 55 |



## Example: Find a Location

Q: Find a location of the first 3<sup>rd</sup> of 5 in a vector named as `vec` and assign its location (index) to `loc`.

```
vec = [1 2 5 5 2 5 3 5 6];

num_5 = 0; % number of 5
idx = 0;

while num_5 < 3
    idx = idx + 1;
    if vec(idx) == 5
        num_5 = num_5 + 1;
    end
end

loc = idx;
```

| Name  | Value               |
|-------|---------------------|
| vec   | [1 2 5 5 2 5 3 5 6] |
| loc   | 6                   |
| num_5 | 3                   |
| idx   | 6                   |

```
vec = [1 2 5 5 2 5 3 5 6];

num_5 = 0; % number of 5
loc = 0;

while num_5 < 3
    loc = loc + 1;
    if vec(loc) == 5
        num_5 = num_5 + 1;
    end
end
```

## Example: Find a Location (Continue)

Optional

If you understand the operation of the while loop, you can design your code in a different way.

```
vec = [1 2 5 5 2 5 3 5 6];  
  
num_5 = 0; % number of 5  
loc = 0;  
  
while num_5 < 3  
    loc = loc + 1;  
    if vec(loc) == 5  
        num_5 = num_5 + 1;  
    end  
end
```

```
vec = [1 2 5 5 2 5 3 5 6];  
  
num_5 = 0; % number of 5  
loc = 0;  
  
while num_5 ~= 3  
    loc = loc + 1;  
    if vec(loc) == 5  
        num_5 = num_5 + 1;  
    end  
end
```



: When `num_5` is equal to 3, the while loop stop repeating but execute all script inside the loop (thus, `idx` becomes 7).

## Example: Find a Location (Continue)

Optional

You can build the same operation using for-loop with break.

```
vec = [1 2 5 5 2 5 3 5 6];

num_5 = 0; % number of 5
loc = 0;

while num_5 < 3
    loc = loc + 1;
    if vec(loc) == 5
        num_5 = num_5 + 1;
    end
end
```

```
vec = [1 2 5 5 2 5 3 5 6];

n_vec = numel(vec);

num_5 = 0;
loc = 0;

for ii=1:n_vec
    if vec(ii) == 5
        num_5 = num_5 + 1;
    end

    if num_5 == 3
        loc = ii;
        break;
    end
end
```

The dot product operation between two compatible vectors is defined as

$$\vec{a} \cdot \vec{b} = \begin{bmatrix} a_1 \\ \vdots \\ a_n \end{bmatrix} \cdot \begin{bmatrix} b_1 \\ \vdots \\ b_n \end{bmatrix} = a_1 b_1 + a_2 b_2 + \cdots + a_n b_n = \sum_{k=1}^n a_k b_k$$

which is the linear combination of all elements in both vectors. The result is a scalar. Interestingly, this linear combination is the same as

$$\vec{a}^T \vec{b} = \begin{bmatrix} a_1 \\ \vdots \\ a_n \end{bmatrix}^T \begin{bmatrix} b_1 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} a_1 & \cdots & a_n \end{bmatrix} \begin{bmatrix} b_1 \\ \vdots \\ b_n \end{bmatrix} = [a_1 b_1 + a_2 b_2 + \cdots + a_n b_n]$$

The dot product is also known as the scalar product or inner product, and sometimes uses the syntax  $(\vec{a}, \vec{b}) = \langle \vec{a}, \vec{b} \rangle = \vec{a} \cdot \vec{b}$ .



## Example: Dot Product

Q. Write a script to compute a dot product of A and B, which are the same size row vectors. Assign its value to AB.

```
A = [3 4 5 6 8];
B = [5 6 7 7 8];

% Loop structure
n_elem = numel(A);

AB_vec = zeros(1, n_elem);

for ii=1:n_elem
    AB_vec(ii) = A(ii)*B(ii);
end % altern: AB_vec = A.*B;

AB = 0;
for ii=1:n_elem
    AB = AB + AB_vec(ii);
end
```

```
A = [3 4 5 6 8];
B = [5 6 7 7 8];

% Loop structure
n_elem = numel(A);

AB = 0;
for ii=1:n_elem
    AB = AB + A(ii)*B(ii);
end
```

```
% Use of a built-in function
AB = dot(A,B);
```

```
% Use of a operator
AB = A * B';
```

# Module 05: Built-in Functions

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## Module 5: Learning Outcomes

- Relate an array as an input argument of built-in functions
- Print elements in variables and format output texts
- Apply built-in arithmetic functions and replicate the same capability using selection and loop statements
- Use a sort function to sort array elements

# Built-in Function (Array as an Input Argument)

## round

R2018b

Round to nearest decimal or integer

### Syntax

```
Y = round(X)
Y = round(X,N)
Y = round(X,N,type)

Y = round(t)
Y = round(t,unit)
```

### Description

`Y = round(X)` rounds each element of  $X$  to the nearest integer. In the case of a tie, where an element has a fractional part of exactly 0.5, the round function rounds away from zero to the integer with larger magnitude.

`Y = round(X,N)` rounds to  $N$  digits:

- $N > 0$ : round to  $N$  digits to the *right* of the decimal point.
- $N = 0$ : round to the nearest integer.
- $N < 0$ : round to  $N$  digits to the *left* of the decimal point.

`Y = round(X,N,type)` specifies the type of rounding. Specify 'significant' to round to  $N$  significant digits (counted from the leftmost digit). In this case,  $N$  must be a positive integer.

### Input Arguments

x — Input array

scalar | vector | matrix | multidimensional array

 It is useful to conduct the function over each elements in an array. We do not have to implement a loop statement. You should check if the function support the array as an input format.

## Built-in Function (Array as an Input Argument) (Continue)

- Entire arrays (vectors or matrices) can be used as input arguments to functions
- The result will have the same dimensions as the input

Q. Write a code to round to the nearest integer of each values in the vector.

```
vec = [1.1 2.3 -3.1 4.7 8.9];
n_vec = numel(vec);

vec_r = zeros(1, n_vec);
for ii=1:n_vec
    vec_r(ii) = round(vec(ii));
End
```

```
vec = [1.1 2.3 -3.1 4.7 8.9];
vec_r = round(vec);
```

| Name  | Value                  |
|-------|------------------------|
| vec   | [1.1 2.3 -3.1 4.7 8.9] |
| n_vec | 5                      |
| vec_r | [1 2 -3 5 9]           |

## Example: Built-in Function

Q. Write a code to compute a square root of each value in the vector.

```
vec = [3 2 4 1 2 4];
n_vec = numel(vec);

for ii=1:n_vec
    vec(ii) = sqrt(vec(ii));
end
```

```
vec = [3 2 4 1 2 4];
vec = sqrt(vec);
```

Q. Write a code to compute a sign of each values in a matrix

```
mat1 = [3 2 4; -1 -2 4; 3 0 -1];
[nr, nc] = size(mat1);
for ii=1:nr
    for jj = 1: nc
        val= sign(mat1(ii, jj));
        mat1(ii, jj) = val;
    end
end
```

```
mat1 = [3 2 4; -1 -2 4; 3 0 -1];
mat1 = sign(mat1);
```

|    |    |    |
|----|----|----|
| 3  | 2  | 4  |
| -1 | -2 | 4  |
| 3  | 0  | -1 |



|    |    |    |
|----|----|----|
| 1  | 1  | 1  |
| -1 | -1 | 1  |
| 1  | 0  | -1 |

# Array Operation

| Function                                     | Description  |
|--|--|
| <code>reshape(x, sz)</code>                  | Changes dimensions of a matrix to any matrix with the same number of elements  |
| <code>flip(x, dim)</code>                    | Flips a row vector left to right, column vector or matrix up to down, the elements in each column or row in a matrix |
| <code>cat(dim, A, B)</code>                  | Concatenate arrays along specified dimension   |
| <code>diag(x)</code><br><code>diag(A)</code> | Create diagonal matrix or get diagonal elements of matrix  |

## Function: **reshape** (**x**, **sz**)

B = reshape (A, sz) reshapes A using the size vector, sz, to define size (B). sz must contain at least 2 elements, product of elements in sz must be the same as numel (A).

```
vec = 3:14; % 12 elements  
  
mat0 = reshape(vec, [2 6]);  
mat1 = reshape(vec, [3 4]);  
mat2 = reshape(mat1, [6 2]);
```

mat1

|   |   |    |    |
|---|---|----|----|
| 3 | 6 | 9  | 12 |
| 4 | 7 | 10 | 13 |
| 5 | 8 | 11 | 14 |

vec

|   |   |   |   |   |   |   |    |    |    |    |    |
|---|---|---|---|---|---|---|----|----|----|----|----|
| 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|----|----|----|----|----|

mat0

|   |   |   |    |    |    |
|---|---|---|----|----|----|
| 3 | 5 | 7 | 9  | 11 | 13 |
| 4 | 6 | 8 | 10 | 12 | 14 |

mat2

|   |    |
|---|----|
| 3 | 9  |
| 4 | 10 |
| 5 | 11 |
| 6 | 12 |
| 7 | 13 |
| 8 | 14 |

## Function: **flip**(x, dim)

B = flip(A, dim) reverses the order of the elements in A along dimension dim.

```
mat0 = reshape(3:14, [3 4]);  
mat1 = flip(mat0, 1);  
mat2 = flip(mat0, 2);
```

: dim - If no value is specified, then the default is 1. 1 indicates the vertical direction, and 2 indicates the horizontal direction.

2: horizontal  
1: vertical



mat0

|   |   |    |    |
|---|---|----|----|
| 3 | 6 | 9  | 12 |
| 4 | 7 | 10 | 13 |
| 5 | 8 | 11 | 14 |

mat1

|   |   |    |    |
|---|---|----|----|
| 5 | 8 | 11 | 14 |
| 4 | 7 | 10 | 13 |
| 3 | 6 | 9  | 12 |



mat2

|    |    |   |   |
|----|----|---|---|
| 12 | 9  | 6 | 3 |
| 13 | 10 | 7 | 4 |
| 14 | 11 | 8 | 5 |



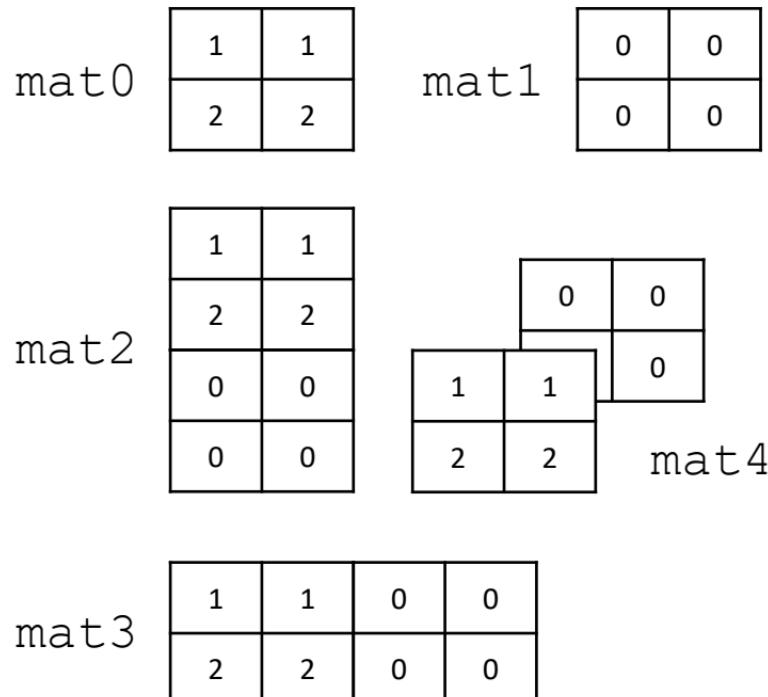
## Function: cat(dim, A, B)

C = cat(dim, A, B) concatenates the arrays A and B along array the dimension specified by the number of dimensions.

```
mat0 = [1 1; 2 2];
mat1 = zeros(2,2);

mat2 = cat(1, mat0, mat1);
mat3 = cat(2, mat0, mat1);
mat4 = cat(3, mat0, mat1);
```

| Name | Value                |
|------|----------------------|
| mat0 | [1 1; 2 2]           |
| mat1 | [0 0; 0 0]           |
| mat2 | [1 1; 2 2; 0 0; 0 0] |
| mat3 | [1 1 0 0; 2 2 0 0]   |
| mat4 | 2 x 2 x 2 double     |



## Function: **diag (x)** , **diag (A)**

- $D = \text{diag}(v)$  returns a square diagonal matrix  $D$  with the elements of vector  $v$  on the main diagonal.
- $x = \text{diag}(A)$  returns a column vector of the main diagonal elements of matrix  $A$ .

```
vec = [1 2 3];
mat0 = [2 1 3; 4 5 2; 2 3 4];

D = diag(vec);
v = diag(mat0)
```

|   |   |   |
|---|---|---|
| 2 | 1 | 3 |
| 4 | 5 | 2 |
| 2 | 3 | 4 |

mat0

|   |
|---|
| 2 |
| 5 |
| 4 |

v

|   |   |   |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 2 | 0 |
| 0 | 0 | 3 |

D

vec

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
|---|---|---|

```
vec = [1 2 3];

D = zeros(3,3);
for ii=1:3
    D(ii,ii) = vec(ii);
end

mat0 = [2 1 3; 4 5 2; 2 3 4];

v = zeros(3,1);
for ii=1:3
    v(ii) = mat0(ii,ii);
end
```

# Output Functions

- There are two basic output functions:
  - `disp`, which is a quick way to display things
  - `fprintf`, which allows formatting
- The `fprintf` function uses format specifiers which include place holders; these have conversion characters:

**`fprintf(formatSpec, A1, A2)`**

- `%d` : integers
  - `%f` : floats (real numbers)
  - `%c` : single characters
  - `%s` : string of characters
- 
- `\n` newline character



: This function and syntax is to print out numeric values or texts in a command window.

## Output Functions (Continue)

```
x = 1234.5678  
v = [ 1 2 3 4]
```

|   |  |
|---|--|
| disp(x)<br>disp(v)<br>disp('Hello! Matlab') | 1.2346e+03<br>1 2 3 4<br>Hello! Matlab |
|---|--|

|  |   |
|--|---|
| fprintf('Hello! Matlab')<br>fprintf('Hello! %c', 'M')<br>fprintf('Hello! %s', 'Mat')<br>fprintf('Hello! \nMatlab') | Hello! Matlab<br>Hello! Matlab<br>Hello! Matlab<br>Hello!<br>Matlab |
|--|---|

```
x = 1234.5678  
y = 10;
```

|  |   |
|--|---|
| fprintf('case1: x is %f.', x);<br>fprintf('case2: y is %d.', y); | case1: x is 1234.567800.<br>case2: y is 10. |
|--|---|

# Sum, Average, Min & Max, and Sorting

## Sum of array elements

- $S = \text{sum}(A)$
- $S = \text{sum}(A, \text{'all'})$
- $S = \text{sum}(A, \text{dim})$

## Maximum elements of an array

- $M = \text{max}(A)$
- $M = \text{max}(A, [], \text{dim})$
- $[M, I] = \text{max}(A)$
- $C = \text{max}(A, B)$

## Average or mean value of array

- $S = \text{mean}(A)$
- $S = \text{mean}(A, \text{'all'})$
- $S = \text{mean}(A, \text{dim})$

## Sort array elements

- $B = \text{sort}(A)$
- $B = \text{sort}(A, \text{dim})$
- $B = \text{sort}(A, \text{direction})$
- $[B, I] = \text{sort}(A)$

## Median value of array

- $S = \text{median}(A)$
- $S = \text{median}(A, \text{'all'})$
- $S = \text{median}(A, \text{dim})$

## Function: sum

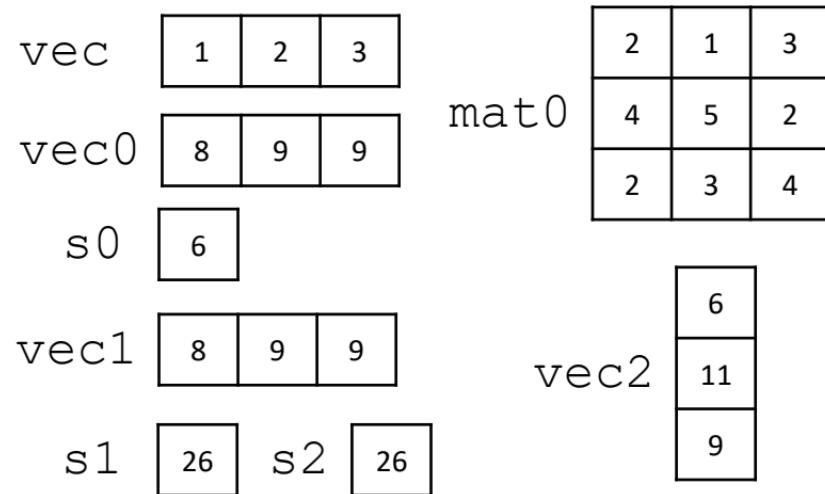
- $S = \text{sum}(A)$  returns the sum of the elements of  $A$ 
  - If  $A$  is a vector, then  $\text{sum}(A)$  returns the sum of the elements.
  - If  $A$  is a matrix, then  $\text{sum}(A)$  returns a row vector containing the sum of each column ( $= \text{sum}(A, 1)$ ).
- $S = \text{sum}(A, \text{dim})$  returns the sum along dimension  $\text{dim}$ .
- $S = \text{sum}(A, \text{'all'})$  computes the sum of all elements of  $A$ .

```
vec = [1 2 3];
mat0 = [2 1 3; 4 5 2; 2 3 4];

s0 = sum(vec);
vec0 = sum(mat0);

vec1 = sum(mat0, 1);
vec2 = sum(mat0, 2);

s1 = sum(mat0, 'all');
s2 = sum(mat0(:));
```



## Function: mean

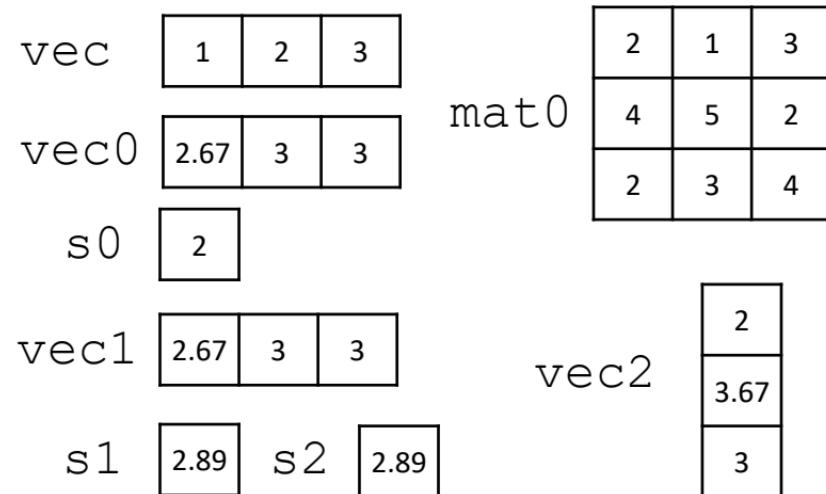
- $M = \text{mean}(A)$  returns the mean of the elements of  $A$ 
  - If  $A$  is a vector, then  $\text{mean}(A)$  returns the mean of the elements.
  - If  $A$  is a matrix, then  $\text{mean}(A)$  returns a row vector containing the mean of each column.
- $M = \text{mean}(A, 'all')$  computes the mean over all elements of  $A$ .
- $M = \text{mean}(A, \text{dim})$  returns the mean along dimension  $\text{dim}$ .

```
vec = [1 2 3];
mat0 = [2 1 3; 4 5 2; 2 3 4];

s0 = mean(vec);
vec0 = mean(mat0);

vec1 = mean(mat0, 1);
vec2 = mean(mat0, 2);

s1 = mean(mat0, 'all');
s2 = mean(mat0(:));
```





## Example: sum and mean

Q. Write a code to compute vec1, vec2, s1, s2 from mat0 without using sum and mean

```
mat0 = [2 1 3; 4 5 2; 2 3 4];  
  
[nr, nc] = size(mat0);  
  
s1 = 0;  
vec1 = zeros(nr, 1);  
for ii=1:nr  
    for jj=1:nc  
        s1 = s1 + mat0(ii,jj);  
        vec1(ii) = vec1(ii) + mat0(ii, jj);  
    end  
end  
  
s2 = s1/(nr*nc);  
vec2 = vec1/nc;
```

mat0 = [2 1 3; 4 5 2; 2 3 4];  
vec1 = sum(mat0, 2);  
vec2 = mean(mat0, 2);  
  
s1 = sum(mat0, 'all');  
s2 = mean(mat0, 'all');

*Replace this script*

mat0

|   |   |   |
|---|---|---|
| 2 | 1 | 3 |
| 4 | 5 | 2 |
| 2 | 3 | 4 |

## Function: median

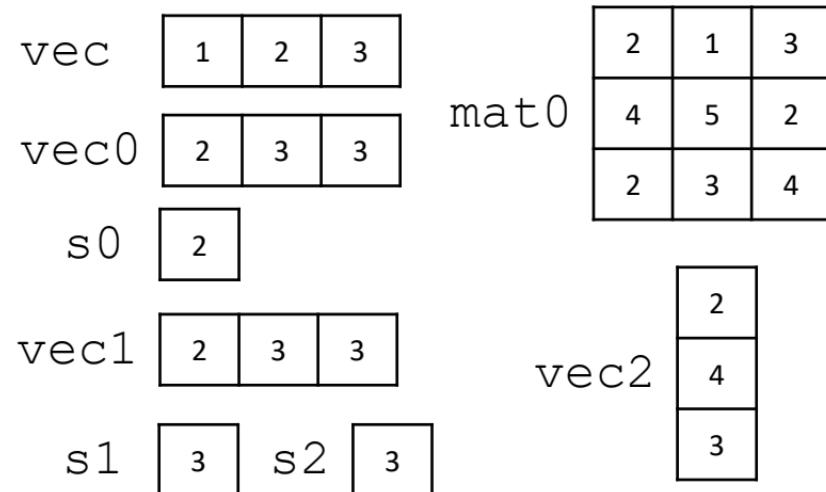
- $M = \text{median}(A)$  returns the median of the elements of  $A$ 
  - If  $A$  is a vector, then  $\text{median}(A)$  returns the median of the elements.
  - If  $A$  is a matrix, then  $\text{median}(A)$  returns a row vector containing the median of each column.
- $M = \text{median}(A, \text{'all'})$  computes the median over all elements of  $A$ .
- $M = \text{median}(A, \text{dim})$  returns the median along dimension  $\text{dim}$ .

```
vec = [1 2 3];
mat0 = [2 1 3; 4 5 2; 2 3 4];

s0 = median(vec);
vec0 = median(mat0);

vec1 = median(mat0, 1);
vec2 = median(mat0, 2);

s1 = median(mat0, 'all');
s2 = median(mat0(:));
```



## Function: max

- $M = \text{max}(A)$  returns the maximum elements of an array.
  - If  $A$  is a vector, then  $\text{max}(A)$  returns the maximum of  $A$ .
  - If  $A$  is a matrix, then  $\text{max}(A)$  is a row vector containing the maximum value of each column.
- $M = \text{max}(A, [], \text{dim})$  returns the largest elements of  $A$  along dimension  $\text{dim}$ . For example, if  $A$  is a matrix, then  $\text{max}(A, [], 2)$  is a column vector containing the maximum value of each row.
- $M = \text{max}(A, [], \text{'all'})$  finds the maximum over all elements of  $A$ .
- $[M, I] = \text{max}(\underline{\hspace{2cm}})$  finds the indices of the maximum values of  $A$  and returns them in output vector  $I$ , using any of the input arguments in the previous syntaxes. If the maximum value occurs more than once, then  $\text{max}$  returns the index **corresponding to the first occurrence**.
- $C = \text{max}(A, B)$  returns an array with the largest elements taken from  $A$  or  $B$ .

