Basic MATLAB Programming

Chul Min Yeum
Assistant Professor
Civil and Environmental Engineering
University of Waterloo, Canada

AE121: Computational Method

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

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Learning Outline

- Variables, Assignments, and Modifying Variables
- Variable Naming Convention
- Data Types, Type Size, and Range
- Encoding + ASCII Table
- Mathematical and Relational Operators
- Operator Precedence
- Using Functions
- Random Numbers
- Output and Formatting
- Programming Tips

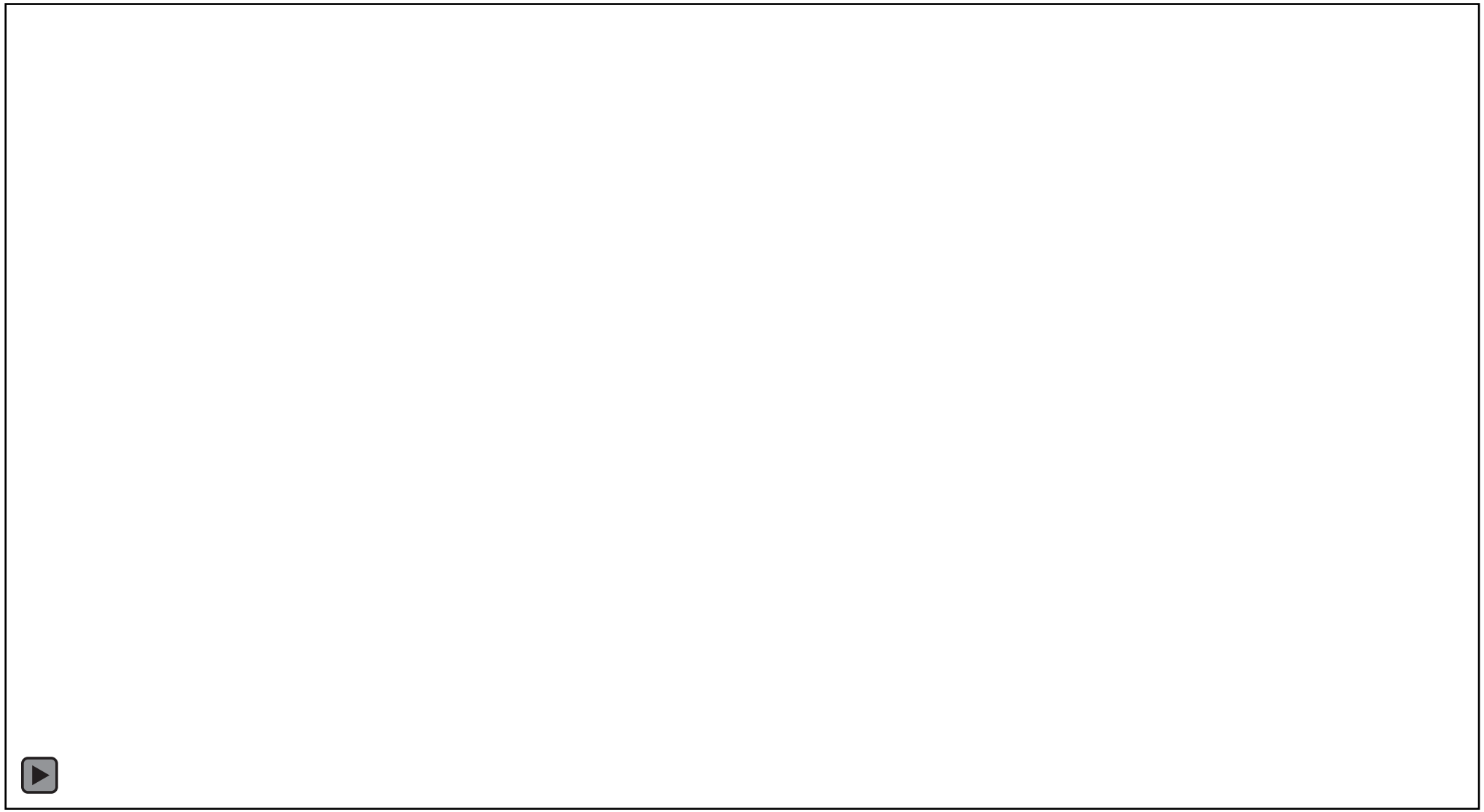
Variables and Assignments

- To store a value, use a *variable*
- One 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 "=" (Note: this does NOT mean equality)
  - expression on the right

