An Introduction to MATLAB

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NOTE: Subject to frequent revisions!

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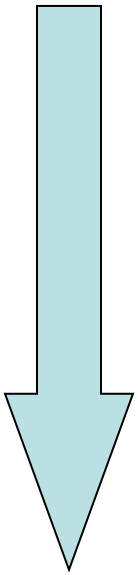
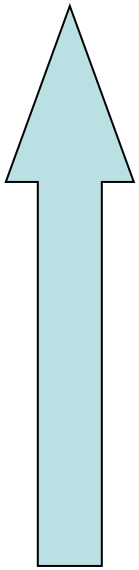
CHAPTER 1

PROLOGUE

FIRST…WHERE IS MATLAB W/R/T PROGRAMMING LANGUAGES?



- **Matlab** (“scripting language”)
- Common Lisp, Python
- Java
- Fortran, C, C++
- Assembly language
- Machine code (binary!)



Increasing program size (fairly objective)

Increasing ease-of-use (fairly subjective)

WHY MATLAB?

"*Softer*" Reasons . . .

- Most scientists and engineers know it
- Widely used in industry, academia and gov
- Easy to learn (it's a "scripting" language)
- **LOTS** of pre-developed application packages
- Very good technical support/user community

"*Harder*" Reasons . . .

- Excellent graphics capabilities
- Includes many modern numerical methods
- Optimized for scientific modeling
- Usually, ***FAST*** matrix operations
- Interfaces well with other languages

WHAT WE PLAN TO STUDY:
The Building Blocks of Programs

Sequence

- ASSIGNMENT: single variables
- ASSIGNMENT: vectors and matrices (arrays)

Repetition

- ITERATION (FOR loops, WHILE loops, and the all-important double nested FOR loops – DNFL)

Selection

- SELECTION (IF statements, single and multi-way)

WHAT THE EXPERTS HAVE SAID:

"The only way to learn a new programming language is by writing programs in it."

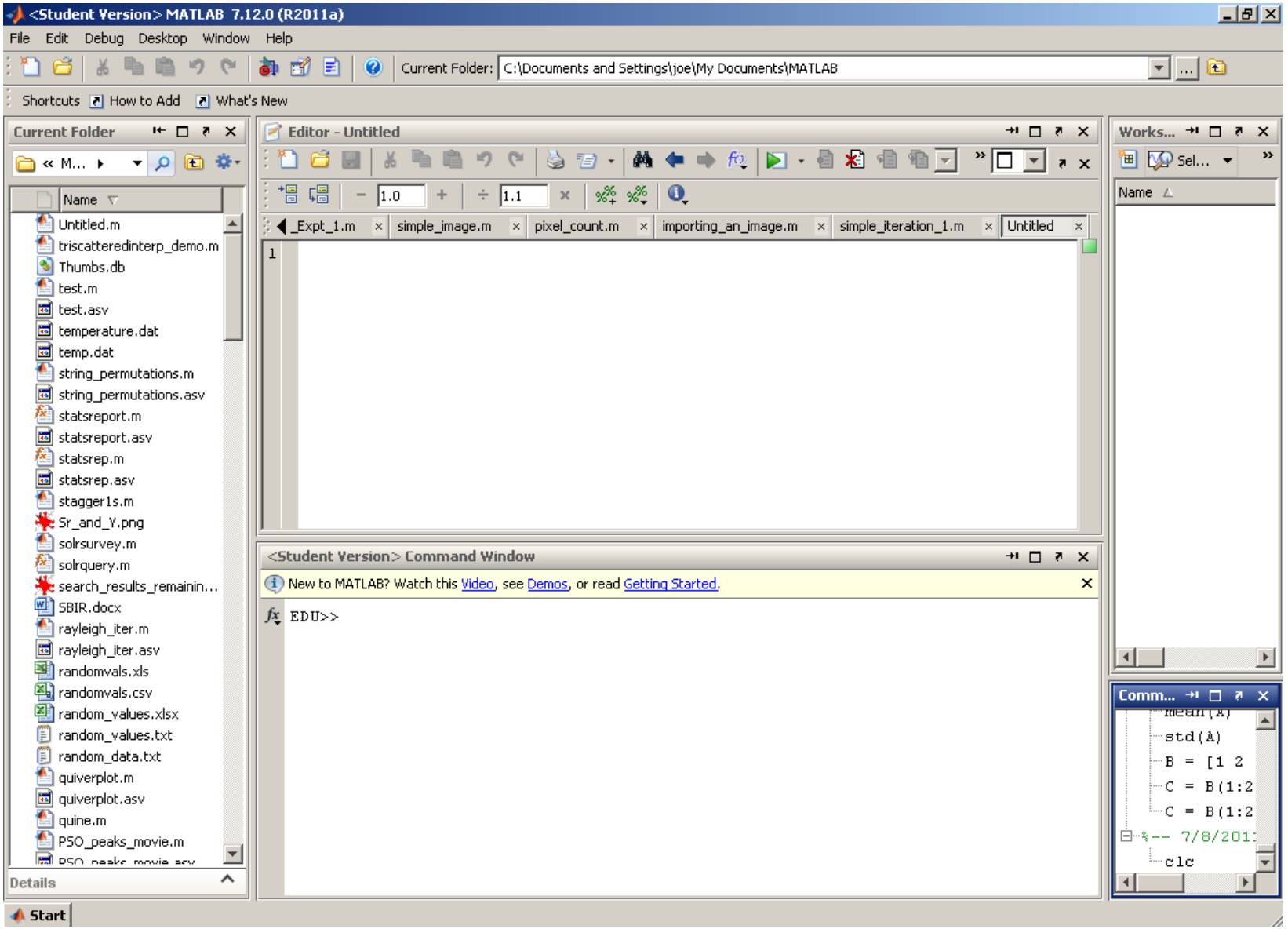
Brian Kernighan & Dennis Richie
"*The C Programming Language*"