## Function: max (Continue)

```
vec = [1 3 2];
mat0 = [2 1 3; 4 5 2; 2 4 4];

s0 = max(1, 2);
s1 = max(vec);
[M, I1] = max(vec);

vec1 = max(mat0)
vec2 = max(mat0, [], 1);
vec3 = max(mat0, [], 2);

[M, I2] = max(mat0, [], 1);
[M, I3] = max(mat0, [], 2);

s2 = max(mat0, [], 'all')
s3 = max(mat0(:))
```

| Name | Value     |
|------|-----------|
| s0   | 2         |
| s1   | 3         |
| M    | 3         |
| I1   | 2         |
| vec1 | [4 5 4]   |
| vec2 | [4 5 4]   |
| vec3 | [3; 5; 4] |
| I2   | [2 2 3]   |
| I3   | [3; 2; 2] |
| s2   | 5         |
| s3   | 5         |

|      |   |   |   |   |   |   |   |   |   |   |
|------|---|---|---|---|---|---|---|---|---|---|
| mat0 | <table border="1"><tr><td>2</td><td>1</td><td>3</td></tr><tr><td>4</td><td>5</td><td>2</td></tr><tr><td>2</td><td>4</td><td>4</td></tr></table> | 2 | 1 | 3 | 4 | 5 | 2 | 2 | 4 | 4 |
| 2    | 1   | 3 |   |   |   |   |   |   |   |   |
| 4    | 5   | 2 |   |   |   |   |   |   |   |   |
| 2    | 4   | 4 |   |   |   |   |   |   |   |   |

|     |   |   |   |   |
|-----|---|---|---|---|
| vec | <table border="1"><tr><td>1</td><td>3</td><td>2</td></tr></table> | 1 | 3 | 2 |
| 1   | 3   | 2 |   |   |

|    |   |   |
|----|---|---|
| I1 | <table border="1"><tr><td>3</td></tr></table> | 3 |
| 3  |   |   |

|    |   |   |   |   |
|----|---|---|---|---|
| I2 | <table border="1"><tr><td>2</td><td>2</td><td>3</td></tr></table> | 2 | 2 | 3 |
| 2  | 2   | 3 |   |   |

|    |   |   |   |   |
|----|---|---|---|---|
| I3 | <table border="1"><tr><td>3</td></tr><tr><td>2</td></tr><tr><td>2</td></tr></table> | 3 | 2 | 2 |
| 3  |   |   |   |   |
| 2  |   |   |   |   |
| 2  |   |   |   |   |



## Example: max (Implementation)

Q. Write a code to find a maximum number of a given array without using max.

```
vec = [2 1 5 7 4 2 3 9 4 2];  
  
n_v = numel(vec);  
  
max_val = vec(1);  
  
for ii=2:n_v  
    if vec(ii) > max_val  
        max_val = vec(ii);  
    end  
end
```

: Check if each number in an array is bigger than the current maximum value, max\_val. If a new value is larger, max\_val is replaced to the new value. In general, max\_val is initialized with the first element of an input array.

Q. How to change the code if the given array is a matrix?

|   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 5 | 7 | 4 | 2 | 3 | 9 | 4 | 2 |
|---|---|---|---|---|---|---|---|---|---|

## Function: min

```
vec = [1 3 2];
mat0 = [2 1 3; 4 5 2; 2 2 4];

s0 = min(1, 2);
s1 = min(vec);
[M, I1] = min(vec);

vec1 = min(mat0)
vec2 = min(mat0, [], 1);
vec3 = min(mat0, [], 2);

[M, I2] = min(mat0, [], 1);
[M, I3] = min(mat0, [], 2);

s2 = min(mat0, [], 'all')
s3 = min(mat0(:))
```

vec

|   |   |   |
|---|---|---|
| 1 | 3 | 2 |
|---|---|---|

mat0

|   |   |   |
|---|---|---|
| 2 | 1 | 3 |
| 4 | 5 | 2 |
| 2 | 2 | 4 |

I1

|   |
|---|
| 1 |
|---|

I2

|   |   |   |
|---|---|---|
| 1 | 1 | 2 |
|---|---|---|

I3

|   |
|---|
| 2 |
| 3 |
| 1 |

| Name | Value     |
|------|-----------|
| s0   | 1         |
| s1   | 1         |
| I1   | 1         |
| vec1 | [2 1 2]   |
| vec2 | [2 1 2]   |
| vec3 | [1; 2; 2] |
| I2   | [1 1 2]   |
| I3   | [2; 3; 1] |
| s2   | 1         |
| s3   | 1         |

## Function: sort

- $B = \text{sort}(A)$  sorts the elements of  $A$  in ascending order.
  - If  $A$  is a vector, then  $\text{sort}(A)$  sorts the vector elements.
  - If  $A$  is a matrix, then  $\text{sort}(A)$  treats the columns of  $A$  as vectors and sorts the elements within each vector column.
- $B = \text{sort}(A, \text{dim})$  returns the sorted elements of  $A$  along dimension  $\text{dim}$ .
- $B = \text{sort}(\_, \text{direction})$  returns sorted elements of  $A$  in the order specified by  $\text{direction}$  using any of the previous syntaxes.  
'ascend' indicates ascending order (the default) and 'descend' indicates descending order.
- $[B, I] = \text{sort}(\_)$  also returns a collection of index vectors for any of the previous syntaxes.  $I$  is the same size as  $A$  and describes the arrangement of the elements of  $A$  into  $B$  along the sorted dimension.

## Function: sort (Continue)

```
vec = [2 1 3];
mat0 = [2 1 3; 4 5 2; 2 3 4];

v0 = sort(vec);
v1 = sort(vec, 'descend');
[B1, I1] = sort(vec, 'descend');
v2 = vec(I1);

mat2 = sort(mat0, 1);
[B2, I2] = sort(mat0, 1);

mat3 = sort(mat0, 2);
[B3, I3] = sort(mat0, 2);
```

mat0

|   |   |   |
|---|---|---|
| 2 | 1 | 3 |
| 4 | 5 | 2 |
| 2 | 3 | 4 |

vec

|   |   |   |
|---|---|---|
| 2 | 1 | 3 |
|---|---|---|

v0

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
|---|---|---|

v1

|   |   |   |
|---|---|---|
| 3 | 2 | 1 |
|---|---|---|

v2

|   |   |   |
|---|---|---|
| 3 | 2 | 1 |
|---|---|---|

B1

|   |   |   |
|---|---|---|
| 3 | 2 | 1 |
|---|---|---|

I1

|   |   |   |
|---|---|---|
| 3 | 1 | 2 |
|---|---|---|

mat2

|   |   |   |
|---|---|---|
| 2 | 1 | 2 |
| 2 | 3 | 3 |
| 4 | 5 | 4 |

I2

|   |   |   |
|---|---|---|
| 1 | 1 | 2 |
| 3 | 3 | 1 |
| 2 | 2 | 3 |

mat3

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 2 | 4 | 5 |
| 2 | 3 | 4 |

I3

|   |   |   |
|---|---|---|
| 2 | 1 | 3 |
| 3 | 1 | 2 |
| 1 | 2 | 3 |



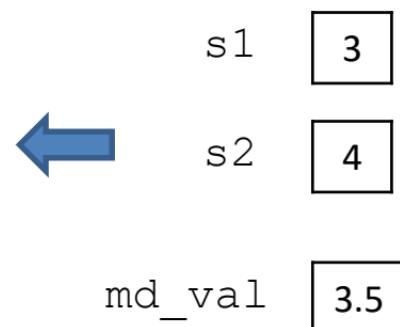
## Example: median (Implementation)

Q. Write a code to find a median of a given vector without using median (use sort).

```
vec = [2 1 5 7 4 2 3 9 4 2]';  
  
n_v = numel(vec);  
s_vec = sort(vec);  
  
if rem(n_v, 2) == 1  
    idx = ceil(n_v/2);  
    md_val = s_vec(idx);  
else  
    idx = n_v/2;  
    s1 = s_vec(idx);  
    s2 = s_vec(idx+1);  
    md_val = (s1+s2)/2;  
end
```

|   |
|---|
| 2 |
| 1 |
| 5 |
| 7 |
| 4 |
| 2 |
| 3 |
| 4 |
| 9 |
| 5 |
| 4 |
| 7 |
| 2 |

|   |
|---|
| 1 |
| 2 |
| 2 |
| 2 |
| 3 |
| 4 |
| 4 |
| 4 |
| 5 |
| 7 |
| 9 |



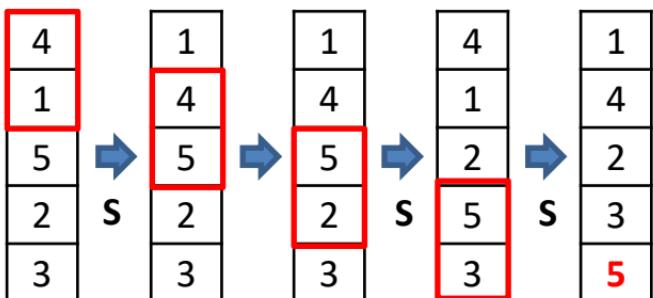
vec

s\_vec

## Sort Algorithm: Bubble Sort

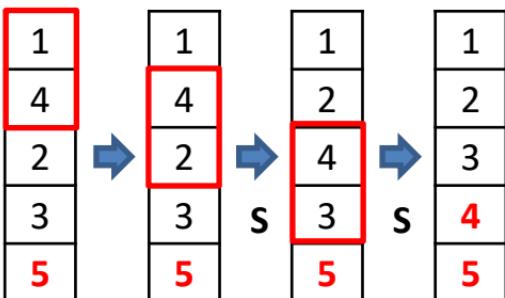
## Challenging

Bubble sort, is a simple sorting algorithm that repeatedly steps through the list, compares adjacent elements and swaps them if they are in the wrong order. The pass through the list is repeated until the list is sorted.

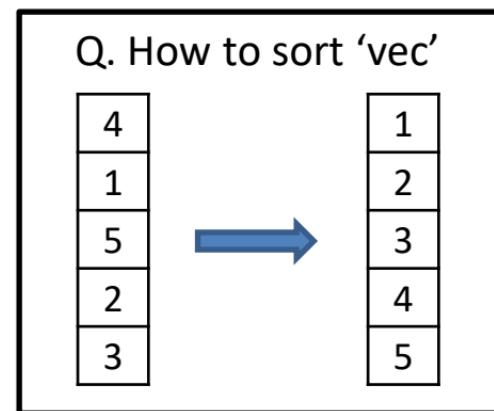


Step1: There are 4 conditions statements performed. At the end of the first step, we can find the last value.

Here 'S' means swapping the values.

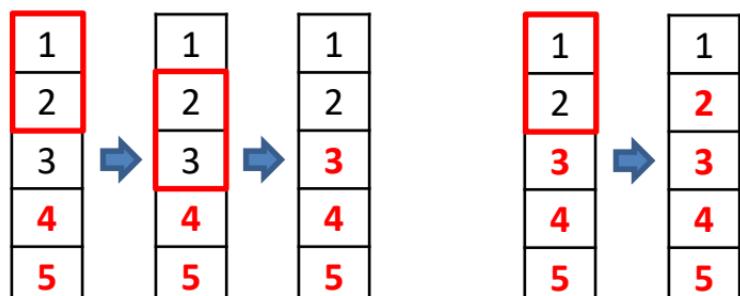
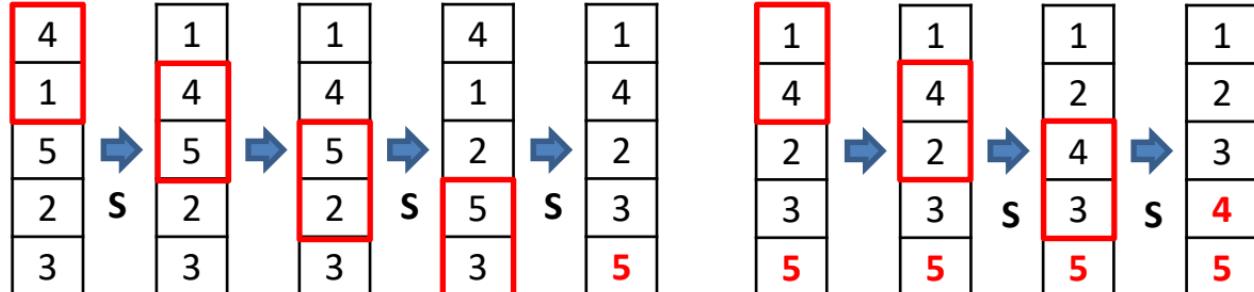


Step2: There are 3 conditions statements performed. At the end of the second step, we can find the 2<sup>nd</sup> last value.



# Sort Algorithm: Bubble Sort (Continue)

Challenging

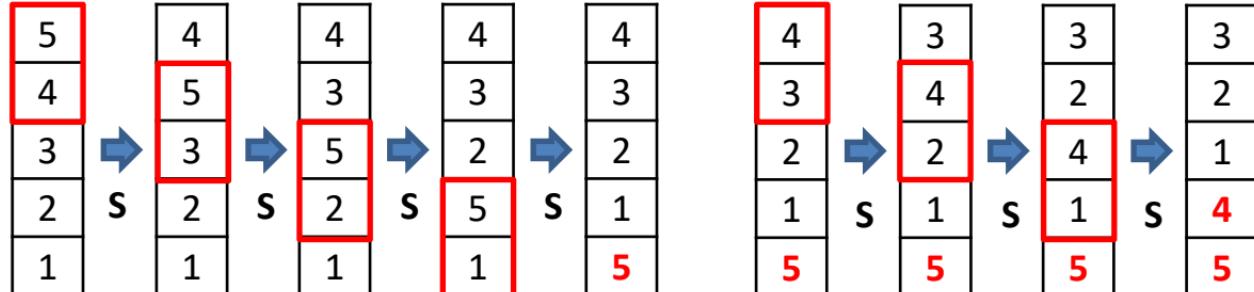


**Summary**

- 5 elements
- 4 steps needed
- Each step, the number of actions (condition statement) is decreased by one.

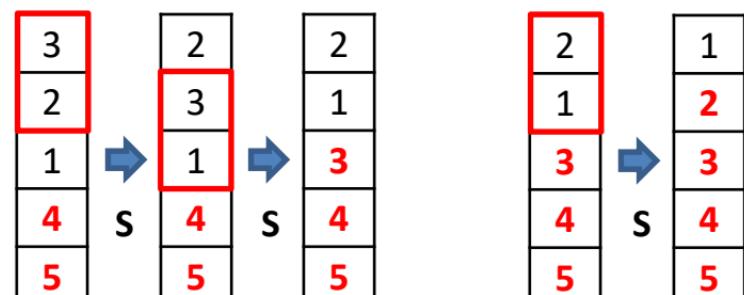
# Sort Algorithm: Bubble Sort (Another Example)

Challenging



Step1

Step2



Step3

Step4

## Summary

- 5 elements
- 4 steps needed
- Each step, the number of actions (condition statement) is decreased by one.

# Sort Algorithm: Bubble Sort (Implementation)

## Challenging

Bubble sort, is a simple sorting algorithm that repeatedly steps through the list, compares adjacent elements and swaps them if they are in the wrong order. The pass through the list is repeated until the list is sorted.

```
vec = [4 1 5 2 3]';  
nv = numel(vec);  
  
for ii=1:nv-1  
    for jj=1:nv-ii  
        if vec(jj)>vec(jj+1)  
            tmp = vec(jj);  
            vec(jj) = vec(jj+1);  
            vec(jj+1) = tmp;  
        end  
    end  
end
```

|   |   |   |   |   |
|---|---|---|---|---|
| 4 | 1 | 1 | 4 | 1 |
| 1 | 4 | 4 | 1 | 4 |
| 5 | 5 | 5 | 2 | 2 |
| 2 | 2 | 2 | 5 | 3 |
| 3 | 3 | 3 | 3 | 5 |

At *ii=1*

|   |   |   |   |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 4 | 4 | 2 | 2 |
| 2 | 2 | 4 | 3 |
| 3 | 3 | 3 | 4 |
| 5 | 5 | 5 | 5 |

At *ii=2*

⌚: The script in italic & bold can be replaced as  
`vec([jj jj+1]) = vec([jj+1 jj]);`

# Module 06: Operators

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## Module 6: Learning Outcomes

- Describe vectorization coding in MATLAB
- Apply numeric, relational, and logical operators to the combinations of scalar, vector, and matrix
- Redesign loop-based scripts using vectorization
- Solve problems using operators

# Vectorization

- MATLAB® is optimized for operations involving matrices and vectors. The process of revising loop-based, scalar-oriented code to use MATLAB matrix and vector operations is called vectorization.
- Vectorizing your code is worthwhile for several reasons:
  - Appearance: Making the code easier to understand.
  - Less error prone: **Without loops, vectorized code is often shorter. Fewer lines of code mean fewer risks to introduce programming errors.**
  - Performance: Vectorized code often runs much faster than the corresponding code containing loops (in MATLAB).



: For example, instead of looping through all elements in a vector `vec` to add 3 to each element, just use scalar addition:    `vec = vec + 3;`

# MATLAB Operator

| Symbol         | Role                        |
|----------------|-----------------------------|
| +              | Addition                    |
| -              | Subtraction                 |
| *              | Multiplication              |
| /              | Division                    |
| <sup>^</sup>   | Matrix power                |
| . /            | Element-wise right division |
| . *            | Element-wise multiplication |
| . <sup>^</sup> | Element-wise power          |
| '              | Transpose                   |

| Symbol | Role                         |
|--------|------------------------------|
| ==     | Equal to                     |
| ~=     | Not equal to                 |
| >      | Greater than                 |
| >=     | Greater than or equal to     |
| <      | Less than                    |
| <=     | Less than or equal to        |
| &&     | Logical AND (scalar logical) |
|        | Logical OR (scalar logical)  |
| ~      | Logical NOT                  |
| &      | Logical AND (array)          |
|        | Logical OR (array)           |

# MATLAB Operator: Arithmetic

```
s1 = 10; % scalar value  
s2 = 2; % scalar value
```

```
v1 = [1 2 3 4]; % vector
```

```
m1 = [1 2; 3 4]; % matrix
```

```
m2 = [5 6; 7 8]; % matrix
```

|           |          |  |    |    |   |   |  |   |   |   |   |   |   |   |   |   |
|-----------|----------|--|----|----|---|---|--|---|---|---|---|---|---|---|---|---|
| <b>10</b> | <b>2</b> | <table border="1"><tr><td>1</td><td>2</td></tr><tr><td>3</td><td>4</td></tr></table> | 1  | 2  | 3 | 4 | <table border="1"><tr><td>5</td><td>6</td></tr><tr><td>7</td><td>8</td></tr></table> | 5 | 6 | 7 | 8 | <table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td></tr></table> | 1 | 2 | 3 | 4 |
| 1         | 2        |  |    |    |   |   |  |   |   |   |   |   |   |   |   |   |
| 3         | 4        |  |    |    |   |   |  |   |   |   |   |   |   |   |   |   |
| 5         | 6        |  |    |    |   |   |  |   |   |   |   |   |   |   |   |   |
| 7         | 8        |  |    |    |   |   |  |   |   |   |   |   |   |   |   |   |
| 1         | 2        | 3  | 4  |    |   |   |  |   |   |   |   |   |   |   |   |   |
| s1        | s2       | m1   | m2 | v1 |   |   |  |   |   |   |   |   |   |   |   |   |

| Operator |
|----------|
| +        |
| -        |
| *        |
| /        |
| ^        |

**Scalar ★ Scalar**

**Vector ★ Scalar**

**Matrix ★ Scalar**

**Vector ★ Vector**

**Vector ★ Matrix**

**Matrix ★ Matrix**

**★: Operator**

|         |                    |
|---------|--------------------|
| s1 + s2 | 12                 |
| s1 * s2 | 20                 |
| s1 / s2 | 5                  |
| s1 ^ s2 | 100                |
| <br>    |                    |
| s1 + v1 | [11 12 13 14]      |
| v1 - s2 | [-1 0 1 2]         |
| v1 * s1 | [10 20 30 40]      |
| v1 / s2 | [0.5 1 1.5 2]      |
| <br>    |                    |
| m1 * s1 | [10 20; 30 40]     |
| m1 / s1 | [0.1 0.2; 0.3 0.4] |
| m1 + s1 | [11 12; 13 14]     |
| <br>    |                    |
| v1 ^ s2 | error              |
| m1 ^ s2 | [7 10; 15 22]      |

# MATLAB Operator: Arithmetic (Continue)

```
v1 = [1 2]; % vector  
v2 = [1; 0]; % vector
```

```
m1 = [1 2; 3 4]; % matrix  
m2 = [1 0; 0 1]; % matrix
```

|   |   |
|---|---|
| 1 | 2 |
| 3 | 4 |

|   |   |
|---|---|
| 1 | 0 |
| 0 | 1 |

|   |   |
|---|---|
| 1 | 2 |
|---|---|

|   |
|---|
| 1 |
| 0 |

m1

m2

v1

v2

| Operator |
|----------|
| +        |
| -        |
| *        |
| /        |
| ^        |

Scalar ★ Scalar

Vector ★ Scalar

Matrix ★ Scalar

Vector ★ Vector

Vector ★ Matrix

Matrix ★ Matrix

★: Operator

v1 \* v2  
v2 \* v1

m1 \* v1  
m1 \* v2  
v1 \* m1  
v2 \* m1

m1 + m2  
m1 \* m2  
m1 \* m1  
m1^2

m2 / m1  
m2 \* inv(m1)

1  
[1 2; 0 0]

error  
[1; 3]  
[7 10]  
error

[2 2; 3 5]  
[1 2; 3 4]  
[7 10; 15 22]  
[7 10; 15 22]

[-2 1; 1.5 -0.5]  
[-2 1; 1.5 -0.5]

# MATLAB Operator (Element-wise Operation)

```
s1 = 2; % scalar  
v1 = [1 2]; % vector  
v2 = [2; 1]; % vector  
  
m1 = [1 2; 3 4]; % matrix  
m2 = [1 0; 0 1]; % matrix
```

|   |   |
|---|---|
| 1 | 2 |
| 3 | 4 |

m1

|   |   |
|---|---|
| 1 | 0 |
| 0 | 1 |

m2

|   |   |
|---|---|
| 1 | 2 |
|---|---|

v1

|   |
|---|
| 2 |
| 1 |

v2

## Operator

+

-

\*

/

^

./

.\*

.^

'

Scalar ★ ScalarVector ★ ScalarMatrix ★ ScalarVector ★ VectorVector ★ MatrixMatrix ★ Matrix**★: Operator**

v1 .\* v1

[1 4]

v1 .\* v2'

[2 2]

v1 ./ v2'

[0.5 2]

m1 .\* m2

[1 0; 0 4]

m2 ./ m1

[1 0; 0 0.25]

m1 .^ s1

[1 4; 9 16]

m1 ^ s1

[7 10; 15 22]

☞: m1 ^ s1 is a matrix power that compute m1 to s1 power. m1 .^ s1 is element-wise operation of s1 power

# MATLAB Operator: Relational

## Challenging

```
s1 = 1; % scalar value  
s2 = 2; % scalar value  
  
v1 = [1 2 3 4]; % vector  
v2 = [1 0 1 4]; % vector
```

|    |          |    |          |          |          |          |
|----|----------|----|----------|----------|----------|----------|
| s1 | <b>1</b> | v1 | <b>1</b> | <b>2</b> | <b>3</b> | <b>4</b> |
| s2 | <b>2</b> | v2 | <b>1</b> | <b>0</b> | <b>1</b> | <b>4</b> |

| Symbol             | Role                     |
|--------------------|--------------------------|
| <code>==</code>    | Equal to                 |
| <code>~=</code>    | Not equal to             |
| <code>&gt;</code>  | Greater than             |
| <code>&gt;=</code> | Greater than or equal to |
| <code>&lt;</code>  | Less than                |
| <code>&lt;=</code> | Less than or equal to    |

|          |           |
|----------|-----------|
| s1 == s2 | 0         |
| s1 < s2  | 1         |
| <br>     |           |
| v1 == s1 | [1 0 0 0] |
| v1 <= s2 | [1 1 0 0] |
| v1 ~= s2 | [1 0 1 1] |
| <br>     |           |
| v1 == v2 | [1 0 0 1] |
| v1 >= v2 | [1 1 1 1] |
| v1 < v2  | [0 0 0 0] |

**⚠:** `v1 == v2` is not checking the equality of `v1` and `v2`. It is checking the element-wise equality and thus the output becomes a vector, not a logical value.