Variables and Assignments



Modifying Variables

- *Initialize* a variable (put its first value in it)

  mynum = 5;

- Change a variable (e.g. by adding 3 to it)

  mynum = mynum + 3;

- *Increment* by one

  mynum = mynum + 1;

- *Decrement* by two

  mynum = mynum – 2;

NOTE: after this sequence, *mynum* would have the value 7 (5+3+1-2)

Example: Arithmetic Operation in MATLAB

If the car has a mass of 300kg and you push the car with an acceleration of 5 in/s^2, compute the force that is generated from the car in netwon

```
% solve this problem using MATLAB as a calculator
300*5*0.0254
```

```
ans = 38.1000
```

```
% solve this problem using MATLAB as a programing tool
inch2m = 0.0254; % inch to m
mass = 300; % kg
acceleration = 5; % inch/s/s

% force  = mass(kg) * acceleration (m/s/s)
force1 = mass * acceleration * inch2m;
force1
```

```
force1 = 38.1000
```

Which approach is better?

Variable names

- Names must begin with a letter of the alphabet
- After that names can contain letters, digits, and the underscore character(_)
- MATLAB is **case-sensitive**
- Names should be mnemonic (they should make sense!)
- The commands **who** and **whos** will show variables (Recommend: You would need to use a workspace browser rather than type these command)
- To delete variables: **clearvars**
- **clear** clears out variables and also functions

Example: Variable Names

```
8val = 10; % error
% comment: must begin with a letter of the alphabet

_col = 0; % error
% comment: must begin with a letter of the alphabet

val = 10;
Val % error
% comment: case-sensitive, the variable val is not Val!
% recommendation: do not use capital letters for variable names

row_3 = 1;
row@3 = 10; % error
col_303 = 10; % error
% comment: cannot contain non-alphanumeric characters other than the underscore

asdf1 = 10; % no error
love10 = 10; % no error
aaaa1 = 100; % no error
% comment: these variable names work, but the names should be mnemonic (make sense)!
```

- ✖ wrong
- ● correct
- ● Not recommended

Types

- Every expression and variable has an associated *type*, or *class*
  - Real numbers: **single**, **double** (ie. 2.145, 0.1586, 2, 3.0, …)
  - 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** (Only +ve integers! ie. 20, 15, 359, …)
- Unsigned integers: **uint8, uint16, uint32, uint64** (+ve and -ve integers! ie. -20, -15, 359, …)
  - Single characters and character vectors: **char** (ie. 'Hello World!')
  - Strings of characters: **string**
  - True/false: **logical** (ie. logical(1), logical(0))
- The default type for numbers in MATLAB is **double**

Range and Type Size

- Range of integer types found with **intmin/intmax**
  - e.g. **intmin('int8')** is -128, **intmax('int8')** is 127
- Converting from one type to another, using any of the type names as a function, is called *casting* or *type casting*, e.g:

1 byte	8 bits
1 kilobyte	1024 byte
1 megabyte	1024 kilobyte
1 gigabyte	1024 megabyte
1 terabyte	1024 gigabyte

Container

```
clear; clc;

intmin('uint8')
```

```
ans = uint8
    0
```

```
intmax('uint8')
```

```
ans = uint8
    255
```

```
val1_uint8 = uint8(10);

val_double = 10;

whos % or see the workspace browser
```

```
  Name           Size              Bytes  Class     Attributes

  ans            1x1                   1  uint8
  val1_uint8     1x1                   1  uint8
  val_double     1x1                   8  double
```

(Off-topic) Binary Number

You do not need to know this topic! int8 takes up 1 byte of memory to store a numeric value. 1 byte has 8 bits and 1 bit contain 0 or 1. Computer stores a numeric (decimal) value as a binary sequence.

```
d_num = [0 1:10 128 255]';
b_num = de2bi(d_num, 8);

[d_num b_num]
```

Decimal number	2^0	2^1	2^2	2^3	2^4	2^5	2^6	2^7
0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0
4	0	0	1	0	0	0	0	0
5	1	0	1	0	0	0	0	0
6	0	1	1	0	0	0	0	0
7	1	1	1	0	0	0	0	0
8	0	0	0	1	0	0	0	0
9	1	0	0	1	0	0	0	0
10	0	1	0	1	0	0	0	0
128	0	0	0	0	0	0	0	1
255	1	1	1	1	1	1	1	1