[NOTE: red emphasis added]

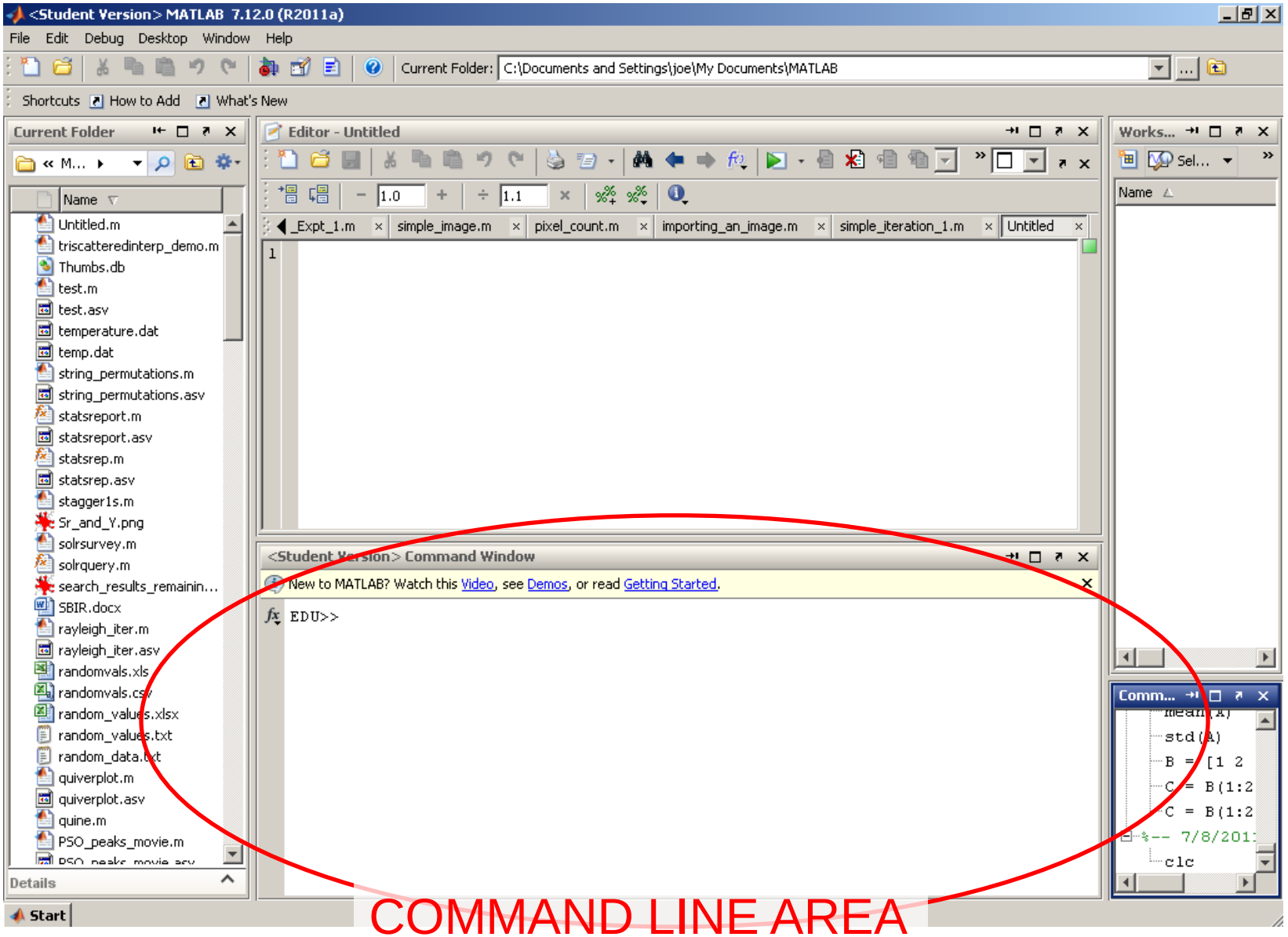
CHAPTER 2