# MATLAB Operator: Relational (Continue)

[Challenging](#)

```
s1 = 1; % scalar value  
s2 = 2; % scalar value  
  
m1 = [1 2; 3 4]; % matrix  
m2 = [1 0; 5 4]; % matrix
```

s1  
**1**  
s2  
**2**

**1** **2**  
**3** **4**  
m1  
**5** **4**  
m2

| Symbol | Role                     |
|--------|--------------------------|
| ==     | Equal to                 |
| ~=     | Not equal to             |
| >      | Greater than             |
| >=     | Greater than or equal to |
| <      | Less than                |
| <=     | Less than or equal to    |

|          |            |
|----------|------------|
| m1 == s1 | [1 0; 0 0] |
| m1 ~= s2 | [1 0; 1 1] |
| m1 == m2 | [1 0; 0 1] |
| m1 ~= m2 | [0 1; 1 0] |
| m1 >= m2 | [1 1; 0 1] |

# MATLAB Operator: Logical

## Challenging

```
s1 = 1; s2 = 0;  
v1 = [1 0]; v2 = [0 0];  
  
m1 = [1 1; 0 0];  
m2 = [1 0; 0 1];
```

| Symbol | Role                         |
|--------|------------------------------|
| &&     | Logical AND (scalar logical) |
|        | Logical OR (scalar logical)  |
| ~      | Logical NOT                  |
| &      | Logical AND (array)          |
|        | Logical OR (array)           |

|   |   |
|---|---|
| 1 | 1 |
| 0 | 0 |

m1

|   |   |
|---|---|
| 1 | 0 |
| 0 | 1 |

m2

v1

|   |   |
|---|---|
| 1 | 0 |
| 0 | 0 |

v2

|          |            |
|----------|------------|
| s1 && s1 | 1          |
| s2 && s2 | 0          |
| s1    s2 | 1          |
| <br>     |            |
| ~ s1     | 0          |
| ~ s2     | 1          |
| <br>     |            |
| m1   s1  | [1 1; 1 1] |
| <br>     |            |
| v2   v1  | [1 0]      |
| v2 & v1  | [0 0]      |
| <br>     |            |
| m1   m2  | [1 1; 0 1] |
| m1 & m2  | [1 0; 0 0] |

 : || and && are used for scalars. For vectors or matrices, | and & are used to go through element-by-element and return logical 1 or 0.



## Example: Count Number

```
vec = [1 3 4 2 5 10 5 9 11];  
  
n_vec = numel(vec);  
  
num5 = 0;  
for ii=1:n_vec  
    tecl_num = vec(ii);  
    if tecl_num == 5  
        num5 = num5 + 1;  
    end  
end
```

```
vec = [1 3 4 2 5 10 5 9 11];  
  
idx = (vec == 5);  
num5 = sum(idx);
```

Q: Write a script to count the number of 5 in the given vector named 'vec'. The resulting count is assigned to 'num5'.

vec

|   |   |   |   |   |    |   |   |    |
|---|---|---|---|---|----|---|---|----|
| 1 | 3 | 4 | 2 | 5 | 10 | 5 | 9 | 11 |
|---|---|---|---|---|----|---|---|----|

idx

|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|

num\_5

2

## Example: Bulls and Cows

Bulls and Cows is a mind game played by two players.

In the game, a random, 4-digit number is chosen and its values are compared to those of another trial number. **All four digits of the number must be different.** If any digit in the chosen number is the exact same value and in the exact same position as any digit in the trial number, this is called a bull. If the digit is present in both the trial number and chosen number, but is not in the same location, this is called a cow.





## Example: Bulls and Cows

```
x_true = [1 2 3 4]; % true  
x_test = [3 2 5 6]; % test  
  
numb = 0; % number of Bull  
for ii=1:4  
    if x_true(ii) == x_test(ii)  
        numb = numb + 1;  
    end  
end
```

x\_true    

|   |   |   |   |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
|---|---|---|---|

x\_test    

|   |   |   |   |
|---|---|---|---|
| 3 | 2 | 5 | 6 |
|---|---|---|---|

is\_same    

|   |   |   |   |
|---|---|---|---|
| 0 | 1 | 0 | 0 |
|---|---|---|---|

Q: Write a script to compute “Bull” and assign its value to num\_b. The true and test sequence is in x\_true and x\_test, respectively.

```
x_true = [1 2 3 4]; % true  
x_test = [3 2 5 6]; % test  
  
is_same = (x_true == x_test);  
  
numb = sum(is_same);
```

⌚: Write these two lines as one line like  
num\_b = sum(x\_true == x\_test);

## Logical Indexing (Vector)

[Challenging](#)

- Use this logical indexing to index into a vector or matrix when the index vector or matrix is the **logical** type.
- In logical indexing, you use a single, logical array for the matrix subscript.
- MATLAB extracts the matrix elements corresponding to the nonzero values of the logical array.

```
v1 = [4 1 3 5]; % vector  
lg_idx = logical([1 0 1 0]);  
v2 = v1(lg_idx);
```

**⚠:** I recommend to use the same size (the number of element) logical indexing vector.

|    |   |   |   |   |
|----|---|---|---|---|
| v1 | 4 | 1 | 3 | 5 |
|----|---|---|---|---|

|        |   |   |   |   |
|--------|---|---|---|---|
| lg_idx | 1 | 0 | 1 | 0 |
|--------|---|---|---|---|

|    |   |   |
|----|---|---|
| v2 | 4 | 3 |
|----|---|---|



## Example: Logical Indexing

Q1: Find numbers more than or equal to 10 in vec

Q2: Find numbers not equal to 5 in vec

Q3: Find numbers larger than 3 and less than 7 in vec

```
1  vec = [1 3 4 2 5 10 2 9 11];
2
3  id1 = (vec >= 10);
4  vq1 = vec(id1);
5
6  id2 = (vec ~= 5);
7  vq2 = vec(id2);
8
9  id3 = (vec >3) & (vec<7);
10 vq3 = vec(id3);
```

⌚: Here, all variables except for vec are a logical type. For lines 3,6,9, () helps readability of your code.

|     |    |    |   |   |    |    |   |    |    |
|-----|----|----|---|---|----|----|---|----|----|
| vec | 1  | 3  | 4 | 2 | 5  | 10 | 2 | 9  | 11 |
| id1 | 0  | 0  | 0 | 0 | 0  | 1  | 0 | 0  | 1  |
| id2 | 1  | 1  | 1 | 1 | 0  | 1  | 1 | 1  | 1  |
| id3 | 0  | 0  | 1 | 0 | 1  | 0  | 0 | 0  | 0  |
| vq1 | 10 | 11 |   |   |    |    |   |    |    |
| vq2 | 1  | 3  | 4 | 2 | 10 | 2  | 9 | 11 |    |
| vq3 | 4  | 5  |   |   |    |    |   |    |    |

# Output from Linear and Logical Indexing

## Optional, Challenging

- When the input array is a **row vector**, regardless of whether a linear indexing or logical indexing vector is a row or column vector, the output vector is a **row vector**. If the input array is a column vector, the output is a column vector.
- When the input is a matrix, if a linear indexing or logical indexing vector is a **row vector**, the output vector is a **row vector**. If the indexing vector is a column vector, the output vector is a column vector.

```
v1 = [4 1 3 5];
v2 = [4 1 3 5]';

m1 = [1 2; 3 4];

lg_idx1 = logical([1 0 1 0]);
lg_idx2 = lg_idx1';

li_idx1 = [2 3];
li_idx2 = li_idx1';
```

|             |        |
|-------------|--------|
| v1(lg_idx1) | [4 3]  |
| v1(lg_idx2) | [4 3]  |
| v1(li_idx1) | [1 3]  |
| v1(li_idx2) | [1 3]  |
| <br>        |        |
| v2(lg_idx1) | [4; 3] |
| v2(lg_idx2) | [4; 3] |
| v2(li_idx1) | [1; 3] |
| v2(li_idx2) | [1; 3] |
| <br>        |        |
| m1(lg_idx1) | [1 2]  |
| m1(lg_idx2) | [1; 2] |
| m1(li_idx1) | [3 2]  |
| m1(li_idx2) | [3; 2] |



## Example: Extracting All Odd Numbers

Q. Write the script that extracts all odd numbers in 'vec1' and assign a resulting vector to 'odd1'.

```
vec1 = [1 2 4 6 7 11 17 12 8];
n_vec1 = numel(vec1);

odd1 = [];
for ii=1:n_vec1
    t_num = vec1(ii);
    if rem(t_num,2) == 1
        odd1 = [odd1 t_num];
    end
end
```

```
vec1 = [1 2 4 6 7 11 17 12 8];

vec1_rem = rem(vec1,2);

logi_odd = (vec1_rem == 1);

odd1 = vec1(logi_odd);
```

Here, `vec1_rem` is a numeric vector (double type) and `logi_odd` is a logical vector.

|      |   |   |   |   |   |    |    |    |   |
|------|---|---|---|---|---|----|----|----|---|
| vec1 | 1 | 2 | 4 | 6 | 7 | 11 | 17 | 12 | 8 |
|------|---|---|---|---|---|----|----|----|---|

|          |   |   |   |   |   |   |   |   |   |
|----------|---|---|---|---|---|---|---|---|---|
| vec1_rem | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
|----------|---|---|---|---|---|---|---|---|---|

|          |   |   |   |   |   |   |   |   |   |
|----------|---|---|---|---|---|---|---|---|---|
| logi_odd | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
|----------|---|---|---|---|---|---|---|---|---|

|      |   |   |    |    |
|------|---|---|----|----|
| odd1 | 1 | 7 | 11 | 17 |
|------|---|---|----|----|

## Logical Indexing (Matrix)

## Challenging

```
A = [1 2 3; 4 5 6; 7 8 9];  
B = A;  
  
ind_lg_3 = A > 3;  
  
vec_lg_3 = A(ind_lg_3);  
  
B(ind_lg_3) = 9;  
B(~ind_lg_3) = 5;
```

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |
| 7 | 8 | 9 |

A

|   |   |   |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 1 | 1 |
| 1 | 1 | 1 |

ind\_lg\_3

|   |
|---|
| 4 |
| 7 |
| 5 |
| 8 |
| 6 |
| 9 |

vec\_lg\_3

 Here, the logical matrix `ind_lg_3` can be used to index the matrix. The logical matrix `ind_lg_3` is linearized before reading the elements (indexing).

|   |   |   |
|---|---|---|
| 1 | 1 | 1 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |

~ind\_lg\_3

|   |   |   |
|---|---|---|
| 5 | 5 | 5 |
| 9 | 9 | 9 |
| 9 | 9 | 9 |

B

## Example: Transform a Matrix



- Write a script to convert matrix A to matrix B and C.

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |
| 7 | 8 | 9 |

A



|   |   |   |
|---|---|---|
| 8 | 2 | 3 |
| 4 | 8 | 6 |
| 7 | 8 | 8 |

B

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |
| 7 | 8 | 9 |

A



|   |   |   |
|---|---|---|
| 1 | 2 | 8 |
| 4 | 8 | 6 |
| 8 | 8 | 9 |

C

```
A = [1 2 3; 4 5 6; 7 8 9];  
  
B = A;  
for ii=1: 3  
    B(ii,ii) = 8;  
end  
  
C = A;  
for ii=1:3  
    col_idx = (3-ii + 1);  
    C(ii, col_idx) = 8;  
end
```

## Example: Transform a Matrix (Continue)

```
A = [1 2 3; 4 5 6; 7 8 9];  
  
B = A;  
for ii=1: 3  
    B(ii,ii) = 8;  
end  
  
C = A;  
for ii=1:3  
    col_idx = (3-ii + 1);  
    C(ii, col_idx) = 8;  
end
```

⌚: flip(x, 2) is identical to  
fliplr(x).

```
A = [1 2 3; 4 5 6; 7 8 9];
```

```
B = A;  
d_idx = logical(eye(3));  
B(d_idx) = 8;  
  
C = A;  
inv_d_idx = flip(d_idx, 2);  
C(inv_d_idx) = 8;
```

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |
| 7 | 8 | 9 |

A

|   |   |   |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | 1 |

d\_idx

|   |   |   |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |

inv\_d\_idx

# Compatible Array Sizes for Operation

## Optional, Challenge

Operators and functions in MATLAB® support numeric arrays that have *compatible sizes*. **Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are either the same or one of them is 1.** MATLAB implicitly expands arrays with compatible sizes to be the same size during the execution of the element-wise operation or function.

```
s1 = 2;  
m1 = [1 2; 3 4];  
m2 = m1 * s1;  
m2 = m1 .* [s1 s1; s1 s1];
```

$$\begin{array}{|c|c|} \hline 1 & 2 \\ \hline 3 & 4 \\ \hline \end{array} \quad * \quad \boxed{2} \quad = \quad \begin{array}{|c|c|} \hline 2 & 4 \\ \hline 6 & 8 \\ \hline \end{array}$$
  
$$\begin{array}{|c|c|} \hline 1 & 2 \\ \hline 3 & 4 \\ \hline \end{array} \quad . * \quad \begin{array}{|c|c|} \hline 2 & 2 \\ \hline 2 & 2 \\ \hline \end{array} \quad = \quad \begin{array}{|c|c|} \hline 2 & 4 \\ \hline 6 & 8 \\ \hline \end{array}$$

Q. Does it work?

$$\begin{array}{|c|c|} \hline 1 & 4 \\ \hline 2 & 5 \\ \hline 3 & 6 \\ \hline \end{array} \quad + \quad \begin{array}{|c|} \hline 1 \\ \hline 2 \\ \hline 3 \\ \hline \end{array} \quad = ?$$

# Compatible Array Sizes for Operation (Continue)

## Optional, Challenge

```
m1 = [1 2; 3 4; 5 6];  
v1 = [2; 3; 4];  
v2 = [1 2];
```

|   |   |
|---|---|
| 1 | 2 |
| 3 | 4 |
| 5 | 6 |

m1

|   |
|---|
| 2 |
| 3 |
| 4 |

v1

|   |   |
|---|---|
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |

Implicit → v1

|   |   |
|---|---|
| 1 | 2 |
| 3 | 4 |
| 5 | 6 |

m1

|   |   |
|---|---|
| 1 | 2 |
| 1 | 2 |

v2

|   |   |
|---|---|
| 1 | 2 |
| 1 | 2 |
| 1 | 2 |

Implicit → v2

```
m1 + v1;  
m1 - v1;  
m1 .* v1;
```

```
[3 4; 6 7; 9 10]  
[-1 0; 0 1; 1 2]  
[2 4; 9 12; 20 24]
```

```
m1 + v2;  
m1 - v2;  
m1 .* v2;
```

```
[2 4; 4 6; 6 8]  
[0 0; 2 2; 4 4]  
[1 4; 3 8; 5 12]
```

```
m1 == v1;  
m1 == v2;
```

```
[0 1; 1 0; 0 0]  
[1 1; 0 0; 0 0]
```

```
m1 > v1  
m1 > v2
```

```
[0 0; 0 1; 1 1]  
[0 0; 1 1; 1 1]
```

```
m1 * v1;  
m1 * v2;
```

```
error  
error
```

MATLAB *implicitly* expands the vector to be the same size as the input matrix

## Logical Built-in Function

- **any** returns true if anything in the input argument is true
- **all** returns true only if everything in the input argument is true
- **find** finds locations and returns indices

```
i1 = [1 1 1 1 1];
i2 = [0 0 0 0 0];
i3 = [0 1 0 1 0];
i4 = [0 0 0 1 0];
```

i1, i2, i3, and  
i4 are logical  
vectors.

|                  |             |
|------------------|-------------|
| all(i1)          | 1           |
| all(i2)          | 0           |
| all(i3)          | 0           |
|                  |             |
| any(i2)          | 0           |
| any(i3)          | 1           |
| any(i4)          | 1           |
|                  |             |
| all(and(i1, i3)) | 0           |
| any(and(i3, i4)) | 1           |
|                  |             |
| find(i1)         | [1 2 3 4 5] |
| find(i3)         | [2 4]       |



## Example: Logical Built-in Function

Q1: Check if there is a number more than or equal to 10 in vec

Q2: Check if there is a number equal to 6 in vec

Q3: Check if there is a number larger than 3 and less than 7 in vec

If Yes, assign true in each variable, q1, q2, and q3. Otherwise, assign false.

```
1  vec = [1 3 4 2 5 10 2 9 11];
2
3  id1 = (vec >= 10);
4  id2 = (vec == 6);
5  id3 = (vec >3) && (vec<7);
6
7  q1 = any(id1);
8  q2 = any(id2);
9  q3 = any(id3);
```

|     |   |   |   |   |   |    |   |   |    |
|-----|---|---|---|---|---|----|---|---|----|
| vec | 1 | 3 | 4 | 2 | 5 | 10 | 2 | 9 | 11 |
| id1 | 0 | 0 | 0 | 0 | 0 | 1  | 0 | 0 | 1  |
| q1  | 1 |   |   |   |   |    |   |   |    |
| id2 | 0 | 0 | 0 | 0 | 0 | 0  | 0 | 0 | 0  |
| q2  | 0 |   |   |   |   |    |   |   |    |
| id3 | 0 | 0 | 1 | 0 | 1 | 0  | 0 | 0 | 0  |
| q3  | 1 |   |   |   |   |    |   |   |    |



## Example: Bulls and Cows

Q: Write a script to compute “Cows” + “Bulls” and assign its value to `num_c`. In other word, you need to compute how many digits are present in both sequences. The true and test sequence is in `x_true` and `x_test`, respectively.

```
x_true = [1 2 3 4]; % true
x_test = [3 2 5 6]; % test

num_c = 0;
for ii=1:4
    for jj=1:4
        if x_true(ii) == x_test(jj)
            num_c = num_c + 1;
        end
    end
end
```

```
x_true = [1 2 3 4]; % true
x_test = [3 2 5 6]; % test

num_c = 0;
for ii=1:4
    if any(x_true == x_test(ii))
        num_c = num_c + 1;
    end
end
```



## Example: Logical Built-in Function

Q. Find id(s) of students whose scores are more than or equal to 80 and less than 90 in their midterm. Here, the indexes of a score vector is student ids.

```
mid_score = [71 82 85 76 91 100 82 83 65 51]';  
  
cond1 = mid_score >=80;  
cond2 = mid_score < 90;  
  
idx = and(cond1, cond2); % or cond1 & cond2  
cl_id = find(idx);
```

|           |    |    |    |    |    |     |    |    |    |    |
|-----------|----|----|----|----|----|-----|----|----|----|----|
| mid_score | 71 | 82 | 85 | 76 | 91 | 100 | 82 | 83 | 65 | 51 |
| cond1     | 0  | 1  | 1  | 0  | 1  | 1   | 1  | 1  | 0  | 0  |
| cond2     | 1  | 1  | 1  | 1  | 0  | 0   | 1  | 1  | 1  | 1  |
| idx       | 0  | 1  | 1  | 0  | 0  | 0   | 1  | 1  | 0  | 0  |
| cl_id     | 2  | 3  | 7  | 8  |    |     |    |    |    |    |

## Example: For-loop and if vs Find vs Logical Indexing



Q. Change 1 to 5, 2 to 7, and the rest to 10 in the given vector named 'vec'

```
vec = [1 1 2 1 3 1 6 7 5];  
  
n_vec = numel(vec);  
for ii=1:n_vec  
    if vec(ii) == 1  
        vec(ii) = 5;  
    elseif vec(ii) == 2  
        vec(ii) = 7;  
    else  
        vec(ii) = 10;  
    end  
end
```

```
vec = [1 1 2 1 3 1 6 7 5];  
  
loc1 = find(vec==1);  
loc2 = find(vec==2);  
locr = find((vec~=1 & vec~=2));  
  
vec(loc1) = 5;  
vec(loc2) = 7;  
vec(locr) = 10;
```

```
vec = [1 1 2 1 3 1 6 7 5];  
  
loc1 = (vec==1);  
loc2 = (vec==2);  
locr = ~(loc1 | loc2);  
  
vec(loc1) = 5;  
vec(loc2) = 7;  
vec(locr) = 10;
```

# Module 07: Function

Chul Min Yeum

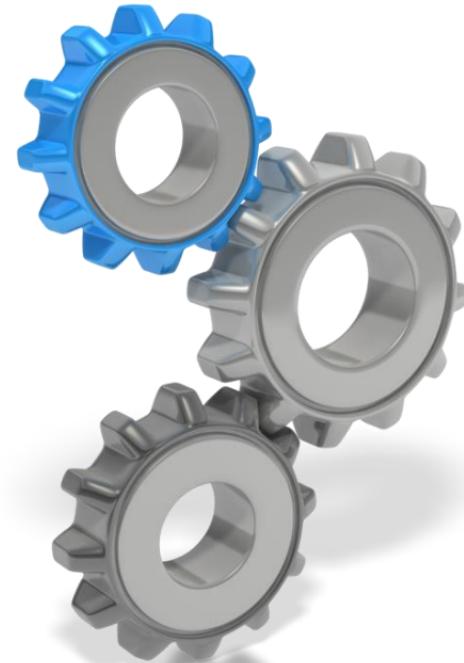
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FACULTY OF ENGINEERING



## Module 07: Learning Outcomes

- Explain the advantages of using functions
- Create the functions that supports various input and output variables
- Illustrate the difference between main and local functions
- Assess variable scope in the script having local functions.
- Program your own functions.

# What is a Function?

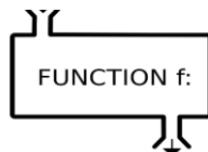
- Function is a type of procedure or routine that performs specific tasks.
- It is a block of **organized** and **reusable** scripts that is used to perform a single and related tasks.
- There are built-in functions provided by MATLAB, but users can write their own functions for reusing a certain operation.
- Advantage: **organized** (readable), **time saving** by avoiding mistake and reusing basic operations

# Types of Functions

A function is a group of statements that together perform a task. In MATLAB, functions are defined in separate files. The name of the file and of the function should be the same.

**Built-in Functions:** Functions that are frequently used or that can take more time to execute are often implemented as executable files. These functions are called built-ins.

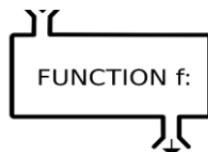
Single input



Single output

```
x = -1  
y = abs(-1)
```

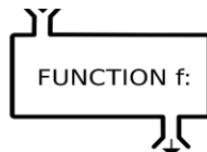
Multiple inputs



Single output

```
vec1 = randi(10,3,3)
```

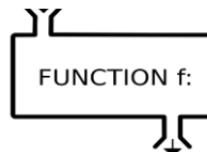
Single/Multiple inputs



Multiple output

```
mat1 = [1 1; 1 1];  
[cz, rz] = size(mat1)
```

Single/Multiple inputs



No return value

```
disp('hello')
```

# Example: Built-in Functions

## sum

R2020a

Sum of array elements

[collapse all in page](#)

### Syntax

```
S = sum(A)
S = sum(A,'all')
S = sum(A,dim)
S = sum(A,vecdim)
S = sum(__,outtype)
S = sum(__,nanflag)
```

### Description

`S = sum(A)` returns the sum of the elements of `A` along the first array dimension whose size does not equal 1.

[example](#)

- If `A` is a vector, then `sum(A)` returns the sum of the elements.
- If `A` is a matrix, then `sum(A)` returns a row vector containing the sum of each column.
- If `A` is a multidimensional array, then `sum(A)` operates along the first array dimension whose size does not equal 1, treating the elements as vectors. This dimension becomes 1 while the sizes of all other dimensions remain the same.

`S = sum(A,'all')` computes the sum of all elements of `A`. This syntax is valid for MATLAB® versions R2018b and later.

[example](#)

`S = sum(A,dim)` returns the sum along dimension `dim`. For example, if `A` is a matrix, then `sum(A,2)` is a column vector containing the sum of each row.