Constants

- In programming, variables are used for values that could change, or are not known in advance
- *Constants* are used when the value is known and is not updated in the program.
- Examples in MATLAB (these are actually functions that return constant values)

  pi 3.14159….

  i, j

  inf infinity

  NaN stands for “not a number”; e.g. the result of 0/0

Example: Constants - Common Mistakes

```
pi; % pi (a circle's circumference to its diameter)
val = 2 + 3i; % complex number

% comment: I highly recommand that you should avoid constnant names as variable
% names. For example, when you define a for-loop, people often use i or j as a
% iterator. I always use ii or jj not to overwrite constants.

pi
```

```
ans = 3.1416
```

```
pi = 3;
pi % no error but it's a really bad practice. You can't use the pi constant anymore.
```

```
pi = 3
```

Expressions

- Expressions can contain values, variables that have already been created, operators, built-in functions, and parentheses
- Operators include:
  - + addition
  - * multiplication
  - / division (divided by e.g. 10/5 is 2)
  - \ division (divided into e.g. 5\10 is 2)
  - ^ exponentiation (e.g. 5^2 is 25)
- Scientific or exponential notation: use e for exponent of 10 raised to a power
  - e.g. 3e5 means 3 * 10^5 (e becomes a operators).
  - Not recommend to use *e* because it is confused with exponential (exp) in your code.

Operator Precedence

- Some operators have precedence over others
- Precedence list (highest to lowest) so far:

  ( ) parentheses

  ^ exponentiation

  - negation

  *, /, \ all multiplication and division

  +, - addition and subtraction

- Nested parentheses: expressions in inner parentheses are evaluated first

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
- Many functions 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

Random Numbers

- Several built-in functions generate random (actually, pseudo-random) numbers
- Random number functions, or random number generators, start with a number called the ***seed***; this is either a predetermined value or from the clock
- By default MATLAB uses a predetermined value so it will always be the same
- To set the seed using the built-in clock:

  rng('shuffle')

```
>> rand

ans =

    0.0558

>> rand

ans =

    0.4968
```

(Off-Topic) Quantum Random Number

NIST's New Quantum Method Generates *Really* Random Numbers

April 11, 2018

Researchers at the National Institute of Standards and Technology (NIST) have developed a method for generating numbers guaranteed to be random by quantum mechanics. Described in the April 12 issue of *Nature*, the experimental technique surpasses all previous methods for ensuring the unpredictability of its random numbers and may enhance security and trust in cryptographic systems.

Credit: K. Irvine/NIST

MEDIA CONTACT

Laura Ost
laura.ost@nist.gov
(303) 497-4880

ORGANIZATIONS

Physical Measurement Laboratory
Applied Physics Division
Faint Photonics Group
Quantum Nanophotonics Group

https://www.nist.gov/news-events/news/2018/04/nists-new-quantum-method-generates-really-random-numbers

Random Real Numbers

- The function **rand** generates uniformly distributed random real numbers in the open interval `(0,1)`
- Calling it with no arguments returns one random real number
- To generate a random real number in the open interval `(0,N)`:

rand * N

This random number generator is to avoid your hard-coding in your labs and assignments because we do not know what values are used to check your code

```
val1 = 10;
val2 = 11;
```

Ex) write a program to add 'val1' and 'val2' and assign a result to 'val3'

```
val3 = val1 + val2;
val3 = 21;
```
hard coding

Example: Random Numbers

```
% A different sequence of random number is generated.
% This is the default in Matlab
rng('shuffle');
% Generate 3 random numbers
% NOTE: the 'rand' function generates a number between 0 and 1.
rand
rand
rand
fprintf('\n')
% Setting the seed of the random number generator to 10.
rng(10);
% Generate 3 random numbers.
rand
rand
rand
```

The random number values **change** from each run!

Run #1	Run #2
ans = 0.0328	ans = 0.9570
ans = 0.7728	ans = 0.5421
ans = 0.9850	ans = 0.3348

The random number values **don't change** from each run!

ans = 0.7713	ans = 0.7713
ans = 0.0208	ans = 0.0208
ans = 0.6336	ans = 0.6336

Characters and Strings

- A ***character*** is a single character in single quotes
- All characters in the computer's character set are put in an order using a ***character encoding***
  - In the character encoding sequence, the letters of the alphabet are in order, e.g. 'a' comes before 'b'
  - Common encoding ASCII has 128 characters, but MATLAB can use a much larger encoding sequence
- The ***character set*** includes all letters of the alphabet, digits, punctuation marks, space, return, etc.
- Character vectors are sequences of characters in single quotes, e.g. 'hello and how are you?'
- ***Strings*** are sequences of characters in double quotes, e.g. "ciao bella"