THE MATLAB ENVIRONMENT

THE MATLAB DESKTOP



THE MATLAB DESKTOP



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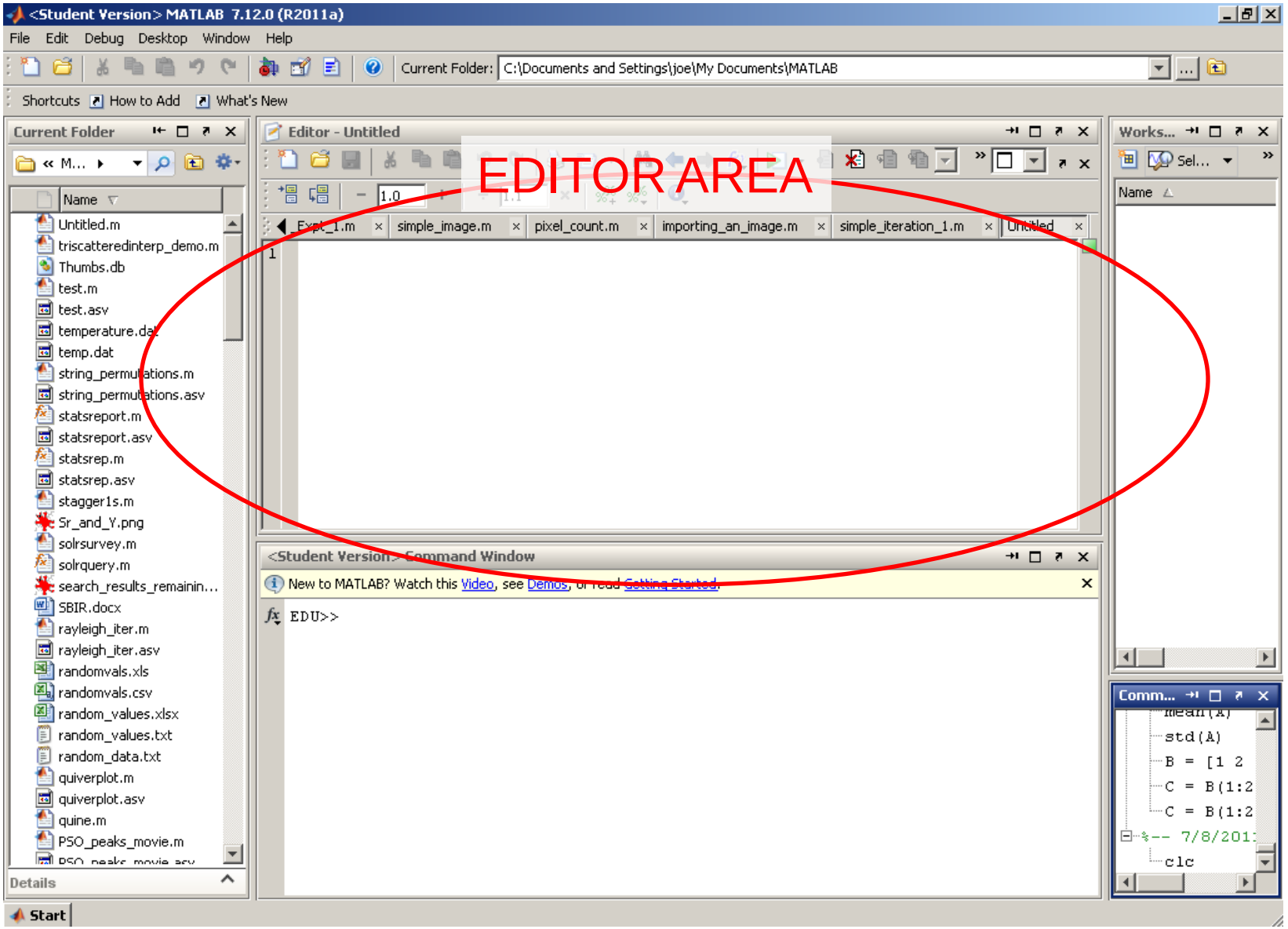