[example](#)

`S = sum(A,vecdim)` sums the elements of `A` based on the dimensions specified in the vector `vecdim`. For example, if `A` is a matrix, then `sum(A,[1 2])` is the sum of all elements in `A`, since every element of a matrix is contained in the array slice defined by dimensions 1 and 2.

[example](#)

`S = sum(__,outtype)` returns the sum with a specified data type, using any of the input arguments in the previous syntaxes. `outtype` can be '`'default'`', '`'double'`', or '`'native'`'.

[example](#)

`S = sum(__,nanflag)` specifies whether to include or omit NaN values from the calculation for any of the previous syntaxes. `sum(A,'includenan')` includes all NaN values in the calculation while `sum(A,'omitnan')` ignores them.

[example](#)

# Generic Function Definition

```
1 function [output arguments] = functionname (input arguments)  
2  
3 Your script  
4  
5 end
```

- The function header (line 1) includes
  - the reserved word **function**
  - output argument(s): listing multiple arguments separating with comma  
(Note that the square bracket in the output arguments is not needed if there is only one output.)
  - function name (optional: start with a capital letter for making difference from other variable names.)
  - Input argument(s): listing multiple arguments separating with comma
- The body of function include your script to compute values in the output arguments using input arguments.
- Finished with the reserved word **end**



: Texts in red and bold are syntax.

## Notes on Functions

- The function header and function call have to match up:
  - the name must be the same
  - the number of input arguments must be the same
  - the number of variables in the left-hand side of the assignment should be the same as the number of output arguments

 For example, if the function header is:

```
function [x,y,z] = fnname(a,b)
```

This indicates that the function is returning three outputs, so a call to the function might be (assuming a and b are numbers):

```
[g,h,t] = fnname(11, 4.3);
```

Or using the same names as the output arguments (**it doesn't matter since the workspace is not shared**):

```
[x,y,z] = fnname(11, 4.3);
```



## Example: Make a Function to Compute an Absolute Value

```
% given an input scalar named  
s1, compute the absolute value  
of s1 and assign it to s2
```

```
s1 = 3;  
  
if s1>=0  
    s2 = s1;  
end  
  
if s1<0  
    s2 = s1*-1;  
end
```

Q. How to make a function called 'MyAbs' that can compute an absolute value like abs.

```
function x_abs = MyAbs(x)  
  
if x>=0  
    x_abs = x;  
end  
  
if x<0  
    x_abs = x*-1;  
end  
end
```

```
s1 = -3;  
s2 = MyAbs(s1);
```

| Name | Value |
|------|-------|
| s1   | 3     |
| s2   | 3     |

# What are the Difference between Scripts and Functions?

**Script:** Script files are program files with a .m extension. In these files, you write series of commands, in which you want to execute together. Scripts do not accept the inputs and do not return any outputs. They operate on data in the base workspace.

Input

Series of processing

Output

**my\_script.m**

**Function:** functions file are also program files with a .m extension. Functions can accept inputs and return outputs. Internal variables are local to the function. They use separate workspace.

Input data

**Output = MyFun(input)**

call

Output data

**function output = MyFun(input)**

Series of processing

**end**

**my\_script.m**

**MyFun.m**

# How to Save and Call Functions

## Save

- The function is stored in a code file with the extension .m
- The file name **must be the same** as the function name.
- The file should be placed at the same folder where the script use the function. Otherwise, you need to add the script folder to search its path.

## Call

- Calling the function should be in an assignment statement with the input and output argument(s), which is the same as the number of the input and output arguments in the function header.
- You can use any input and output variable names when you call the function because they are not sharing the Workspace (different variable scope).

# How to Use the Function

## MyAbs.m

```
function x_abs = MyAbs(x)

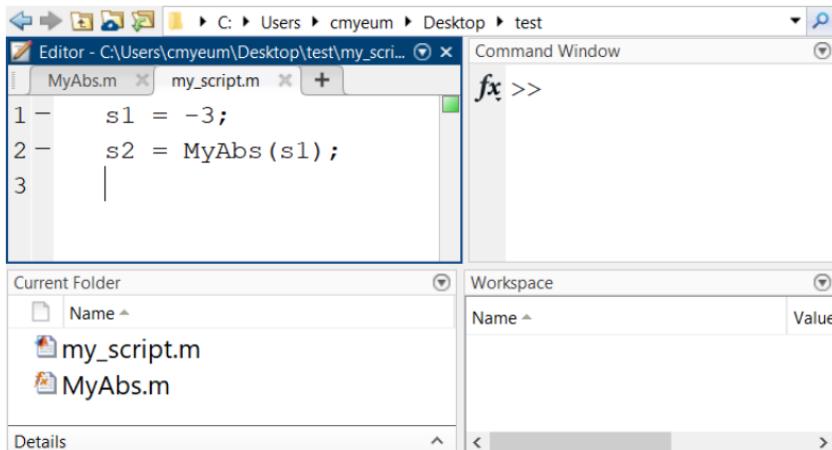
if x>=0
    x_abs = x;
end

if s1<0
    x_abs = x*-1;
end

end
```

## my\_script.m

```
s1 = -3;
s2 = MyAbs(s1);
```



❑: Function and script files should be placed at the same folder. If not, we need add folders (addpath) where the functions are present so that MATLAB can search for the functions

## Example: Bulls and Cows

Bulls and Cows is a mind game played by two players.

In the game, a random, 4-digit number is chosen, and its values are compared to those of another trial number. **All four digits of the number must be different.** If any digit in the chosen number is the exact same value and in the exact same position as any digit in the trial number, this is called a bull. If the digit is present in both the trial number and chosen number, but is not in the same location, this is called a cow.





## Example: Bulls and Cows – Compute Bulls

Q: Write a function named ‘CompBulls’ to compute ‘bulls’ when test and true numbers are given, which are named as ‘x\_true’ and ‘x\_test’.

```
% This is the code that we  
developed in the previous  
module!
```

```
x_true = [1 2 3 4]; % true  
x_test = [3 2 5 6]; % test
```

```
is_same = (x_true == x_test);  
num_b = sum(is_same);
```

my\_script.m

```
x_true = [1 2 3 4]; % true  
x_test = [3 2 5 6]; % test  
  
bulls = CompBulls(x_true, x_test);
```

CompBulls.m

```
function num_b = CompBulls(x_tr, x_ts)  
  
is_same = (x_tr == x_ts);  
num_b = sum(is_same);  
  
end
```



## Example: Bulls and Cows – Compute Cows

Q: Write a function named ‘CompCows’ to compute ‘cows’ when test and true numbers are given, which are named as ‘x\_true’ and ‘x\_test’.

```
function cows = CompCows(x_tr, x_ts)

num_c = 0; % bulls + cows

for ii=1:4
    if any(x_tr == x_ts(ii))
        num_c = num_c + 1;
    end
end

is_same = (x_tr == x_ts);
num_b = sum(is_same); % bulls

cows = num_c - num_b; % cows

end
```

*Option 1*

```
x_true = [1 2 3 4]; % true
x_test = [3 2 5 6]; % test

cows = CompCows(x_true, x_test);
```

```
function cows = CompCows(x_tr, x_ts)

num_c = 0; % bulls + cows
for ii=1:4
    if any(x_tr == x_ts(ii))
        num_c = num_c + 1;
    end
end

num_b = CompBulls(x_tr, x_ts)
cows = num_c - num_b; % cows

end
```

*Option 2*



## Example: Bulls and Cows – Compute Bulls and Cows

Q: Write a function named ‘CompBC’ to compute ‘bulls’ and ‘cows’ when test and true numbers are given, which are named as ‘x\_true’ and ‘x\_test’.

```
function [bulls, cows] = CompBC(x_true, x_test)

bulls = CompBulls(x_true, x_test);
cows = CompCows(x_true, x_test);

end
```

```
function num_b = CompBulls(x_tr, x_ts)

is_same = (x_true == x_test);
num_b = sum(is_same);

end
```

Assume that each function is stored in its m-file with the file name identical to its function name.

```
function cows = CompCows(x_tr, x_ts)

num_c = 0; % bulls + cows
for ii=1:4
    if any(x_tr == x_ts(ii))
        num_c = num_c + 1;
    end
end

num_b = CompBulls(x_tr, x_ts)
cows = num_c - num_b; % cows

end
```



## Example: Is this Character English Alphabet?

Q: Given a character named 'one\_char', write a function to check if 'one\_char' is in the English alphabet. If yes, assign true to 'is\_alpha', otherwise false.

```
one_char = 'a'; % input character

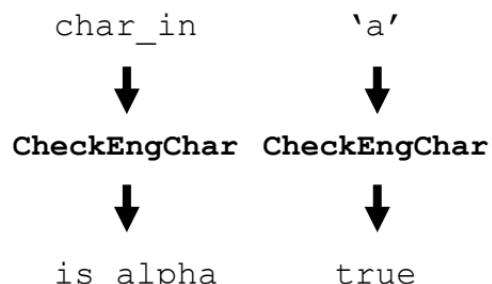
char_db = double(one_char);
cond1 = and(65 <= char_db, char_db <=90); % upper case
cond2 = and(97 <= char_db, char_db <=122); % lower case

is_alpha = or(cond1, cond2); % output
```

```
function is_alpha = CheckEngChar(char_in)

char_db = double(char_in);
cond1 = and(65 <= char_db, char_db <=90);
cond2 = and(97 <= char_db, char_db <=122);
is_alpha = or(cond1, cond2); % output

end
```



# Example: How Many English Alphabets in a Character Vector?



```
char_vec = 'asbdec#43!@3';
num_char = numel(char_vec);

num_alpha = 0;
for ii=1:num_char

    one_char = char_vec(ii);
    char_db = double(one_char);
    cond1 = and(65 <= char_db, char_db <=90);
    cond2 = and(97 <= char_db, char_db <=122);

    is_alpha = or(cond1, cond2); % output

    if is_alpha == 1
        num_alpha = num_alpha + 1;
    end
end
```

Q: Given a character vector named 'char\_vec', write a script to count the number of English alphabet characters in 'char\_vec'. Assign the number to 'num\_alpha'.

⌚: If you pack the script as a function, the code can be shortened and readable.

```
char_vec = 'asbdec#43!@3';
num_char = numel(char_vec);

num_alpha = 0;
for ii=1:num_char
    is_alpha = CheckEngChar(char_vec(ii));

    if is_alpha
        num_alpha = num_alpha + 1;
    end
end
```

# Example: Is There Non-Alphabet Character in a Character Vector?

```
char_vec = 'asbdec#43!@3';
num_char = numel(char_vec);

is_all_alpha = true;
for ii=1:num_char

    one_char = char_vec(ii);
    char_db = double(one_char);
    cond1 = and(65 <= char_db, char_db <=90);
    cond2 = and(97 <= char_db, char_db <=122);

    is_alpha = or(cond1, cond2);

    if is_alpha ~= true
        is_all_alpha = false;
        break;
    end
end
```

Q: Given a character vector named 'char\_vec', write a script to check if the vector only contain English alphabet characters. If yes, assign true to 'is\_all\_alpha', otherwise assign false.

```
char_vec = 'asbdec#43!@3';
num_char = numel(char_vec);

is_all_alpha = true;
for ii=1:num_char
    is_alpha = CheckEngChar(char_vec(ii));

    if is_alpha ~= true
        is_all_alpha = false;
        break;
    end
end
```



## Example: Vectorization

```
function is_alpha = CheckEngChar(char_in)

char_db = double(char_in);

cond1 = and(65 <= char_db, char_db <=90);
cond2 = and(97 <= char_db, char_db <=122);
is_alpha = or(cond1, cond2); % output

end
```

: Here, the input does not have to be a single character. The script supports a character vector as an input. Then, the output will be the same size as its input vector.

### Q. How many English alphabet?

```
char_vec = 'asbdec#43!@3';

is_alpha = CheckEngChar(char_vec);

num_alpha = sum(is_alpha);
```

### Q. Is there non-alphabet character in a character vector?

```
char_vec = 'asbdec#43!@3';

is_alpha = CheckEngChar(char_vec);

is_all_alpha = all(is_alpha);
```

# Example: How Many Upper-Case and Lower-Case Letters?



```
function [num_up, num_low] = CheckCharCase(char_in)

char_db = double(char_in);

lg_up = and(65 <= char_db, char_db <=90); % index upper case
lg_low = and(97 <= char_db, char_db <=122); % index lower case

num_up = sum(lg_up);
num_low = sum(lg_low);

end
```

```
>> char_vec = 'asbdEc#43!@3';
>> [num_up, num_low] = CheckCharCase(char_vec)
```

```
num_up =
```

```
1
```

```
num_low =
```

```
5
```



The function designed here computes numbers of both upper and lower-case letters when one input vector is provided.

## Example: How Many Lower-Case and Upper-Case Letters? (Continue)

```
function num_char = CheckCharCase(char_in, lt_case)
    char_db = double(char_in);

    if isequal(lt_case, 'upper')
        lg_up = and(65 <= char_db, char_db <=90);
        num_char = sum(lg_up);

    elseif isequal(lt_case, 'lower')
        lg_low = and(97 <= char_db, char_db <=122);
        num_char = sum(lg_low);

    else
        error('wrong second argument of lt_case');
    end
```

**End**

**Challenging**

 We can make the function to selectively compute either lower- or upper-case letter by providing the second argument.

```
>> char_vec = 'asbdEc#43!@3';
>> num_low_char = CheckCharCase(char_vec, 'lower')

num_low_char =
```

5

# Local Function

MATLAB® program files can contain code for more than one function. In a function **script** file, the first function in the file is called the **main function**. This function is visible to functions in other files, or you can call it from the command line. Additional functions within the file are called **local functions**, and they can occur in any order after the main function.

**MyFun.m**

```
function out = MyFun(in)
call MyFunSub1
call MyFunSub2

processing using outputs
from sub functions

end
```

**MyFunSub1.m**

```
function out = MyFunSub1 (in)
a series of processing
end
```

**MyFunSub2.m**

```
function out = MyFunSub2 (in)
a series of processing
end
```

**MyFunAll.m**

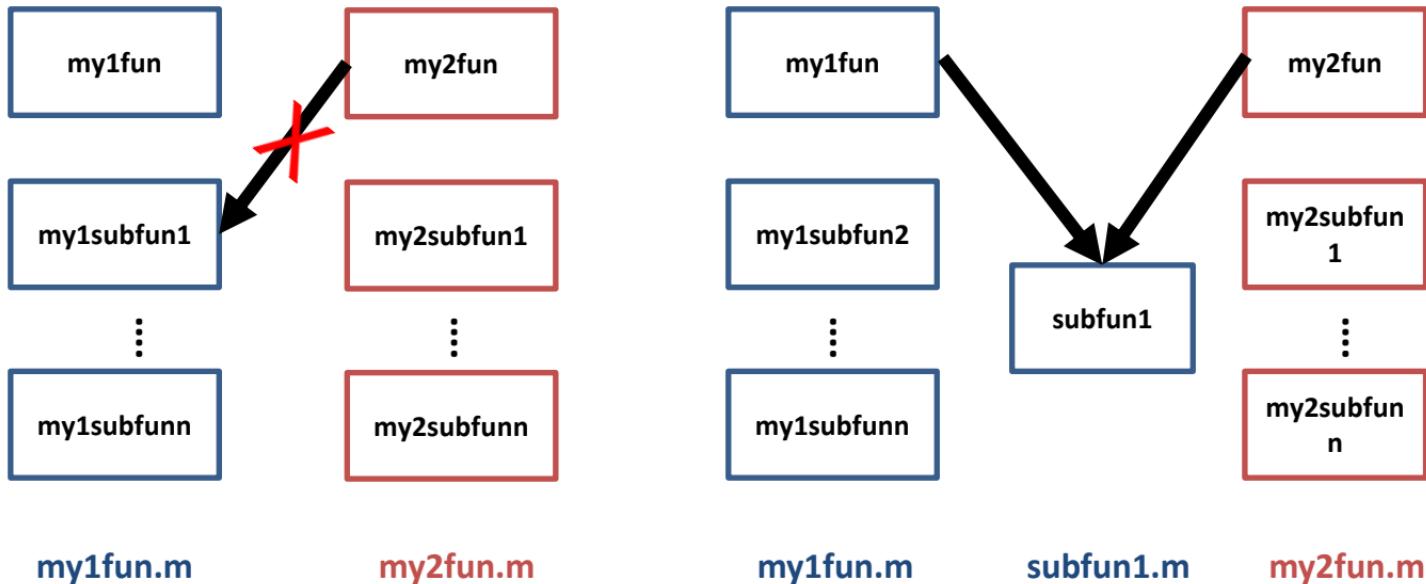
```
function out = MyFunAll(in) ← main function
call MyFunSub1
call MyFunSub2
processing using outputs from sub functions
end

function out = MyFunSub1 (in) ← local function
a series of processing
end

function out = MyFunSub2 (in) ← local function
a series of processing
end
```

# Call Local Functions

Local functions are only visible to other functions in the same file. They are equivalent to subroutines in other programming languages and are sometimes called subfunctions.





## Example: Bulls and Cows – Compute Bulls and Cows

```
function [bulls, cows] = CompBC(x_true, x_test)
    bulls = CompBulls(x_true, x_test);
    cows = CompCows(x_true, x_test);
end

function num_b = CompBulls(x_tr, x_ts)

    is_same = (x_tr == x_ts);
    num_b = sum(is_same);

end

function num_c = CompCows(x_tr, x_ts)

    num_c = 0;
    for ii=1:4
        if any(x_tr == x_ts (ii))
            num_c = num_c + 1;
        end
    end
    bulls = CompBulls(x_tr, x_ts);
    num_c = num_c - bulls;

end
```

CompBC.m

```
>> x_tr = [1 2 3 6]; % true
>> x_ts = [3 2 5 6]; % test
>> [bls, cws] = CompBC(x_tr, x_ts)
bls =
```

2

```
cws =
```

1

my\_script.m

```
x_tr = [1 2 3 6]; % true
x_ts = [3 2 5 6]; % test

[bls, cws] = CompBC(x_tr, x_ts)
```

## Add Functions to Scripts

- MATLAB® scripts, including live scripts, can contain code to define functions. These functions are called local functions. Local functions are useful if you want to reuse code within a script. By adding local functions, you can avoid creating and managing separate function files. They are also useful for experimenting with functions, which can be added, modified, and deleted easily as needed. Functions in scripts are supported **in R2016b or later**.
- Local functions are only visible within the file where they are defined, both to the script code and other local functions within the file. They are not visible to functions in other files and cannot be called from the command line. They are equivalent to subroutines in other programming languages and are sometimes called subfunctions.

## Example: Add Functions to Your Script

```
x_tr = [1 2 3 6]; % true
x_ts = [3 2 5 6]; % test
[bulls, cows] = CompBC(x_tr, x_ts)

function [bulls, cows] = CompBC(x_true, x_test)

bulls = CompBulls(x_true, x_test);
cows = CompCows(x_true, x_test);

end

function num_b = CompBulls(x_tr, x_ts)

is_same = (x_tr == x_ts);
num_b = sum(is_same);

end

function num_c = CompCows(x_tr, x_ts)
num_c = 0;
for ii=1:4
    if any(x_tr == x_ts (ii))
        num_c = num_c + 1;
    end
end
bulls = CompBulls(x_tr, x_ts);
num_c = num_c - bulls;

end
```

 We can write both script and function at the same m-file. In this case, all functions become local function, which means these cannot be accessed from the other files.

 This is very useful when you test your function. Before 2016, we need to have a separate script to test function or using a command window.

## Variable Scope

- The **scope** of any variable is the workspace in which it is valid.
- The workspace created in the Command Window is called the **base workspace**.
- Scripts also create variables in the base workspace. That means that variables created in the Command Window can be used in scripts and vice versa
- Functions do not use the base workspace. Every function has **its own function workspace**. Each function workspace is separate from the base workspace and all other workspaces to protect the integrity of the data. Even local functions in a common file have their own workspaces. Variables specific to a function workspace are called local variables. Typically, local variables do not remain in memory from one function call to the next.

# Change Workspace and Variable Scope

## Challenging

```
my_script.m
1 - x_tr = [1 2 3 6]; % true
2 - x_ts = [3 2 5 6]; % test
3
4 - [bls, cws] = CompBC(x_tr, x_ts);
5
6 disp('Done!');
7
8 function [bulls, cows] = CompBC(x_true, x_test)
9 bulls = CompBulls(x_true, x_test);
10 cows = CompCows(x_true, x_test);
11 end
12
13 function num_b = CompBulls(x_tr, x_ts)
14 is_same = (x_tr == x_ts);
15 num_b = sum(is_same);
16 end
17
18 function num_c = CompCows(x_tr, x_ts)
19 num_c = 0;
20 for ii=1:4
21     if any(x_tr == x_ts(ii))
22         num_c = num_c + 1;
23     end
24 end
25 bulls = CompBulls(x_tr, x_ts);
26 num_c = num_c - bulls;
27 end
```

| Workspace - CompBulls |             |
|-----------------------|-------------|
| Name                  | Value       |
| is_same               | 1x4 logical |
| num_b                 | 2           |
| x_tr                  | [1,2,3,6]   |
| x_ts                  | [3,2,5,6]   |

Stop at line 16

| Workspace - CompBC |           |
|--------------------|-----------|
| Name               | Value     |
| bulls              | 2         |
| x_test             | [3,2,5,6] |
| x_true             | [1,2,3,6] |

Stop at line 10

| Workspace - CompCows |           |
|----------------------|-----------|
| Name                 | Value     |
| ii                   | 4         |
| num_c                | 3         |
| x_tr                 | [1,2,3,6] |
| x_ts                 | [3,2,5,6] |

Stop at line 25

| Workspace - CompBulls |             |
|-----------------------|-------------|
| Name                  | Value       |
| is_same               | 1x4 logical |
| num_b                 | 2           |
| x_tr                  | [1,2,3,6]   |
| x_ts                  | [3,2,5,6]   |

Stop at line 16

| Workspace - my_script |           |
|-----------------------|-----------|
| Name                  | Value     |
| bls                   | 2         |
| cws                   | 1         |
| x_test                | [3,2,5,6] |
| x_true                | [1,2,3,6] |

Stop at line 11

| Workspace - my_script |           |
|-----------------------|-----------|
| Name                  | Value     |
| bls                   | 2         |
| cws                   | 1         |
| x_tr                  | [1,2,3,6] |
| x_ts                  | [3,2,5,6] |

Stop at line 6



# Example: Variable Scope (Which is a Valid Code ?)

```
in_vec = [1 2 3 4];  
n_elem = numel(in_vec);  
mean_val = myfun_mean(in_vec);  
  
function mean_val = myfun_mean(vec)  
  
mean_val = sum(vec)/n_elem;  
  
end
```

Error

```
vec = [1 2 3 4];  
n_elem = numel(vec);  
m_val = mf_mean(vec);  
  
function m_val = mf_mean(vec, n_elem)  
  
m_val = sum(vec)/n_elem;  
  
end
```

Error

```
vec = [1 2 3 4];  
vall = myfun_mean(vec);  
  
function mean_val = myfun_mean(vec)  
  
n_elem = numel(vec);  
mean_val = sum(vec)/n_elem;  
  
end
```

No Error

```
vec = [1 2 3 4];  
n_elem = numel(vec);  
mean_val = myfun_mean(vec);  
  
function mean_val = myfun_mean(vec)  
  
n_elem = numel(vec);  
mean_val = sum(vec)/n_elem;  
  
end
```