Characters and Encoding

- Standard ASCII has 128 characters; integer equivalents are 0-127
- Any number function can convert a character to its integer equivalent

  >> numequiv = double('a')

  numequiv =

  97
- The function **char** converts an integer to the character equivalent (e.g. **char(97)**)
- MATLAB uses an encoding that has 65535 characters; the first 128 are equivalent to ASCII

```
name_cm_char = 'Chul Min Yeum';
size(name_cm_char)
```

```
ans = 1×2
     1    13
```

```
% comment: name_cm_char is a set of characters. It's an array

name_cm_str = "Chul Min Yeum";
size(name_cm_str)
```

```
ans = 1×2
     1     1
```

```
% comment: name_cm_str is a "string" type. It's a value.
```

https://ee.hawaii.edu/~tep/EE160/Book/chap4/subsection2.1.1.1.html

ASCII Table

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH (start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX (start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX (end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT (end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ (enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK (acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL (bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS (backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB (horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF (NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT (vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF (NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR (carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO (shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI (shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE (data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1 (device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2 (device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3 (device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4 (device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK (negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN (synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB (end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN (cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM (end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB (substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC (escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS (file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS (group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS (record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US (unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

http://www.asciitable.com/

Output

- 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***:

  %d integers

  %f floats (real numbers)

  %c single characters

  %s string of characters

- Use %#x where # is an integer and x is the conversion character to specify the ***field width*** of #
- %#.#x specifies a field width and the number of decimal places
- %.#x specifies just the number of decimal places (or characters in a string); the field width will be expanded as necessary

Example: Field & Numeric Formatting

```
x = 1234.56789;
fprintf('case1: x is %f \n', x);
fprintf('case2: x is %9.4f \n', x);
fprintf('case3: x is %9.1f \n', x);
fprintf('case4: x is %.1f \n', x);
fprintf('case5: x is %6.1f \n', x);
fprintf('case6: x is %10.6f \n', x);
fprintf('case7: x is %10.10f \n', x);
```

```
case1: x is 1234.567890
case2: x is 1234.5679
case3: x is    1234.6
case4: x is 1234.6
case5: x is 1234.6
case6: x is 1234.567890
case7: x is 1234.5678900000
```

Formatting Output

- Other formatting:
  - \n newline character
  - \t tab character
  - left justify with ‘-’ e.g. %-5d
  - to print one slash: \\
  - to print one single quote: ‘ ‘ (two single quotes)
- Printing vectors and matrices: usually easier with **disp**

Example: Print Formatting

```
fprintf('Hello! Chul Min');
fprintf('Hello! \tChul Min');
fprintf('Hello! \nChul Min');
fprintf('Hello! AE121');
fprintf('Hello! %cE121', 'A');
fprintf('Hello! %s','AE121'); % string of characters
fprintf('Today is 04\\23\\2019.'); % two one slash to print one slash
fprintf('What is ''fprintf''?'); % two single quotes to print one quote
% Please copy above lines and paste them in the command window.
%
% comment: all outputs are placed on the same line (except the thrid one).
% This is because the live editor print the output based on the line of the
% code but the comand window (and editor) run them without adding new line.
% Please add \n at the end of your text to print ensuing output text on
% next line.
```

```
Hello! Chul Min
Hello!  Chul Min
Hello!
Chul Min
Hello! AE121
Hello! AE121
Hello! AE121
Today is 04\23\2019.
What is 'fprintf'?
```

```
fprintf('Hello! %cE121', 'A');
fprintf('Hello! %s','AE121'); % string of characters
fprintf('Today is 04\\23\\2019.'); % two one slash to print one slash
fprintf('What is ''fprintf''?'); % two single quotes to print one quote
Hello! Chul MinHello!   Chul MinHello!
Chul MinHello! AE121Hello! AE121Hello! AE121Today is 04\23\2019.What is 'fprintf'?>>
```

Relational Expressions

- The relational operators in MATLAB are:

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

- The resulting type is **logical** 1 for true or 0 for false
- The logical operators are:

||	or for scalars
&&	and for scalars
~	not

- Also, **xor** function which returns logical true if only one of the arguments is true

Very important !!!