No error

# Module 08: Plotting

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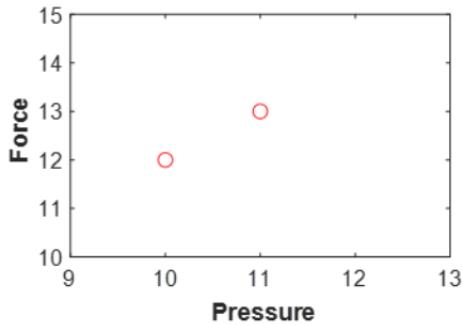
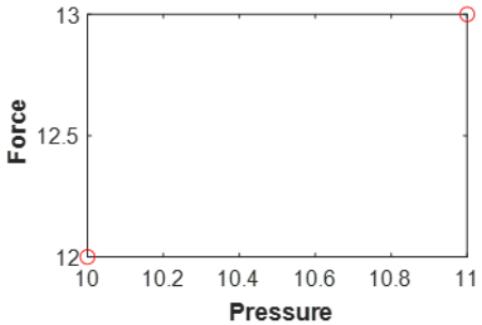
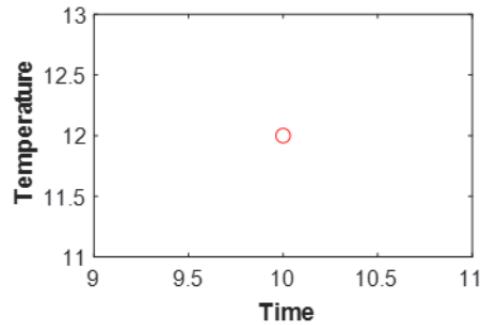
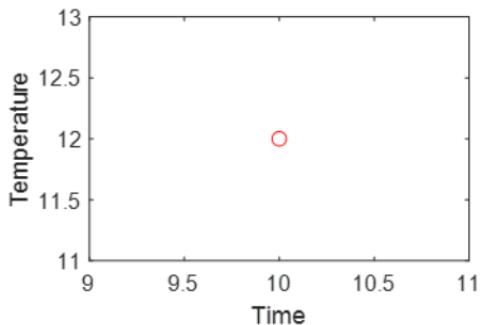
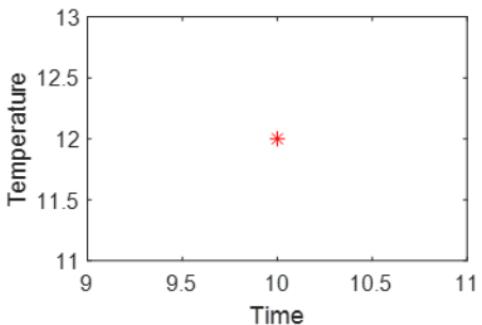
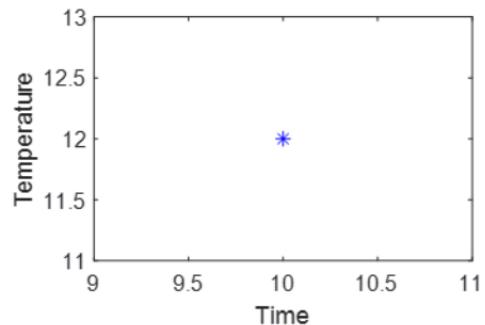


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## Module 08: Learning Outcomes

- Create a graph using the ‘plot’ function
- Customize your plot: marker color & type, line color, labels, set range, etc
- Draw multiple plots or graphs in a single figure window
- Save your graph

# Plot a Point (Overview)



# Plot a Point: Change Marker Color

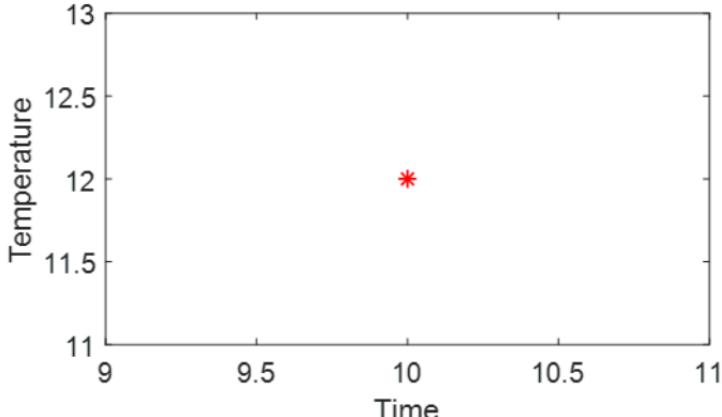
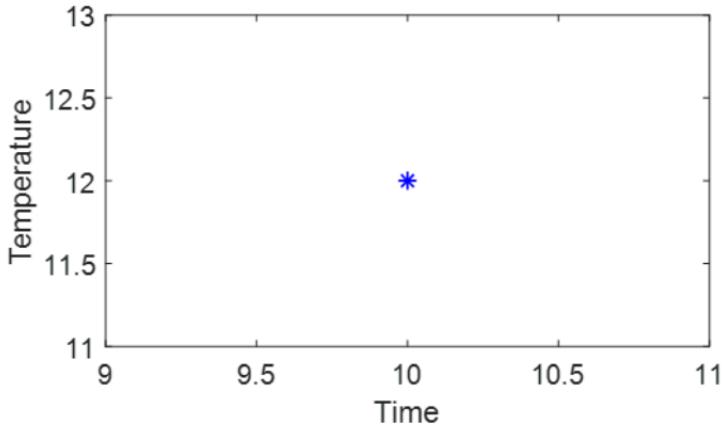
```
x = 10;  
y = 12;  
plot(x,y, 'b*')
```

```
xlabel('Time');  
ylabel('Temperature');
```

```
x = 10;  
y = 12;  
plot(x,y, 'r*')
```

```
xlabel('Time');  
ylabel('Temperature');
```

☞ Color can be specified as a character. 'r': red, 'b': blue, 'm': magenta, 'g': green, 'k': black, 'y': yellow.



# Plot a Point: Change Marker Type & Make Labels as a Bold Font

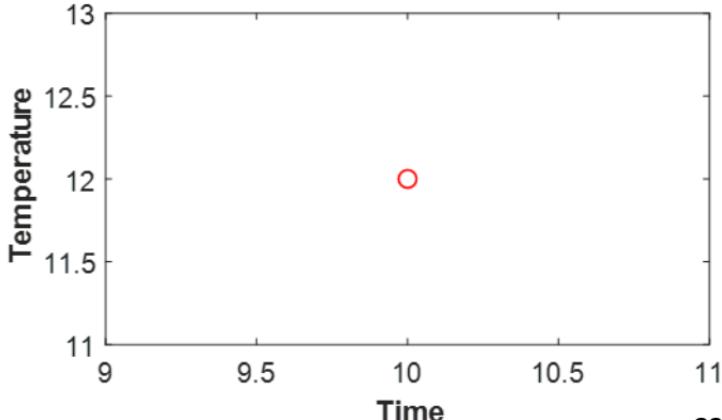
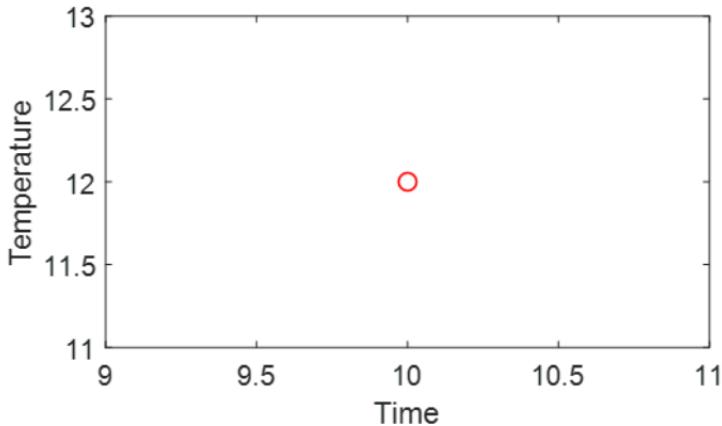
```
x = 10;  
y = 12;  
plot(x,y, 'ro')
```

```
xlabel('Time');  
ylabel('Temperature');
```

```
x = 10;  
y = 12;  
plot(x,y, 'ro')
```

```
xlabel('\bf Time');  
ylabel('\bf Temperature');
```

 Marker type can be specified as a character. 'o': circle, 'x': cross, '\*': asterisk, '+': plus sign



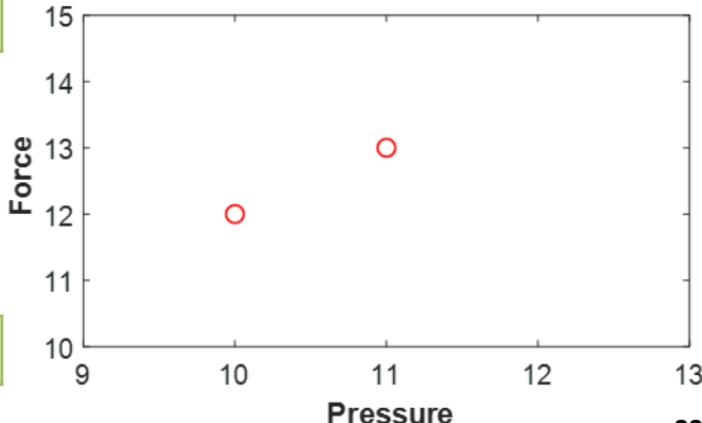
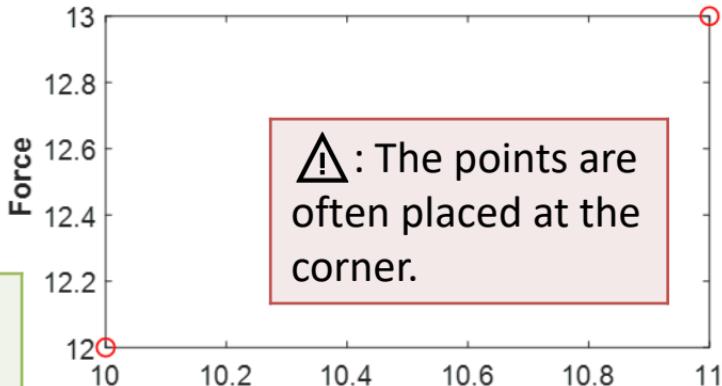
# Plot Point(s): Add Point(s) & Change Min. and Max Value in X & Y-axis

```
x = [10 11];  
y = [12 13];  
plot(x,y, 'ro')  
  
xlabel('bf Pressure');  
ylabel('bf Force');
```

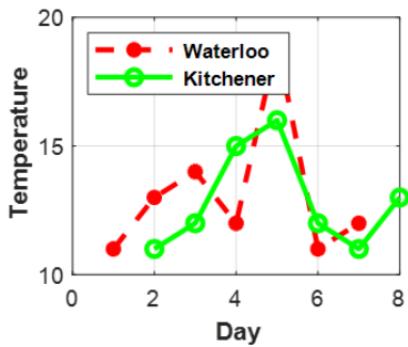
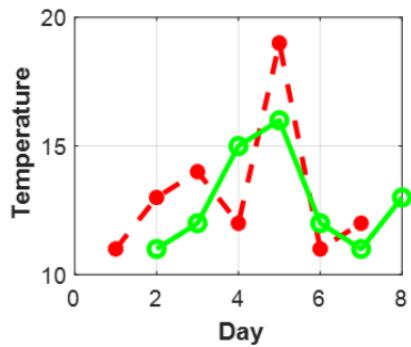
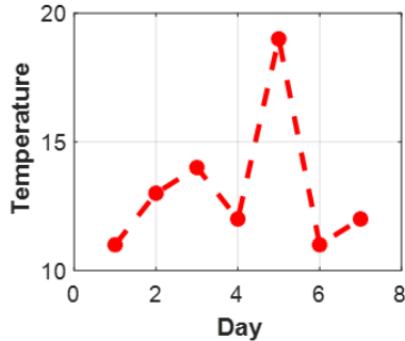
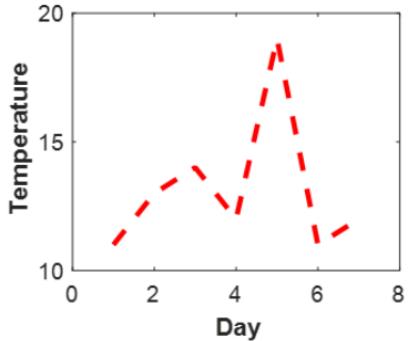
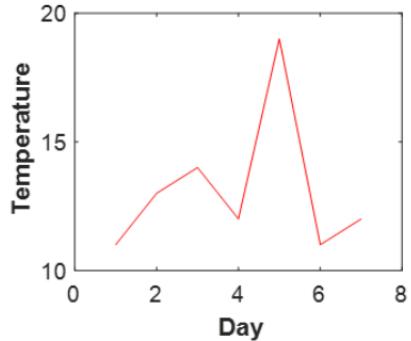
📖: x and y are inputted as a vector to plot multiple points.

```
x = [10 11];  
y = [12 13];  
plot(x,y, 'ro')  
  
xlabel('bf Pressure');  
ylabel('bf Force');  
axis([9 13 10 15]);
```

📖: axis([xmin xmax ymin ymax])



# Plot a Vector (Overview)



# Plot a Vector: Change a Line as a Dashed Line & its Line Width

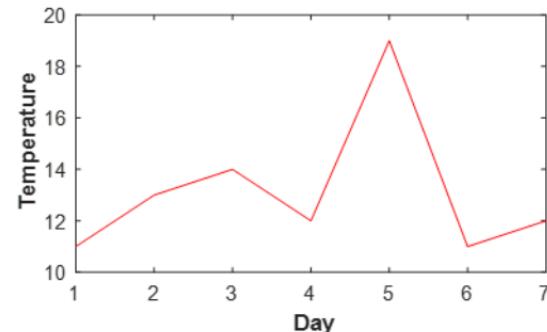
```
x = 1:7;  
y = [11 13 14 12 19 11 12];  
plot(x,y, 'r')
```

```
xlabel('bf Day');  
ylabel('bf Temperature');
```

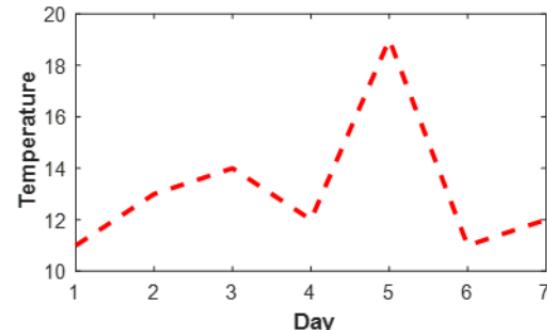
```
x = 1:7;  
y = [11 13 14 12 19 11 12];  
plot(x,y, '--r', 'linewidth', 2)
```

```
xlabel('bf Day');  
ylabel('bf Temperature');
```

: If you include color without specifying marker type, the points are connected (default: solid line). Line style character can specify the line style. '-': solid, '--': dash, ':': dotted, '-.': dash-dot.

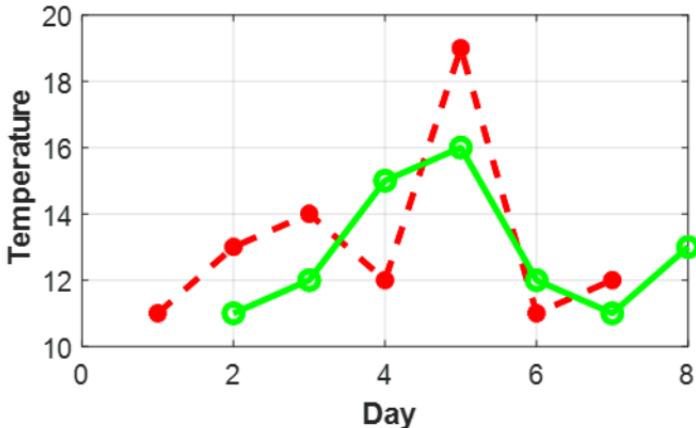


: Plot(... , 'linewidth', value) is to change line width. As increasing value, the line width is thicker.



# Plot a Vector: Add Data Point Marker and Grid & Add Another Line

```
x = 1:7;  
y = [11 13 14 12 19 11 12];  
plot(x,y, '--r*', 'linewidth', 2)  
  
hold on;  
x2 = 2:8;  
y2 = [11 12 15 16 12 11 13];  
plot(x2,y2, '-go', 'linewidth', 2)  
  
xlabel('Day'); grid on;  
ylabel('Temperature');
```



📖: The way of plotting two graphs in one plot is to overlay (combine) two graphs using `hold on`.

📖: `grid on` is to display a grid.

📖: When you combine line and marker style with a color like `--r*`, you can plot the markers on the line, which are used for drawing the corresponding line.

😊: By selecting different line styles, color, line width, marker styles, you can draw nice looking graphs!

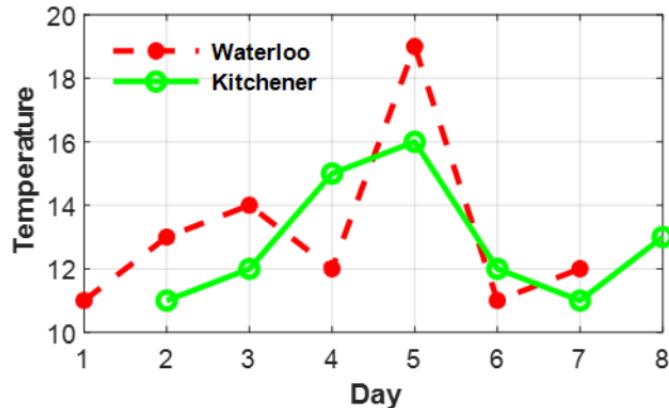
# Plot a Vector: Add Labels & Their Configuration

```
x = 1:7; y = [11 13 14 12 19 11 12];
plot(x,y, '--r*', 'linewidth', 2); hold on

x2 = 2:8; y2 = [11 12 15 16 12 11 13];
plot(x2,y2, '-go', 'linewidth', 2)

legend('bf Waterloo', 'bf Kitchener');
legend('location', 'northwest')
legend('boxoff')

xlabel('bf Day'); grid on
ylabel('bf Temperature');
```



📖: You can create a legend with descriptive labels for each plotted data using `legend(label1, ...)`

📖: You can remove legend background and outline using `legend('boxoff')`.

📖: The graphs might overlap with the legends. Then, you can change the location of the legend using `legend(..., 'Location', lcn)`. Here, lcn includes 'north', 'south', .. 'northwest', etc.

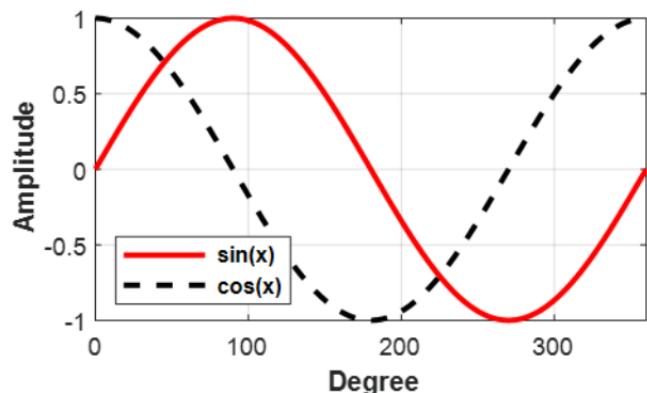
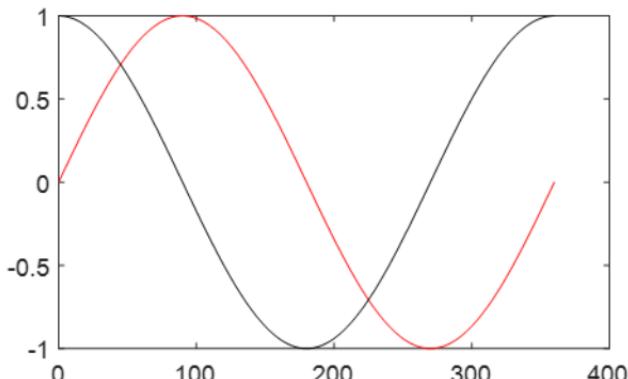
# Trigonometric Functions

| Function                          | Description   | Script   | Value              |
|-----------------------------------|---|--|--------------------|
| <b>deg2rad (x)</b>                | Converts degrees to radians   | <code>deg2rad(90)</code><br><code>deg2rad(180)</code>                    | 1.5708<br>3.1416   |
| <b>rad2deg (x)</b>                | Converts radians to degrees   | <code>rad2deg(pi)</code><br><code>rad2deg(pi/2)</code>                   | 180<br>90          |
| <b>sin(x)</b><br><b>sind(x)</b>   | Find the sine of <b>x</b> when <b>x</b> is expressed in radian/degree                             | <code>sin(pi)</code><br><code>sind(90)</code><br><code>sin(90)</code>    | 0<br>1<br>0.8940   |
| <b>cos(x)</b><br><b>cosd(x)</b>   | Find the cosine of <b>x</b> when x is expressed in radian/degree                                  | <code>cos(pi)</code><br><code>cosd(90)</code><br><code>cos(-90)</code>   | -1<br>0<br>-0.4481 |
| <b>asin(x)</b><br><b>asind(x)</b> | Find the inverse sin of <b>x</b> and reports the result in radian (-pi .. pi)/degree(-180 .. 180) | <code>asin(1)</code><br><code>asind(1)</code><br><code>asind(0.5)</code> | 1.5708<br>90<br>30 |



: '-d' at the end of the name stands for degree.

# Example: How to Change and Draw a Graph



```
x = 0:360;
y1 = sind(x);
y2 = cosd(x);
plot(x, y1, 'r'); hold on;
plot(x, y2, ':k')
```

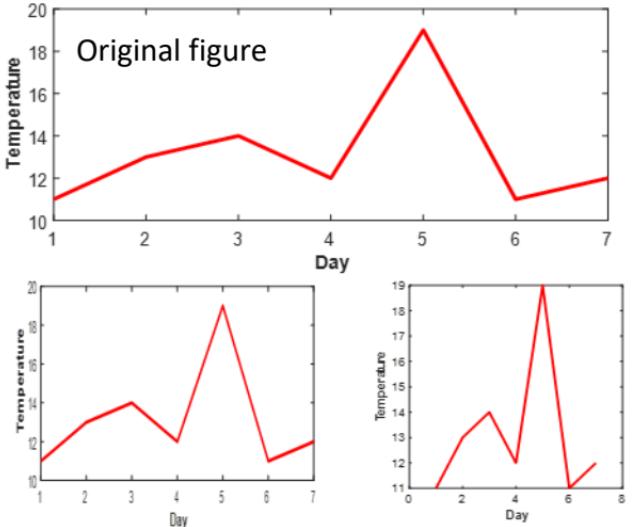
Q. How to change the style of the graph?

```
x = 0:360;
y1 = sind(x);
y2 = cosd(x);
plot(x, y1, 'r', 'linewidth', 2); hold on;
plot(x, y2, '--k', 'linewidth', 2)

legend('\bf sin(x)', '\bf cos(x)');
legend('location', 'southwest')

xlabel('\bf Degree'); grid on
ylabel('\bf Amplitude')
axis([0 360 -1 1]);
```

# Figure Size Control



Resizing with/without keeping aspect ratio of graph contents

```
x = 1:7;
y = [11 13 14 12 19 11 12];

figure(1);
plot(x,y, 'r', 'linewidth', 2)
xlabel('bf Day');
ylabel('bf Temperature');
set(gcf, 'Position', [100 100 500 200]);

figure(2);
plot(x,y, 'r', 'linewidth', 2)
xlabel('bf Day');
ylabel('bf Temperature');
set(gcf, 'Position', [100 100 300 300]);
```

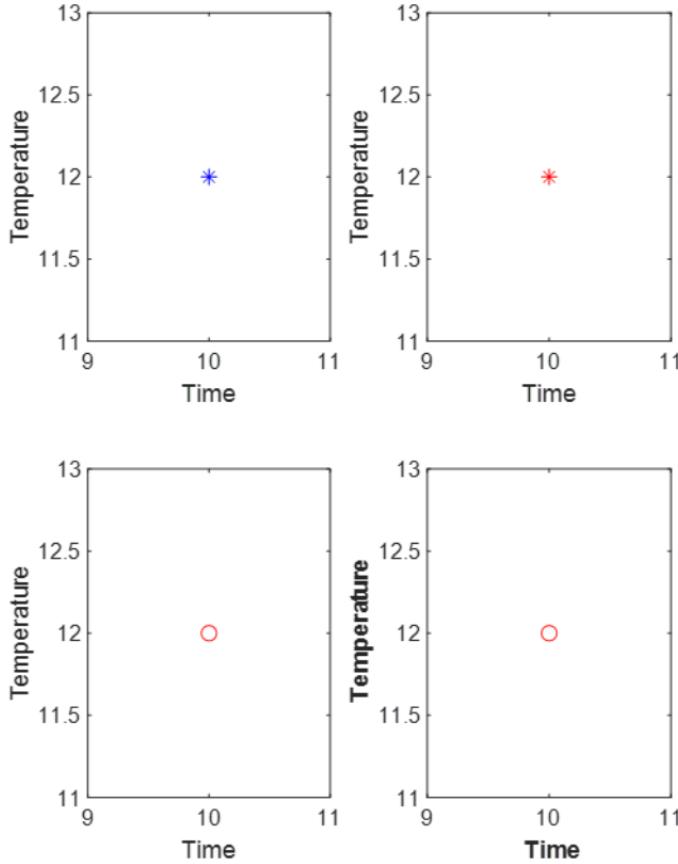
📘: figure (n) create a new figure window in which name is n.

📘: When you resize the figure after copying your image, you cannot keep the aspect ratio of graph contents or the original figure. There are two ways to resize figure with the original aspect ratio. Change the figure window before copying the figure or use 'position' argument.

```
set (gcf, 'position', [left bottom width height])
```

Here, [left bottom ...] indicates the location of left-bottom corner of your figure window.

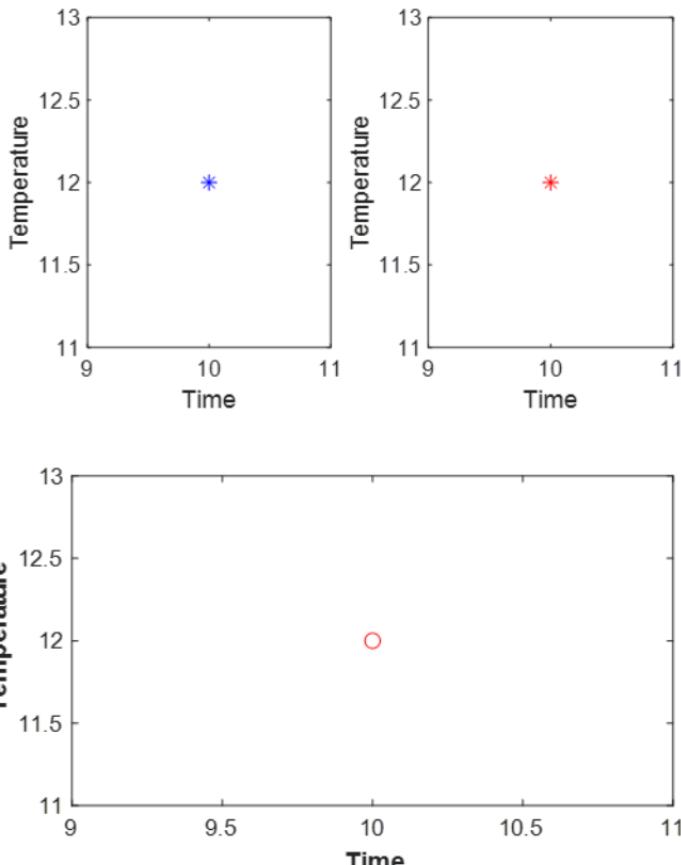
# Multiple Figures in One Figure Window



```
figure(1);  
  
x = 10; y = 12;  
  
subplot(2,2,1);  
plot(x,y, 'b*')  
xlabel('Time'); ylabel('Temperature');  
  
subplot(2,2,2);  
plot(x,y, 'r*')  
xlabel('Time'); ylabel('Temperature');  
  
subplot(2,2,3);  
plot(x,y, 'ro')  
xlabel('Time'); ylabel('Temperature');  
  
subplot(2,2,4);  
plot(x,y, 'ro')  
xlabel('\bf Time');  
ylabel('\bf Temperature');  
  
set(gcf,'Position', [100 100 400 500]);
```

# Multiple Figures (Continue)

## Challenging



```
figure(1);
x = 10; y = 12;

subplot(2,2,1);
plot(x,y, 'b*')
xlabel('Time'); ylabel('Temperature');

subplot(2,2,2);
plot(x,y, 'r*')
xlabel('Time'); ylabel('Temperature');

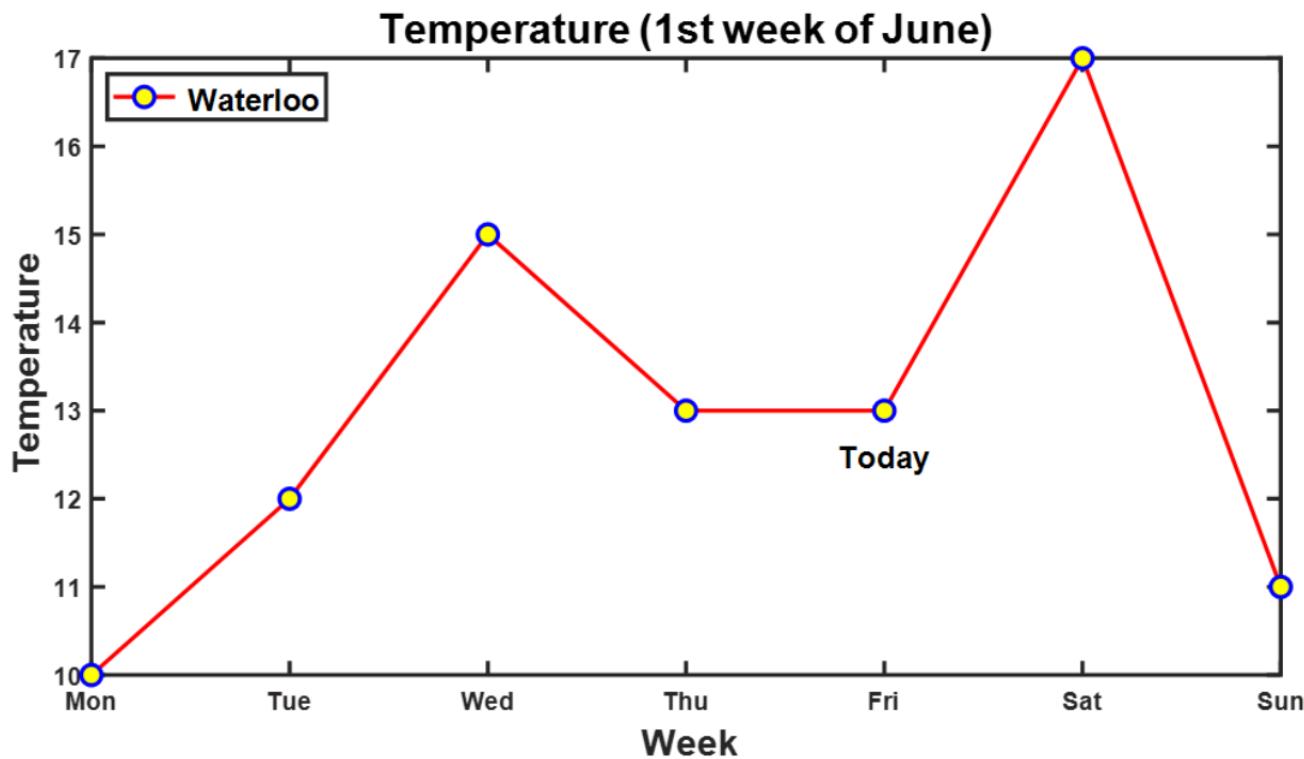
subplot(2,2,[3 4]);
plot(x,y, 'ro')
xlabel('\bf Time');
ylabel('\bf Temperature');

set(gcf,'Position', [100 100 400 500]);
```

**subplot(2,2,n)    subplot(2,3,n)**

|   |   |
|---|---|
| 1 | 2 |
| 3 | 4 |

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | 6 |



## Advanced Plotting (Continue)

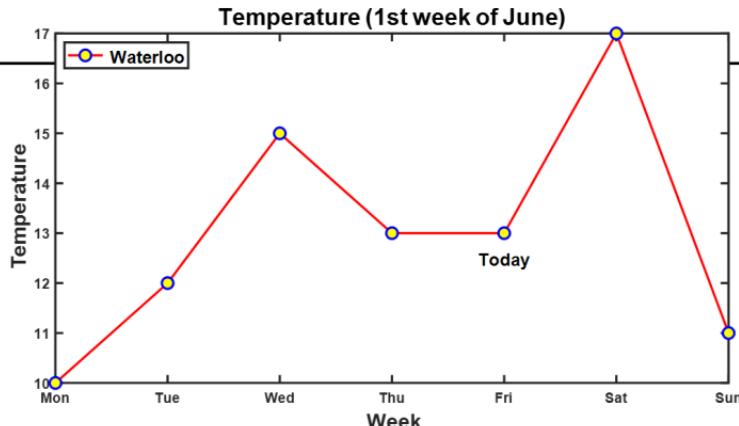
```
x = 1:7; y = [10 12 15 13 13 17 11];
plot(x,y, '-ro', ...
    'LineWidth', 2, ...
    'MarkerSize', 10, ...
    'MarkerEdgeColor', 'b', ...
    'MarkerFaceColor', 'y')
```

```
text(x(5), y(5)-0.5, 'Today', ...
    'FontSize' , 15, ...
    'FontWeight', 'bold', ...
    'HorizontalAlignment', 'center');
```

```
xticks(1:7);
xticklabels({'Mon', 'Tue', 'Wed', 'Thu', 'Fri', 'Sat', 'Sun'});
```

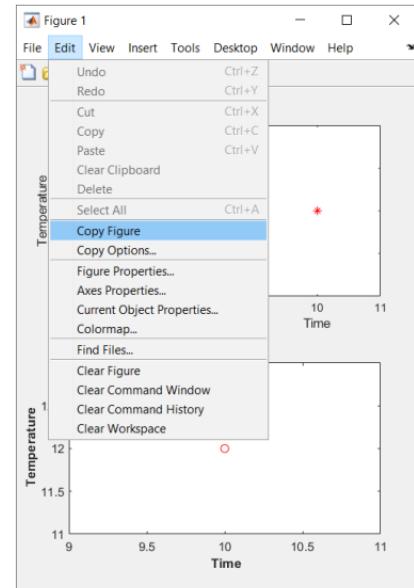
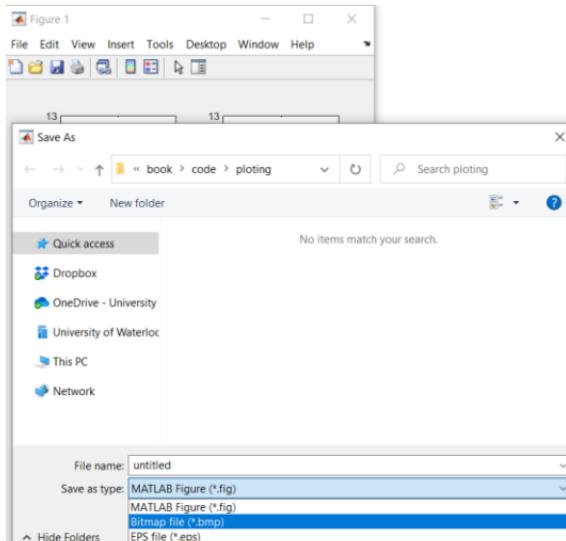
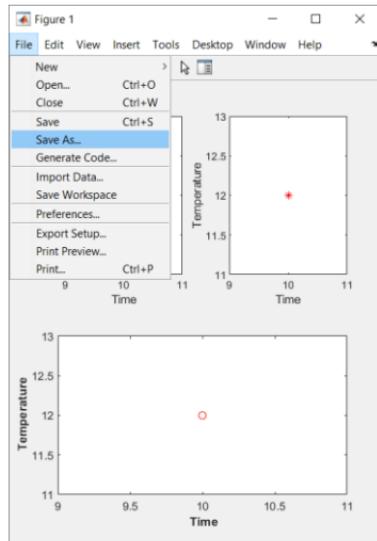
```
legend('bf Waterloo', 'Location', 'northwest', 'FontSize', 15);
set(gca, 'Fontsize', 12, 'FontWeight', 'bold');
set(gca, 'LineWidth', 2);
set(gcf, 'Position', [100 100 1000 500]);
```

```
xlabel('bf Week', 'fontsize', 18);
ylabel('bf Temperature', 'fontsize', 18);
title('Temperature (1st week of June)', 'fontsize', 20);
```



□: ... is to  
continue long  
statements on multiple  
lines

# Save Your Graphs



: Save a graph in an image format: Go to “File-Save As” and select file types to save the figure.

: You can copy and paste a graph.

# Module 09: Data Structure

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## Module 09: Learning Outcomes

- Explain cell and structure data type
- Describe a problem that require these new data type
- Access values in cell and structure array
- Illustrate the difference between cell and structure data type
- Understand vectorization of the operations involving cell arrays

## Cell Array

- A **cell array** is a **data type** that can **store different types and sizes of values** in its elements (cell).
- For example, when you store combinations of text and numbers as one variable which are often read from **spreadsheets**, this cell type is very useful.
- A cell array could be a vector (row or column) or matrix of cells.
- A cell array is an array, so indices are used to refer to the elements.
- The syntax used to create a cell array is **curly braces {} instead of []**  
(e.g. `var = {'abc', 3, [1 2 3]}`)
- The `cell` function can also be used to preallocate empty cells by passing the dimensions of the cell array, e.g. `cell(4, 2)`.
- The contents in cells can be access (write and read) by indexing with curly braces {}.
- () is to **refer a set of cells**, for example, to define a subset of the cell array.

# Create Cell Array

```
cl_info = {'Chul Min', 'CIVE', 1076123, [80 90], [70 30 50], ...
[4 5 1 2], '4B'};
```

option 1

```
cl_info = cell(1,7);  
  
cl_info{1,1} = 'Chul Min';  
cl_info{1,2} = 'CIVE';  
cl_info{1,3} = 1076123;  
cl_info{1,4} = [80 90];  
cl_info{1,5} = [70 30 50];  
cl_info{1,6} = [4 5 1 2];  
cl_info{1,7} = '4B';
```

option 2

⌚: Option 2 is more general when you put multiple input data.

```
>> cl_info  
  
cl_info =  
  
1×7 cell array
```

Columns 1 through 3

```
{'Chul Min'}    {'CIVE'}    {[1076123]}
```

Columns 4 through 5

```
{1×2 double}    {1×3 double}
```

Columns 6 through 7

```
{1×4 double}    {'4B'}
```

⌚: ... is to continue long statements on multiple lines

## Example: How to Create and Access Cell Array

Suppose that you want to store the following data using a cell array:

| Name     | Program | ID      | Exam     | Quiz       | Homework  | Cohort |
|----------|---------|---------|----------|------------|-----------|--------|
| Chul Min | CIVE    | 1076123 | [80 90]  | [70 30 50] | [4 5 2 1] | 4B     |
| Noreen   | ENVE    | 3026327 | [100 70] | [10 20 70] | [2 7 8 9] | 2A     |
| Vlad     | ENVE    | 2046426 | [50 90]  | [90 60 80] | [1 2 6 2] | 2A     |

```
cl_info = cell(3,7);  
  
cl_info{1,1} = 'Chul Min';  
cl_info{1,2} = 'CIVE';  
cl_info{1,3} = 1076123;  
cl_info{1,4} = [80 90];  
cl_info{1,5} = [70 30 50];  
cl_info{1,6} = [4 5 1 2];  
cl_info{1,7} = '4B';  
  
cl_info{2,1} = 'Noreen';  
cl_info{2,2} = 'ENVE';
```

```
% continue  
cl_info{2,3} = 3026327;  
cl_info{2,4} = [100 70];  
cl_info{2,5} = [10 20 70];  
cl_info{2,6} = [2 7 8 9];  
cl_info{2,7} = '2A';  
  
cl_info{3,1} = 'Vlad';  
cl_info{3,2} = 'ENVE';  
cl_info{3,3} = 2046426;  
cl_info{3,4} = [50 90];  
cl_info{3,5} = [90 60 80];  
cl_info{3,6} = [1 2 6 2];  
cl_info{3,7} = '2A';
```

**⚠:** We cannot store multiple character vectors using basic array type when their lengths are different.

## Example: How to Create and Access Cell Array (Continue)

| Name     | Program | ID      | Exam     | Quiz       | Homework  | Cohort |
|----------|---------|---------|----------|------------|-----------|--------|
| Chul Min | CIVE    | 1076123 | [80 90]  | [70 30 50] | [4 5 2 1] | 4B     |
| Noreen   | ENVE    | 3026327 | [100 70] | [10 20 70] | [2 7 8 9] | 2A     |
| Vlad     | ENVE    | 2046426 | [50 90]  | [90 60 80] | [1 2 6 2] | 2A     |

Q1. What's Chul Min's ID? Assign to 'test\_id'.

```
[nr, nc] = size(cl_info);
for ii=1:nr
    if strcmp(cl_info{ii, 1}, 'Chul Min')
        test_id = cl_info{ii,3};
        break;
    end
end
```

💡 You can shorten the following script

```
test_exam = cl_info{ii,4};
test_grade = test_exam(1);

% shortened
test_grade = cl_info{ii,4}(1);
```

Q2. What's Noreen's the first exam grade? Assign to 'test\_grade'.

```
[nr, nc] = size(cl_info);
for ii=1:nr
    if strcmp(cl_info{ii, 1}, 'Noreen')
        test_exam = cl_info{ii,4};
        test_grade = test_exam(1);
        break;
    end
end
```

# What's the Difference Between {} and ()?

Challenging

```
cl_info = cell(3,7);  
  
cl_info{1,1} = 'Chul Min';  
cl_info{1,2} = 'CIVE';  
cl_info{1,3} = 1076123;  
cl_info{1,4} = [80 90];  
cl_info{1,5} = [70 30 50];  
cl_info{1,6} = [4 5 1 2];  
cl_info{1,7} = '4B';  
  
cl_info{2,1} = 'Noreen';  
cl_info{2,2} = 'ENVE';  
cl_info{2,3} = 3026327;  
cl_info{2,4} = [100 70];  
cl_info{2,5} = [10 20 70];  
cl_info{2,6} = [2 7 8 9];  
cl_info{2,7} = '2A';  
  
cl_info{3,1} = 'Vlad';  
cl_info{3,2} = 'ENVE';  
cl_info{3,3} = 2046426;  
cl_info{3,4} = [50 90];  
cl_info{3,5} = [90 60 80];  
cl_info{3,6} = [1 2 6 2];  
cl_info{3,7} = '2A';
```

```
cl_info = cell(3,7);  
  
cl_info(1,:) = {'Chul Min', 'CIVE', 1076123, [80 90], ...  
[70 30 50], [4 5 1 2], '4B'};  
  
cl_info(2,:) = {'Chul Min', 'CIVE', 1076123, [80 90], ...  
[70 30 50], [4 5 1 2], '4B'};  
  
cl_info(3,:) = {'Chul Min', 'CIVE', 1076123, [80 90], ...  
[70 30 50], [4 5 1 2], '4B'};
```

```
>> class(cl_info{1,1})
```

```
ans = Read the value  
inside the cell  
'char'
```

```
>> class(cl_info(1,1))
```

```
ans = Read the cell  
itself  
'cell'
```

: () is to refer a set of cells. You refer cell(s) themselves and assign a cell or cell array to the space. {} is to refer a value in a cell. You refer a space inside the cell and assign the value to the cell. Remember that cell is a data type!

: **class** is a function of determining a class of object.

# How to Create and Access Cell Array using Vectorization

[Challenging](#)

| Name     | Program | ID      | Exam     | Quiz       | Homework  | Cohort |
|----------|---------|---------|----------|------------|-----------|--------|
| Chul Min | CIVE    | 1076123 | [80 90]  | [70 30 50] | [4 5 2 1] | 4B     |
| Noreen   | ENVE    | 3026327 | [100 70] | [10 20 70] | [2 7 8 9] | 2A     |
| Vlad     | ENVE    | 2046426 | [50 90]  | [90 60 80] | [1 2 6 2] | 2A     |

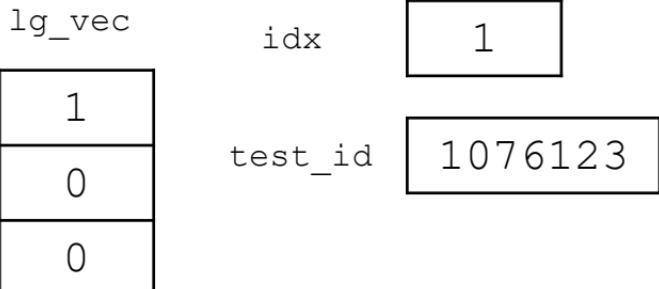
Q1. What's Noreen's ID? Assign to 'test\_id'.

```
lg_vec = strcmp(cl_info(:,1), 'Chul Min');  
idx = find(lg_vec);  
test_id = cl_info{idx, 3};
```

💡: We don't need to do

`find(lg_vec == 1)`

because `find` function is designed to find the 1 (true) values.



📖: `strcmp` supports a cell array of character vectors as inputs. The output produces the logical array with the same size as the input array. Here, the input is the column vector of a cell array that contains character vectors (names). The function compares each element with the second input of the character vector.

# How to Create and Access Cell Array using Vectorization

[Challenging](#)

| Name     | Program | ID      | Exam     | Quiz       | Homework  | Cohort |
|----------|---------|---------|----------|------------|-----------|--------|
| Chul Min | CIVE    | 1076123 | [80 90]  | [70 30 50] | [4 5 2 1] | 4B     |
| Noreen   | ENVE    | 3026327 | [100 70] | [10 20 70] | [2 7 8 9] | 2A     |
| Vlad     | ENVE    | 2046426 | [50 90]  | [90 60 80] | [1 2 6 2] | 2A     |

Q2. What's name of the student whose ID is 3026327? Assign the name to 'test\_name'.

```
mat_id = [cl_info{:,3}];  
lg_vec = mat_id == 3026327;  
idx = find(lg_vec);  
test_name = cl_info{idx, 1};
```

mat\_id

|         |
|---------|
| 1076123 |
| 3026327 |
| 2046426 |

lg\_vec

|   |
|---|
| 0 |
| 1 |
| 0 |

idx

|   |
|---|
| 2 |
|---|

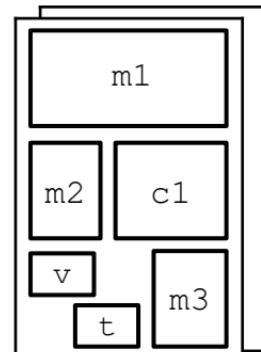
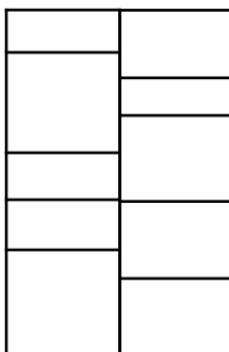
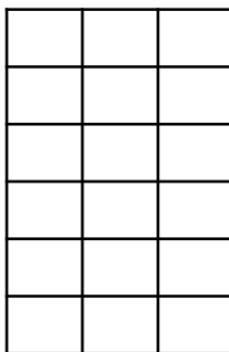
test\_name

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| N | o | r | e | e | n |
|---|---|---|---|---|---|

📘: This is the way of vectorizing the numeric cell array. `cl_info{:,3}` is the script to read all values in the referred cells. If it is inside `[ ]`, this becomes a numeric array. You can use a `cell2mat` built-in function. Once we convert the cell array to the numeric array, we can solve this problem using a vectorized script.

# Structure Variables

- A structure array is a data type that groups related data using data containers called field.
- Each field can contain any type of data.
- Fields are given names; they are referred to as **structurename.fieldname** using the dot operator.