Truth Table

- A truth table shows how the results from the logical operators for all combinations

x	y	~x	x || y	x && y	xor(x,y)
true	true	false	true	true	false
true	false	false	true	false	true
false	false	true	false	false	false

- Note that the logical operators are commutative (.e.g., x|| y is equivalent to y || x)

Example: Truth Table

```
x = true; % x = logical(1);
y = true; % y = logical(1)
fprintf('x is %d and y is %d. \n', x, y);
fprintf('~x: %d, x||y: %d, x&&y: %d, and(x,y): %d, xor(x,y): %d.', ~x, x||y, x&&y, and(x,y), xor(x,y));

x = true; % x = logical(1);
y = false; % y = logical(0)
fprintf('x is %d and y is %d. \n', x, y);
fprintf('~x: %d, x||y: %d, x&&y: %d, and(x,y): %d, xor(x,y): %d.', ~x, x||y, x&&y, and(x,y), xor(x,y));

x = false; % x = logical(0);
y = false; % y = logical(0)
fprintf('x is %d and y is %d. \n', x, y);
fprintf('~x: %d, x||y: %d, x&&y: %d, and(x,y): %d, xor(x,y): %d.', ~x, x||y, x&&y, and(x,y), xor(x,y));

% how about this?
x = 1;
y = -1;
fprintf('x is %d and y is %d. \n', x, y);
fprintf('~x: %d, x||y: %d, x&&y: %d, and(x,y): %d, xor(x,y): %d.', ~x, x||y, x&&y, and(x,y), xor(x,y));
% comment: it is the same with the result when x and y are true. Bascially,
% logical values corresponding all values except 0 are true.
```

```
x is 1 and y is 1.
~x: 0, x||y: 1, x&&y: 1, and(x,y): 1, xor(x,y): 0.
x is 1 and y is 0.
~x: 0, x||y: 1, x&&y: 0, and(x,y): 0, xor(x,y): 1.
x is 0 and y is 0.
~x: 1, x||y: 0, x&&y: 0, and(x,y): 0, xor(x,y): 0.
x is 1 and y is -1.
~x: 0, x||y: 1, x&&y: 1, and(x,y): 1, xor(x,y): 0.
```

Operator Precedence

Parentheses ( )

Transpose (.'), power (.^), complex conjugate transpose ('), matrix power (^)

Multiplication (.*), right division (./), left division (.\), matrix multiplication (*), matrix right division (/), matrix left division (\)

Addition (+), subtraction (-)

Colon operator (:)

Less than (<), less than or equal to (<=), greater than (>), greater than or equal to (>=), equal to (==), not equal to (~=)

Short-circuit AND (&&)

Short-circuit OR (||)

https://www.mathworks.com/help/matlab/matlab_prog/operator-precedence.html

Example: Good Practice for Arithmetic Operations

I recommend that you always use paranethese to avoid potential mistakes regardless of their operator precedance. For example

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

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

Tip: However, the more the number of terms and parantheses in your equation, the larger is the probability that you would be making a mistake. In this case, I usually do like this:

```
y_nom = (x^2)*(100*x + 10) + (x^3)*(20*(x^2) + 3);
y_den = -x^(-3)+1;
y2 = y_nom/y_den; clearvars y_nom y_den % clear temporary variables
y2
```

Example: Operator Precedence

How to make an expression of ? in other words, how to write a code to check if x lies in between 5 and 10. If yes, 1 and otherwise 0.

```
x = 1;
disp('x is 1.')
5< x <10
(5<x)<10
5<(x<10)
(5<x) & (x<10)
```

```
x is 1.
ans = logical
   1
ans = logical
   1
ans = logical
   0
ans = logical
   0
```

Common Pitfalls

- Confusing the format of an assignment statement (make sure that the variable name is always on the left)
- Forgetting to use parentheses to pass an argument to a function (e.g., typing “fix 2.3” instead of “fix(2.3)”)
- Confusing || and xor
- Using = instead of == for equality
- Using an expression such as “5 < x < 10” – which will always be true, regardless of the value of the variable x (because the expression is evaluated from left to right; 5 < x is either true (1) or false (0); both 1 and 0 are less than 10)

Programming Style Guidelines

- Use mnemonic variable names (names that make sense; for example, *radius* instead of *xyz*)
- Although variables named *result* and *RESULT* are different, avoid this as it would be confusing. (recommendation: do not use capital letters in your variable names)
- Do not use names of built-in functions as variable names
- Store results in named variables (rather than using ***ans***) if they are to be used later

Slide Credits and 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”
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