Basic array (A)

Cell array (B)

Structure array (C)

```
A = [1 2 3; 4 5 6];
B = { 'A', 'B', 'C' };
C.a = 'CIVE';
C.b = 'ENVE';
```

|      |        |
|------|--------|
| A(1) | 1      |
| B{2} | 'B'    |
| C.a  | 'CIVE' |

# Create Structure Array

```
st_info(1) = struct('name', 'Chul Min', 'program', 'CIVE', 'id', ...
    1076123, 'exam', [80 90], 'quiz', [70 30 50], 'homework', ...
    [4 5 1 2], 'cohort', '4B');
```

option 1

```
st_info(1).name = 'Chul Min';
st_info(1).program = 'CIVE';
st_info(1).id = 1076123;
st_info(1).exam = [80 90];
st_info(1).quiz = [70 30 50];
st_info(1).homework = [4 5 1 2];
st_info(1).cohort = '4B';
```

option 2

⌚: You can initialize the structure array in the beginning however, there might not be a formal way to do it. If you know the size of the structure array (e.g., # of students in the above case), you can do

```
st_info(10) = struct;
```

```
>> st_info
st_info =
struct with fields:
    name: 'Chul Min'
    program: 'CIVE'
        id: 1076123
    exam: [80 90]
    quiz: [70 30 50]
    homework: [4 5 1 2]
    cohort: '4B'
```

## Example: How to Create and Access Structure Array

Suppose that you want to store the following data using a structure array:

| Name     | Program | ID      | Exam     | Quiz       | Homework  | Cohort |
|----------|---------|---------|----------|------------|-----------|--------|
| Chul Min | CIVE    | 1076123 | [80 90]  | [70 30 50] | [4 5 2 1] | 4B     |
| Noreen   | ENVE    | 3026327 | [100 70] | [10 20 70] | [2 7 8 9] | 2A     |
| Vlad     | ENVE    | 2046426 | [50 90]  | [90 60 80] | [1 2 6 2] | 2A     |

```
st_info(1).name = 'Chul Min';
st_info(1).program = 'CIVE';
st_info(1).id = 1076123;
st_info(1).exam = [80 90];
st_info(1).quiz = [70 30 50];
st_info(1).homework = [4 5 1 2];
st_info(1).cohort = '4B';

st_info(2).name = 'Noreen';
st_info(2).program = 'ENVE';
st_info(2).id = 3026327;
st_info(2).exam = [100 70];
```

```
st_info(2).exam = [100 70];
st_info(2).quiz = [10 20 70];
st_info(2).homework = [2 7 8 9];
st_info(2).cohort = '2A';

st_info(3).name = 'Vlad';
st_info(3).program = 'ENVE';
st_info(3).id = 2046426;
st_info(3).exam = [50 90];
st_info(3).quiz = [90 60 80];
st_info(3).homework = [1 2 6 2];
st_info(3).cohort = '2A';
```

## Example: How to Create and Access Structure Array (Continue)

| Name     | Program | ID      | Exam     | Quiz       | Homework  | Cohort |
|----------|---------|---------|----------|------------|-----------|--------|
| Chul Min | CIVE    | 1076123 | [80 90]  | [70 30 50] | [4 5 2 1] | 4B     |
| Noreen   | ENVE    | 3026327 | [100 70] | [10 20 70] | [2 7 8 9] | 2A     |
| Vlad     | ENVE    | 2046426 | [50 90]  | [90 60 80] | [1 2 6 2] | 2A     |

Q1. What's Chul Min's ID? Assign to 'test\_id'.

```
nst = numel(st_info);
for ii=1:nst
    if strcmp(st_info(ii).name, 'Chul Min')
        test_id = st_info(ii).id;
        break;
    end
end
```

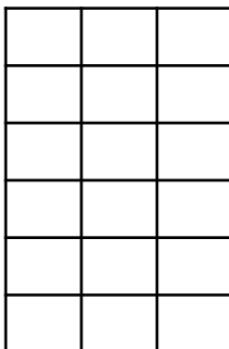
 You can shorten the following script  
test\_exam = st\_info(ii).exam;  
test\_grade = test\_exam(1);  
  
% shortened  
test\_grade = st\_info(ii).exam(1);

Q2. What's Noreen's the first exam grade? Assign to 'test\_grade'.

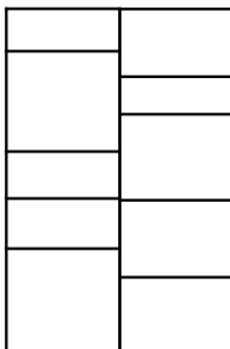
```
nst = numel(st_info);
for ii=1:nst
    if strcmp(st_info(ii).name, 'Noreen')
        test_exam = st_info(ii).exam;
        test_grade = test_exam(1);
    end
end
```

# Cell Arrays vs Structures

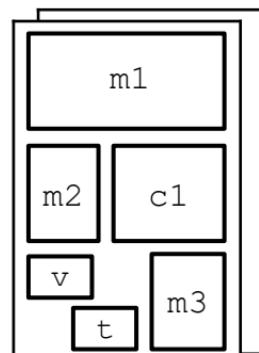
- Cell arrays are arrays, so they can be indexed. That means that you can loop through the elements in a cell array – or have MATLAB do that for you by using a vectorized code
- **Structs are not indexed**, so you cannot loop. However, the field names are mnemonic, so it is clearer what is being stored in a struct.
- For example: variable{1} vs. variable.weight: which is more mnemonic?



Basic array (A)



Cell array (B)



Structure array (C)

```
A = [1 2 3; 4 5 6]  
A(1)
```

```
B = {'A', 'B', 'C'};  
B{1}
```

```
B.a = 'CIVE';  
B.b = 'ENVE';  
B.a
```

# Passing Multiple Input Variable to Function using Structure Optional

Suppose that you are making a function named 'CompGrade' to compute a student grade using his/her record during a term. The ten records are stored in each variable named 'r1', 'r2', ... 'r10'. Thus, the function accepts for 10 inputs and produce one output. How to design your function?

```
function final_grade = CompGrad(r1, r2, ..., r10)
Do something
end
```

```
function final_grade = CompGrad(record)
r1 = record.r1;
r2 = record.r2;
:
r10 = record.r10;
end
```

☞ Rather than passing all ten input variables to the function, we can pass one single structure variable and store all ten variables in the structure variable.

...  
record.r1 = r1;  
record.r2 = r2;  
:  
record.r10 = r10;  
final\_grade = ...  
CompGrad(record);  
...

script

# Module 10: File I/O

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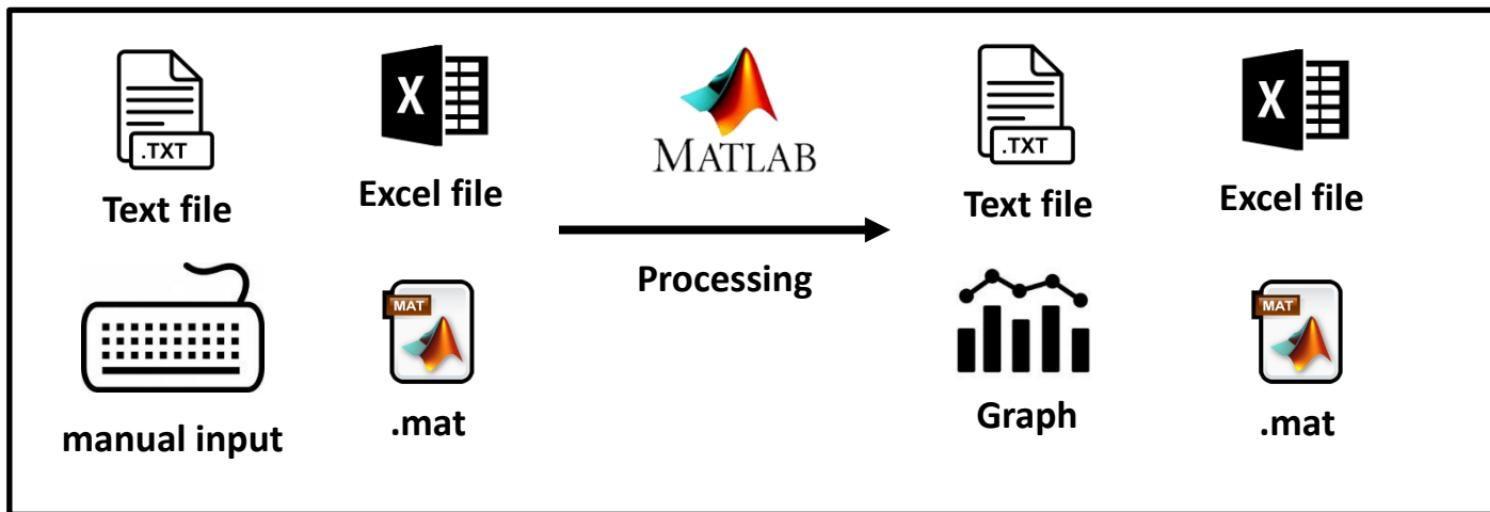


## Module 10: Learning Outcomes

- Store variables in MATLAB Workspace to a MAT-file
- Import text files to MATLAB Workspace
- Explain the difference between text and numeric data when they are read from the file
- Read and Write MS Excel files

# File Input & Output (I/O)

- MATLAB has functions to read from and write to many different file types, for example, spreadsheets.
- MATLAB has a special binary file type that can be used to store variables and their contents in MAT-files.



## Using MAT-files for Variables

- MATLAB has functions that allow reading and saving variables from files.
- These files are called MAT-files (because the extension is .mat).
- Variables can be written to MAT-files, appended to them, and read from them.
- Rather than just storing data, MAT-files **store variable names and their values**
- To save all workspace variables in a file, the command is:  
**save** filename
- To save just one variable to a file, the format is:  
**save** filename variablename
- To read variables from a MAT-file into the base workspace:  
**load** filename variablelist

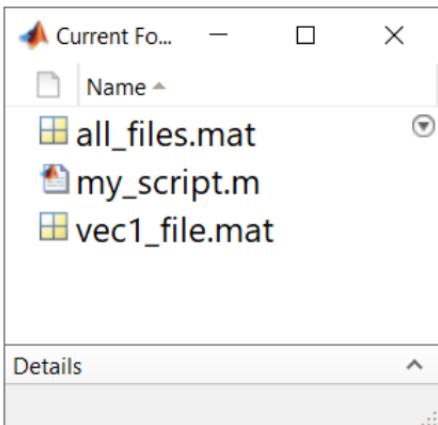
# Example Save and Load Variables Using MAT files

**my\_script.m**

```
vec1 = zeros(1, 3);
mat1 = ones(2, 2);
char1 = 'a';

save all_files
save vec1_file vec1
```

**Current folder**



load all\_files

| Name  | Value      |
|-------|------------|
| vec1  | [0 0 0]    |
| mat1  | [1 1; 1 1] |
| char1 | 'a'        |

load vec1\_file

| Name | Value   |
|------|---------|
| vec1 | [0 0 0] |

load all\_files mat1

| Name | Value      |
|------|------------|
| mat1 | [1 1; 1 1] |

**⚠:** When you are working on a large-scale project, saving all files causes long saving and loading time. Selectively saving and loading is recommended.

## Importing Data from a .txt File

- The text file must be saved in the current folder that you are working in on MATLAB
- Delimiter: sequence of one or more characters used to specify boundaries between separate regions (e.g., comma (,), semicolon (;), space( ))
- Three importing scenarios:
  - Importing numeric data
  - Importing character (string) data
  - Importing numeric and character data

## Print Formatting Text

- The print formatting texts specify in what layout and what data type a column of data will be imported/exported as – for multiple columns of data, use multiple print format operators
- Common print formatting texts:
  - `%d` –For integer numbers
  - `%f` –For floating point (decimal) numbers
  - `%s` –For entire character vectors or strings
- Note that you can only use 1 format text per column (you cannot specify '`%s`' for the first value in a column and '`%f`' for all other values)
- Example: If you wanted your first column of data to be integer data, the second column to be stored as character data and the third to be floating point numbers, the correct format text would be: '`%d %s %f`'

## **textscan Function**

- The `textscan` function will create a **cell** array from the data read on the `.txt` file

```
C = textscan(fileID, formatSpec)
```

- This function can be used to import **numeric data, text data, and both types of data** from the same file easily
- When importing using `textscan`, the data is imported column-by-column.
- You can specify using print formatting texts what type of data you want each column to be.
- Data will be stored in a cell, **where each column is a different cell array element**
- You have the option of specifying a delimiter. The default delimiter is white-space.

## fopen and fclose function

- Used to open a file for a specific purpose
- You can specify your purpose using a permission specifier(the second input)
- The file does not have to already exist (although for reading data it should)

- Read only access (default):

```
fid = fopen('sample_data.txt', 'r')
```

- Write only access (discard original contents of a file):

```
fid = fopen('sample_data.txt', 'w')
```

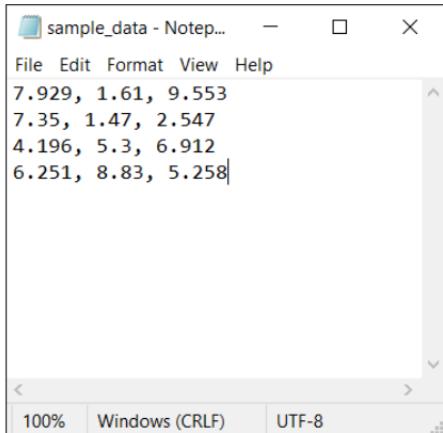
- Read and write access (discard original contents of file if writing):

```
fid = fopen('sample_data.txt', 'w+')
```

- Once you finish read/write operation on the file, you need to close the file  
**fclose**(fid)

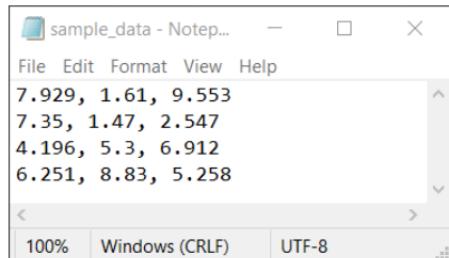
## General Procedure for Importing Data using textscan

```
1 fid = fopen('sample_data.txt');  
2  
3 test_data = textscan(fid, '%f %f %f', 'delimiter', ',');  
4  
5 fclose(fid);
```



- Line 1: Open the file to be read by creating a 'fid'. This is creating a numeric ID that represents the file.
- Line 3: Use the textscan function to import the data using the proper format string and delimiter. If the delimiter is whitespace, you do not need to specify a delimiter.
- Line 5: Close the file you have just read.

# Example: Read Numeric Data



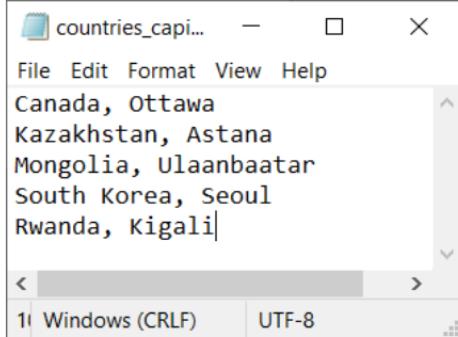
sample\_data - Notepad... File Edit Format View Help  
7.929, 1.61, 9.553  
7.35, 1.47, 2.547  
4.196, 5.3, 6.912  
6.251, 8.83, 5.258  
100% Windows (CRLF) UTF-8

Three columns of numeric data – when importing, you will need to specify three print formatting texts.

```
fid = fopen('sample_data.txt');  
  
samp_data = textscan(fid, '%f %f %f', 'delimiter', ',');  
  
fclose(fid);
```

```
>> samp_data  
  
samp_data =  
  
    1×3 cell array  
  
        {4×1 double}    {4×1 double}    {4×1 double}  
  
>> samp_data{1}  
  
ans =  
  
    7.9290  
    7.3500  
    4.1960  
    6.2510
```

# Example: Read Text Data



The screenshot shows a text editor window with the following content:

```
File Edit Format View Help
Canada, Ottawa
Kazakhstan, Astana
Mongolia, Ulaanbaatar
South Korea, Seoul
Rwanda, Kigali
```

Below the text area, there are status bar elements: 'Windows (CRLF)' and 'UTF-8'.

**⚠: When you read or write text information in a text file, you should not use the white-space delimiter because texts likely include the white space.**

```
fid = fopen('countries_capitals.txt');

text_data = textscan(fid, '%s %s', 'delimiter', ',');

fclose(fid);
```

```
>> text_data

text_data =

    1×2 cell array

    {5×1 cell}    {5×1 cell}

>> text_data{1}

ans =

    5×1 cell array

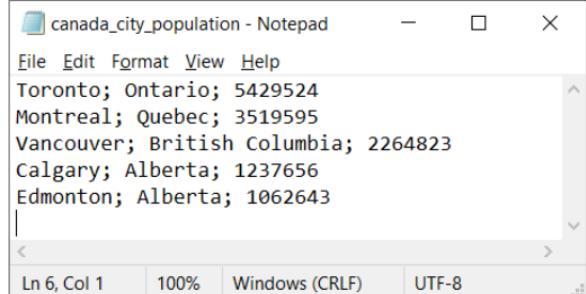
    {'Canada'      }
    {'Kazakhstan'  }
    {'Mongolia'     }
    {'South Korea' }
    {'Rwanda'       }
```

## Example: Read Numeric and Text Data

```
fid = fopen('canada_city_population.txt');

city_data = textscan(fid, '%s %s %f', 'delimiter', ';');

fclose(fid);
```



A screenshot of a Windows Notepad window titled "canada\_city\_population - Notepad". The window displays the following text:

```
Toronto; Ontario; 5429524
Montreal; Quebec; 3519595
Vancouver; British Columbia; 2264823
Calgary; Alberta; 1237656
Edmonton; Alberta; 1062643
```

The Notepad interface includes standard menu options (File, Edit, Format, View, Help), a toolbar, and status bar indicating "Ln 6, Col 1", "100%", "Windows (CRLF)", and "UTF-8".

```
>> city_data

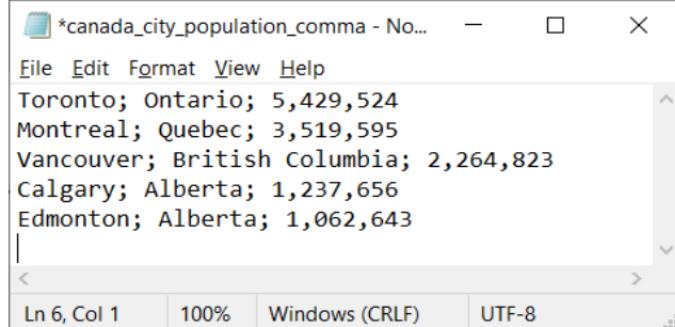
city_data =
1×3 cell array
{5×1 cell}    {5×1 cell}    {5×1 double}

>> city_data{3}

ans =
5429524
3519595
2264823
1237656
1062643
```

# Example: Read Number (with Comma) and Text Data

Optional



The screenshot shows a MATLAB editor window with the following content:

```
File Edit Format View Help
Toronto; Ontario; 5,429,524
Montreal; Quebec; 3,519,595
Vancouver; British Columbia; 2,264,823
Calgary; Alberta; 1,237,656
Edmonton; Alberta; 1,062,643
```

Ln 6, Col 1 | 100% | Windows (CRLF) | UTF-8

```
fid = fopen( ...
'canada_city_population_comma.txt');

text_data = textscan(fid, ...
'%s %s %f', 'delimiter', ',');

fclose(fid);
```

**Not working**

**⚠:** 5,429,524 is not a numeric type because of commas. Thus, the corresponding column can't be read using '%f'.

```
fid = ...
fopen('canada_city_population_comma.txt');

text_data = textscan(fid, '%s %s %s',...
'delimiter', ',');

fclose(fid);

pop_data_cell = text_data{3};

n_data = numel(pop_data_cell);
pop_data = zeros(n_data,1);
for ii=1:n_data
    text_text = pop_data_cell{ii};
    num_text = text_text(text_text ~= ',');
    pop_data(ii) = str2double(num_text);
end
```

```
>> pop_data
```

```
pop_data =
5429524
3519595
2264823
1237656
1062643
```

## Read and Write Excel Data

- The `xlsread` function can be used for importing MS Excel data into MATLAB. However, the use of `xlsread` function is not recommended starting in R2019a.
- MATLAB introduced a **new data type** called **table**. It is suitable for column-oriented or tabular data that is often stored as columns in a text file or a spreadsheet. However, we will not cover this new data type in this course.
- Instead, we will import the data as a cell array using `readcell` or `readmatrix`

## readmatrix and readcell Function

- `readmatrix` creates an array by reading column-oriented data from a file.

```
M = readmatrix(filename)
```

```
M = readmatrix(filename, 'Sheet', sheet, 'Range', range)
```

- `readcell` creates a cell array by reading column-oriented data from a file.

```
C = readcell(filename)
```

```
C = readcell(filename, 'Sheet', sheet, 'Range', range)
```



: `readmatrix` or `readcell` determines the file format from the file extension:

- .txt, .dat, or .csv for delimited text files
- .xls, .xlsh, .xlsm, .xlsx, .xltm, .xltx, or .ods for spreadsheet files

# Example: Read Data from an Excel File (File)

lec10\_excel\_file.xlsx

The screenshot shows a Microsoft Excel spreadsheet titled "lec10\_excel\_file.xlsx". The spreadsheet contains data for 8 students across 12 columns. The columns are labeled A through L, and the rows are numbered 1 through 8. The data includes first names, last names, usernames, programs, IDs, cohorts, and various scores. The "Course" tab is selected at the bottom.

|   | A          | B          | C            | D       | E       | F      | G       | H     | I   | J   | K   | L   |
|---|------------|------------|--------------|---------|---------|--------|---------|-------|-----|-----|-----|-----|
| 1 | First name | Last name  | Username     | Program | ID      | Cohort | Midterm | Final | HW1 | HW2 | HW3 | HW4 |
| 2 | Chul Min   | Yeum       | cmyeum       | CIVE    | 6498498 | 2A     | 63      | 99    | 80  | 90  | 61  | 77  |
| 3 | Noreen     | Gao        | x97gao       | ENVE    | 7122711 | 2A     | 71      | 79    | 86  | 76  | 63  | 75  |
| 4 | Jason      | Connelly   | jpcnelly     | GEOE    | 7571398 | 3B     | 82      | 92    | 61  | 86  | 93  | 91  |
| 5 | Vlad       | Fierastrau | vafierastrau | ENVE    | 2832648 | 2A     | 99      | 65    | 94  | 67  | 88  | 92  |
| 6 | Ju An      | Park       | jpark        | ENVE    | 6829056 | 3B     | 99      | 77    | 98  | 88  | 73  | 67  |
| 7 | Max        | Midwinter  | max.midwin   | CIVE    | 6585470 | 2A     | 66      | 97    | 87  | 61  | 98  | 80  |
| 8 | Rishabh    | Bajaj      | rs2ajaj      | GEOE    | 1709856 | 3B     | 99      | 92    | 91  | 71  | 61  | 78  |

Header

⚠: We need to use a cell array to contain all these data in one variable.

Text values

Numeric values

# Example: Read Data from an Excel File (readmatrix)

A screenshot of Microsoft Excel showing a table of student data. The columns are labeled A through L, and the rows are numbered 1 through 8. The data includes columns for First name, Last name, Username, Program, ID, Cohort, and grades for Midterm, Final, HW1, HW2, HW3, and HW4. The data is as follows:

|   | A          | B          | C            | D       | E       | F      | G       | H     | I   | J   | K   | L   |
|---|------------|------------|--------------|---------|---------|--------|---------|-------|-----|-----|-----|-----|
| 1 | First name | Last name  | Username     | Program | ID      | Cohort | Midterm | Final | HW1 | HW2 | HW3 | HW4 |
| 2 | Chul Min   | Yeun       | cmyeum       | CIVE    | 6498498 | 2A     | 63      | 99    | 80  | 90  | 61  | 77  |
| 3 | Noreen     | Gao        | x97gao       | ENVE    | 7122711 | 2A     | 71      | 79    | 86  | 76  | 63  | 75  |
| 4 | Jason      | Connelly   | jpcnelly     | GEOE    | 7571398 | 3B     | 82      | 92    | 61  | 86  | 93  | 91  |
| 5 | Vlad       | Fierastrau | vafierastrau | ENVE    | 2832648 | 2A     | 99      | 65    | 94  | 67  | 88  | 92  |
| 6 | Ju An      | Park       | jpark        | ENVE    | 6829056 | 3B     | 99      | 77    | 98  | 88  | 73  | 67  |
| 7 | Max        | Midwinter  | max.midwin   | CIVE    | 6585470 | 2A     | 66      | 97    | 87  | 61  | 98  | 80  |
| 8 | Rishabh    | Bajaj      | rs2ajaj      | GEOE    | 1709856 | 3B     | 99      | 92    | 91  | 71  | 61  | 78  |

```
filename = 'lec10_excel_file.xlsx';
M = readmatrix(filename);
```

```
M_num = M;
lg_mat = isnan(M_num);
idx = logical(sum(lg_mat));
M_num(:, idx) = [];
```

option1

```
filename = 'lec10_excel_file.xlsx';
M = readmatrix(filename);
```

```
K=> M
M =
NaN     NaN     NaN     NaN    6498498
NaN     NaN     NaN    7122711
NaN     NaN     NaN    2832648
NaN     NaN     NaN    6829056
NaN     NaN     NaN    6585470
NaN     NaN     NaN  1709856
```

: `isnan` returns a logical array containing 1 where the elements are NaN. Here NaN means it is not a numeric (number) value. We extract numeric array using a vectorized code.

```
filename = 'lec10_excel_file.xlsx';
M = readmatrix(filename);
```

option2

```
M1 = readmatrix(filename, 'Range', ...
'E2:E8'); % set range
M2 = readmatrix(filename, 'Range', ...
'G2:L8'); % set range
```

```
M_num = [M1 M2]; % joining cell arrays
```

# Example: Read Data from an Excel File (readcell)

|   | A          | B          | C            | D       | E         | F      | G       | H     | I   | J   | K   | L   |
|---|------------|------------|--------------|---------|-----------|--------|---------|-------|-----|-----|-----|-----|
| 1 | First name | Last name  | Username     | Program | ID        | Cohort | Midterm | Final | HW1 | HW2 | HW3 | HW4 |
| 2 | Chul Min   | Yeum       | cmyeum       | CIVE    | [6498498] | 2A     | 63      | 99    | 80  | 90  | 61  | 77  |
| 3 | Noreen     | Gao        | x97gao       | ENVE    | [7122711] | 2A     | 71      | 79    | 86  | 76  | 63  | 75  |
| 4 | Jason      | Connelly   | jpcnelly     | GEOE    | [7571398] | 3B     | 82      | 92    | 61  | 86  | 93  | 91  |
| 5 | Vlad       | Fierastrau | vafierastrau | ENVE    | [2832648] | 2A     | 99      | 65    | 94  | 67  | 88  | 92  |
| 6 | Ju An      | Park       | jpark        | ENVE    | [6829056] | 3B     | 99      | 77    | 98  | 88  | 73  | 67  |
| 7 | Max        | Midwinter  | max.midwin   | CIVE    | [6585470] | 2A     | 66      | 97    | 87  | 61  | 98  | 80  |
| 8 | Rishabh    | Bajaj      | rs2ajaj      | GEOE    | [1709856] | 3B     | 99      | 92    | 91  | 71  | 61  | 78  |

```
filename = 'lec10_excel_file.xlsx';
M = readcell(filename);
```

```
filename = 'lec10_excel_file.xlsx';
```

```
M1 = readcell(filename, 'Range', ...
'E2:E8');
M2 = readcell(filename, 'Range', ...
'G2:L8');
```

```
M_num_cell = [M1 M2];
M_num = cell2mat(M_num_cell);
```

```
--> H
H =
8x12 cell array

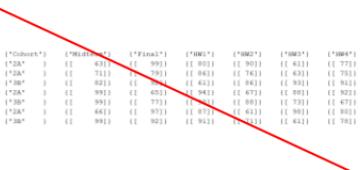
{'First name'} {'Last name'} {'Username'} {'Program'} {'ID'} ...
{'Chul Min'} {'Yeum'} {'cmyeum'} {'CIVE'} {[6498498]} ...
{'Noreen'} {'Gao'} {'x97gao'} {'ENVE'} {[7122711]} ...
{'Jason'} {'Connelly'} {'jpcnelly'} {'GEOE'} {[7571398]} ...
{'Vlad'} {'Fierastrau'} {'vafierastrau'} {'ENVE'} {[2832648]} ...
{'Ju An'} {'Park'} {'jpark'} {'ENVE'} {[6829056]} ...
{'Max'} {'Midwinter'} {'max.midwin'} {'CIVE'} {[6585470]} ...
{'Rishabh'} {'Bajaj'} {'rs2ajaj'} {'GEOE'} {[1709856]}
```

```
>> M
```

```
M =
```

```
8x12 cell array

{'First name'} {'Last name'} {'Username'} {'Program'} {'ID'} ...
{'Chul Min'} {'Yeum'} {'cmyeum'} {'CIVE'} {[6498498]} ...
{'Noreen'} {'Gao'} {'x97gao'} {'ENVE'} {[7122711]} ...
{'Jason'} {'Connelly'} {'jpcnelly'} {'GEOE'} {[7571398]} ...
```

 : All data will be read using cell types. We can access both text and numeric data. However, when you process only numeric data, and spreadsheet contains large volume of text data, the size of M will get larger causing taking up large memory and slow processing speed. Thus, in such case, I recommend using `reamatrix` rather than `readcell`.

## writematrix and writecell Function

- `writematrix` writes numeric array A to a file with the name and extension specified by filename

```
writematrix(A, filename)
```

```
writematrix(A, filename, 'Sheet', sheet, 'Range', range)
```

- `writecell` write cell array C to a file with the name and extension specified by filename

```
writecell(C, filename)
```

```
writecell(C, filename, 'Sheet', sheet, 'Range', range)
```



:`writematrix` or `writecell` determines the file format based on the specified extension:

- .txt, .dat, or .csv for delimited text files
- .xls, .xlsh, .xlsm, .xlsx, .xltm, .xltx, or .ods for spreadsheet files

## Example: Write Data to an Excel File (writecell)

```
cl_info = cell(3,7);  
  
cl_info{1,1} = 'Chul Min';  
cl_info{1,2} = 'CIVE';  
cl_info{1,3} = 1076123;  
cl_info{1,4} = [80 90];  
cl_info{1,5} = [70 30 50];  
cl_info{1,6} = [4 5 1 2];  
cl_info{1,7} = '4B';  
  
cl_info{2,1} = 'Noreen';  
cl_info{2,2} = 'ENVE';  
cl_info{2,3} = 3026327;  
cl_info{2,4} = [100 70];  
cl_info{2,5} = [10 20 70];  
cl_info{2,6} = [2 7 8 9];  
cl_info{2,7} = '2A';  
  
cl_info{3,1} = 'Vlad';  
cl_info{3,2} = 'ENVE';  
cl_info{3,3} = 2046426;  
cl_info{3,4} = [50 90];  
cl_info{3,5} = [90 60 80];  
cl_info{3,6} = [1 2 6 2];  
cl_info{3,7} = '2A';
```

```
cl_header = {'Name', 'Program', 'ID', 'Exam', 'Quiz', ...  
'Homework', 'Cohort'};  
  
cl_all = cat(1, cl_header, cl_info);  
% cl_all = [cl_header; cl_info];  
  
writecell(cl_all, 'cl_info.xlsx');
```

class\_info.xlsx

In the original cell, there is no header. Thus, before you store the cell array data, you need to append the header to the cell data.

# Tip for Quick Testing

Optional

Sometimes, you want to do quick testing on a part of data in an excel file, but you do not want to write a script to read/extract the values from the file.

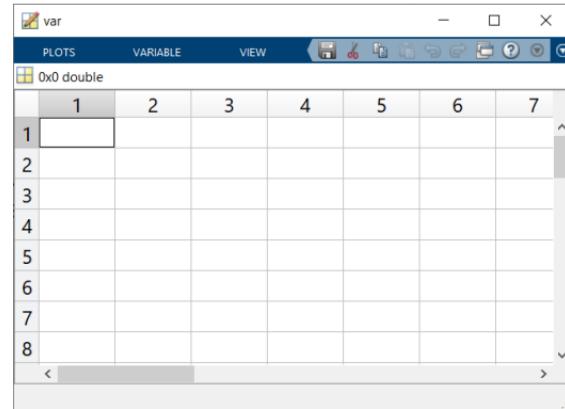
**Step 1.** Make an empty variable

**Step 2.** Double click the variable in Workspace to edit the values of the variable.

**Step 3.** Copy the data from the excel file or text file and paste them in the values of the variable.

**Step 4.** Save the variable in .mat file.

**Step 5.** Use the variable for your computation



☞ You can copy excel data and paste them in the variable through this variable window. You can open it by double-clicking the variable name in Workspace. The format of the variable window is similar to the ones in Excel.

# Module 11: Text Manipulation

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## Module 11: Learning Outcomes

- Distinguish the difference between a character vector and a string scalar
- Distinguish the difference between a string scalar and a string array.
- Explain how to read and extract individual characters in a string
- Apply built-in functions specially designed for operations using string or character vector
- Explain how to use operators ( $==$ ,  $+$ ) when string variables are involved.
- Convert strings or character vectors to numbers and vice versa.

## Text Terminology

- Text in MATLAB can be represented using:
  - character vectors (in single quotes)
  - string arrays, introduced in R2016b (in double quotes)
- Prior to R2016b, the word “string” was used for what are now called character vectors.
- Many functions that manipulate text can be called using **either a character vector or a string.**
- Additionally, several new functions have been created for the string type

## Review: Character vs Character Vector

- **Characters** include letters of the alphabet, digits, punctuation marks, white space, and control characters. Individual characters in **single quotation** marks are the type **char** (so, the class is **char**)
- Character vectors consist of any number of characters and contained in single quotation marks. Their type are **char**.
- Since these are **vectors** of characters, **built-in functions and operators that we've seen already work with character vectors as well as numbers**. You can also index into a character vector to get individual characters or to get subsets

```
>> letter = 'x';
>> size(letter)

ans =
1      1

>> class(letter)

ans =
'char'
```

```
>> myword = 'Hello';
>> size(myword)

ans =
1      5

>> class(myword)

ans =
'char'
```

# String Scalar

- A string scalar is a data type of ‘string’, a single string, and is used to store a group of characters.
- The group of characters defined as a string is a single scalar variable, not a vector.
- String can be created
  - using double quotes, e.g., “Chul Min”
  - using the string type cast function, e.g., string ('Chul Min')
- Strings are displayed using double quotes.

```
>> myword = 'Hello';
>> size(myword)

ans =
1      5

>> class(myword)

ans =
'char'
```

```
>> myword = "Hello";
>> size(myword)

ans =
1      1

>> class(myword)

ans =
'string'
```

**⚠:** A character vector is an array of characters. A string is a single data type (dimension) that can contain a string of characters. It is not an array of characters!

# String Indexing

# Challenging

- You can index into a string array using curly braces {}, to access characters directly.
- Indexing with curly braces provides compatibility for code that could work with either string arrays or cell arrays of character vectors.

```
mystr = "CM121";  
  
mycharv = 'CM121';  
  
mystrarry = ["ENVE121",...  
"GEOE121", "AE121"];
```

: `strlength` is to count the number of characters in a string value.

|                                 |           |
|---------------------------------|-----------|
| <code>size(mystr)</code>        | [1 1]     |
| <code>mystr(1)</code>           | "CM121"   |
| <code>mystr{1}</code>           | 'CM121'   |
| <code>mystr{1}(1)</code>        | 'C'       |
| <code>mystr{1}(4)</code>        | '2'       |
| <br>                            |           |
| <code>size(mycharv)</code>      | [1 5]     |
| <code>mycharv(1)</code>         | 'C'       |
| <code>mycharv(4)</code>         | '2'       |
| <br>                            |           |
| <code>size(mystrarry)</code>    | [1 3]     |
| <code>mystrArry(2)</code>       | "GEOE121" |
| <code>mystrArry{1}</code>       | 'ENVE121' |
| <code>mystrArry{2}(1)</code>    | 'G'       |
| <code>mystrArry{2}(5)</code>    | '1'       |
| <br>                            |           |
| <code>numel(mystr)</code>       | 1         |
| <code>numel(char(mystr))</code> | 5         |
| <code>strlength(mystr)</code>   | 5         |

# Group of Strings

# Challenging

- Groups of strings can be stored in **(1) string arrays, (2) character matrices, (3) cell arrays.**
- Strings are created using double quotes or by passing a character vector to the string function
- The plus function or operator can **join, or concatenate**, two strings together (e.g., "abc" + "xyz" => "abcxyz")

|                         |                   |
|-------------------------|-------------------|
| [char1 char2]           | 'ENVE121'         |
| char1 + char2           | error             |
| char1 + char1           | [138 156 172 138] |
| [str1 str2]             | "AE" "Hello"      |
| str1 + str2             | "AEHello"         |
| strcat(str1, str2)      | "AEHello"         |
| str1 + string(char1)    | "AEEENVE"         |
| [char(str1) char(str2)] | 'AEHello'         |

```
char1 = 'ENVE';
char2 = '121';

str1 = "AE";
str2 = "Hello";
```

💡 You can initialize a string array using strings.  
str = strings(sz1, ..., szN)

```
str_arr = strings(1, 2);
str_arr(1,1) = "AE"
str_arr(1,2) = "Hello"
```



## Example: Print Texts

Q. Print out the following texts in the command window when variables containing the first and last names are given.

```
Welcome ! Park, Ju An
Welcome ! Yeum, Chul Min
Welcome ! Gao, Noreen
Welcome ! Fierastrau, Vlad
Welcome ! Connnelly, Jason
```

```
num_name = 5;
fname = ["Ju An", "Chul Min", "Noreen", "Vlad", "Jason"];
lname = ["Park", "Yeum", "Gao", "Fierastrau", "Connnelly"];
```

```
for ii=1:num_name
    fprintf('Welcome ! %s, %s \n', lname(ii), fname(ii));
end
```

option1

: '... %s, %s \n'  
Here, the comma is not  
to separate arguments.  
It is in the text.

```
for ii=1:num_name
    str = lname(ii) + ", " + fname(ii);
    fprintf('Welcome ! %s \n', str);
end
```

option2

: %s is to print both  
strings and characters.

# Built-in Functions for Text

Many functions can have either character vectors or strings as input arguments.

Generally, **if a character vector is passed to the function, a character vector will be returned, and if a string is passed, a string will be returned**



: Again, you do not have to memorize the functions and their usage. You can simply search for their usage in google or type `doc fun_name` in command window.

| Function              | Description  |
|-----------------------|--|
| <code>upper</code>    | Convert strings to uppercase                             |
| <code>lower</code>    | Convert strings to lowercase                             |
| <code>reverse</code>  | Reverse order of characters in strings                   |
| <code>strcmp</code>   | Compare strings  |
| <code>strcmpi</code>  | Compare strings (case insensitive)                       |
| <code>strncmp</code>  | Compare first n characters of strings (case sensitive)   |
| <code>strncmp</code>  | Compare first n characters of strings (case insensitive) |
| <code>contains</code> | Determine if pattern is in strings                       |
| <code>strfind</code>  | Find strings within other strings                        |
| <code>strrep</code>   | Find and replace substrings                              |
| <code>count</code>    | Count occurrences of pattern in strings                  |



## Example: upper Built-in Function

Q. Write a custom function named 'MyUpper' to replicate the same operation of upper. The input and output types are assumed to be string.

```
function newStr = MyUpper(str)

char_db = double(char(str));

lgv = 97 <= char_db & char_db <= 122;

char_db(lgv) = char_db(lgv)-32;

newStr = string(char(char_db));

end
```

```
>> str = "abc!ABC?";
>> upper(str)

ans =

"ABC!ABC?"

>> MyUpper(str)

ans =

"ABC!ABC?"
```

□: Here is the syntax for upper built-in function: newStr = upper(str) converts all lowercase characters in str to the corresponding uppercase characters and leaves all other characters unchanged.

⚠: string type has no equivalent numeric values. Thus, we cannot do the type casting of strings to numeric values using double().



## Example: strfind and count Built-in Function

Q. Write a script to count the number of 'word' in 'char\_vec'

```
char_vec = 'abcardcsecar';
word = 'car';

vec_len = numel(char_vec);
n_char = numel(word);

n_word = 0;
for ii=1:vec_len-n_char+1
    test_loc = ii:ii+n_char-1;
    if isequal(char_vec(test_loc), word)
        n_word = n_word + 1;
    end
end
```

**option1**

```
char_vec = 'abcardcsecar';
word = 'car';

idx = strfind(char_vec, word);
n_word = numel(idx);
```

**option2**

```
char_vec = 'abcardcsecar';
word = 'car';

n_word = count(char_vec, word);
```

**option3**

: `k = strfind(str, pattern)` searches str for occurrences of pattern. The output, k, indicates the starting index of each occurrence of pattern in str.

`A = count(str, pattern)` returns the number of occurrences of pattern in str.

: Again, the function support both **strings** and **character** vectors as the input for str.

# Example: strfind Built-in Function (Word Finder Puzzle)



Q. Rewrite a script for a word finder puzzle using strfind.

```
word_loc = zeros(n_word, 2);
for ii=1:puzzle_size
    col_vec = puzzle(:,ii); % column
    row_vec = puzzle(ii,:); % row

    for jj=1:(puzzle_size-n_word+1)
        test_loc = jj:(jj+n_word-1);

        test_word_col = col_vec(test_loc);
        test_word_row = row_vec(test_loc);

        if isequal(test_word_col, word_db')
            word_loc(:,2) = ii;
            word_loc(:,1) = test_loc';
        elseif isequal(test_word_row, word_db)
            word_loc(:,1) = ii;
            word_loc(:,2) = test_loc';
        end
    end
end
```

```
for ii=1:puzzle_size
    col_vec = char(puzzle(:,ii)); % column
    row_vec = char(puzzle(ii,:)); % row

    id_col = strfind(col_vec', char(word_db));
    id_row = strfind(row_vec, char(word_db));

    if ~isempty(id_col)
        word_loc(:,2) = ii;
        word_loc(:,1) = (id_col:id_col+n_word-1)';
    elseif ~isempty(id_row)
        word_loc(:,1) = ii; % row
        word_loc(:,2) = (id_row:id_row+n_word-1)';
    end
end
```



: k = strfind(str,pattern)  
searches str for occurrences of pattern. The output, k, indicates the starting index of each occurrence of pattern in str.

# Comparing Strings: Equality Operator (String)

To use the equality operator == with character vectors, they must be the same length, and each element will be compared. The output is the same size as the input vector size. However, for strings, it will simply return 1 or 0 instead of comparing each element.

```
char1 = 'ENVE';
char2 = 'GEOE';
char3 = 'ENVE';
char4 = 'AE';
char5 = 'G';

str1 = "AE";
str2 = "Hello";
str3 = "AE";
str4 = "A";
```

|                      |           |
|----------------------|-----------|
| char1 == char2       | [0 0 0 1] |
| char1 == char3       | [1 1 1 1] |
| char1 == char4       | error     |
| char2 == char5       | [1 0 0 0] |
| char2 ~= char5       | [0 1 1 1] |
| str1 == str2         | 0         |
| str1 == str3         | 1         |
| str1 == str4         | 0         |
| str1 ~= str4         | 1         |
| [str1 str2] == str3  | [1 0]     |
| [str1 str2] == str4  | [0 0]     |
| string(char1) == ... | 1         |
| string(char3)        |           |

**⚠:** You need to clearly understand the usage of the equality operator when character or strings are involved.

# Create Strings using sprintf

- sprintf creates text so it can be used to customize the format of text.

```
str = sprintf(formatSpec,A1,...,An)
```

- Formats the data in arrays A1, ..., An using the formatting texts specified by formatSpec and returns the resulting text.
- In formatSpec, if you use a **single quote**, the output becomes a **character vector**. If it has **double quote**, the output becomes a **string**.

**⚠:** sprintf and fprintf have the same syntax for the input. The difference is sprintf creates a string or character vector whereas fprintf prints it in a command window or file.

```
>> str1 = "AEG";
>> str2 = "121";

>> "Welcome! " + str1 + str2

ans =

    "Welcome! AEG121"

>> sprintf("Welcome! %s%s", str1, str2)

ans =

    "Welcome! AEG121"

>> sprintf('Welcome! %s%s', str1, str2)

ans =

    'Welcome! AEG121'
```



## Example: Generate a Card Sequence String

The standard 52-card deck has 13 numbers and 4 different suits. The suit order is 'Clubs (♣)', 'Diamonds (♦)', 'Hearts (♥)', and 'Spades (♠)'. Each integer from 1 to 52 will represent the value and suit of a card, where from 1 to 52, and the value and suit of the cards will proceed in the following order:

| Num | Card |
|-----|------|
| 1   | 1C   |
| 2   | 1D   |
| 3   | 1H   |
| 4   | 1S   |
| 5   | 2C   |
| 6   | 2D   |
| :   | :    |
| 50  | 13D  |
| 51  | 13H  |
| 52  | 13S  |

```
function str_cards = StrCard(cards)

suits = 'CDHS';
str_cards = "";
for ii = 1:numel(cards)
    card_num = ceil(cards(ii)/4);
    card_rem = rem(cards(ii),4);

    if card_rem==0
        card_rem=4;
    end

    card_suit = suits(card_rem);

    str_cards = str_cards + ...
        sprintf("%d%s ", card_num, card_suit);
end

str_cards{1}(end) = [];
end
```

**Q.** Create a function named 'StrCard' that generate a card sequence string. The input named 'cards' is a  $1 \times 7$  numeric vector and include the integer card number. The output named 'str\_cards' is a string scalar and include all name of the cards separated by a space. The text for suits is 'C', 'D', 'H' and 'S', corresponding to 'Clubs', 'Diamonds', 'Hearts', and 'Spades'.

```
>> cards = [1 2 3 4 5 6 7];
>> str_cards = StrCard(cards);
>> str_cards

str_cards =
"1C 1D 1H 1S 2C 2D 2H"
```

# String/Number Functions

## Challenging

Converting from strings or character vectors to numbers and vice versa:

- `num2str` converts a real number to a character vector containing the number
- `string` converts number(s) to strings
- `str2double` converts from a string or character vector containing number(s) to a number array

```
num1 = 75;  
num2 = 12345;  
  
char1 = 'abcd'  
char2 = '678910'
```

|                                |                     |
|--------------------------------|---------------------|
| <code>char(num1)</code>        | 'K'                 |
| <code>char(num2)</code>        | '+'                 |
| <br>                           |                     |
| <code>char(num1)</code>        | 'K'                 |
| <code>num2str(num1)</code>     | '75'                |
| <code>string(num1)</code>      | "75"                |
| <br>                           |                     |
| <code>char(num2)</code>        | '+'                 |
| <code>num2str(num2)</code>     | '12345'             |
| <code>string(num2)</code>      | "12345"             |
| <br>                           |                     |
| <code>double(char1)</code>     | [97 98 99 100]      |
| <code>str2double(char1)</code> | NaN                 |
| <br>                           |                     |
| <code>double(char2)</code>     | [54 55 56 57 49 48] |
| <code>str2double(char2)</code> | 678910              |

⚠: This is very confusing!! You should not be confused with **type casting** and number conversion from **string or character vectors**.

# Example: How Many Digit in Your Number?



Q. Create a function named 'CountNum' to count the appearance of the given digit in a single numeric number. The digit should be within 0 and 9. For example:

|                     |   |
|---------------------|---|
| CountNum(454214, 4) | 3 |
| CountNum(454221, 2) | 2 |

```
function countd = CountNum(num, digit)
chard_num = num2str(num);
chard_digit = num2str(digit);
lg_vec = chard_num == chard_digit;
countd = sum(lg_vec);
end
```

option1

```
function countd = CountNum(num, digit)
countd = count(num2str(num), num2str(digit));
% countd = count(string(num), string(digit));
end
```

option2

|                     |
|---------------------|
| CountNum(454214, 4) |
|---------------------|

| Name       | Value         |
|------------|---------------|
| num        | 454214        |
| digit      | 4             |
| card_num   | '454214'      |
| card_digit | '4'           |
| lg_vec     | [1 0 1 0 0 1] |
| countd     | 3             |