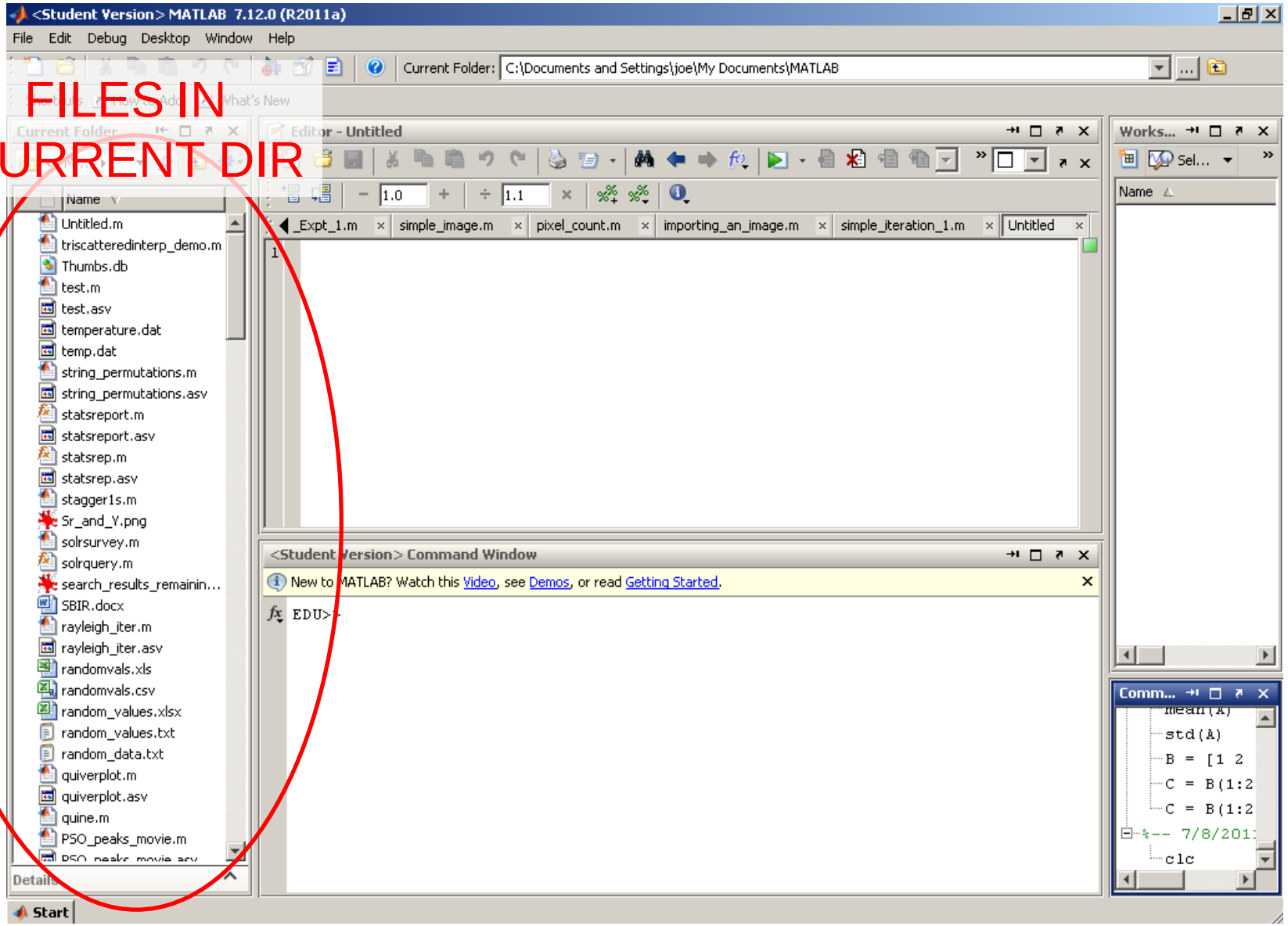
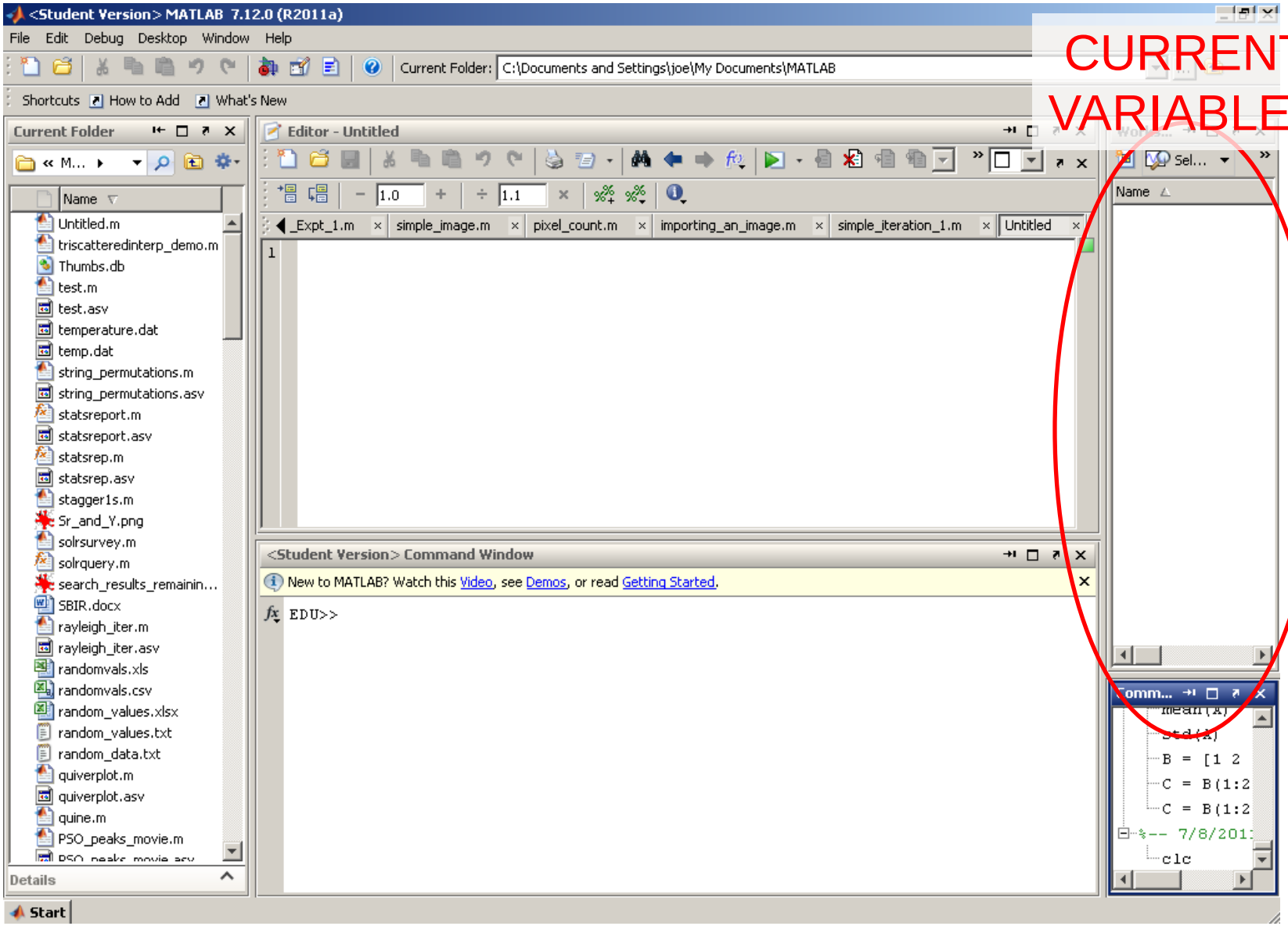


THE MATLAB DESKTOP

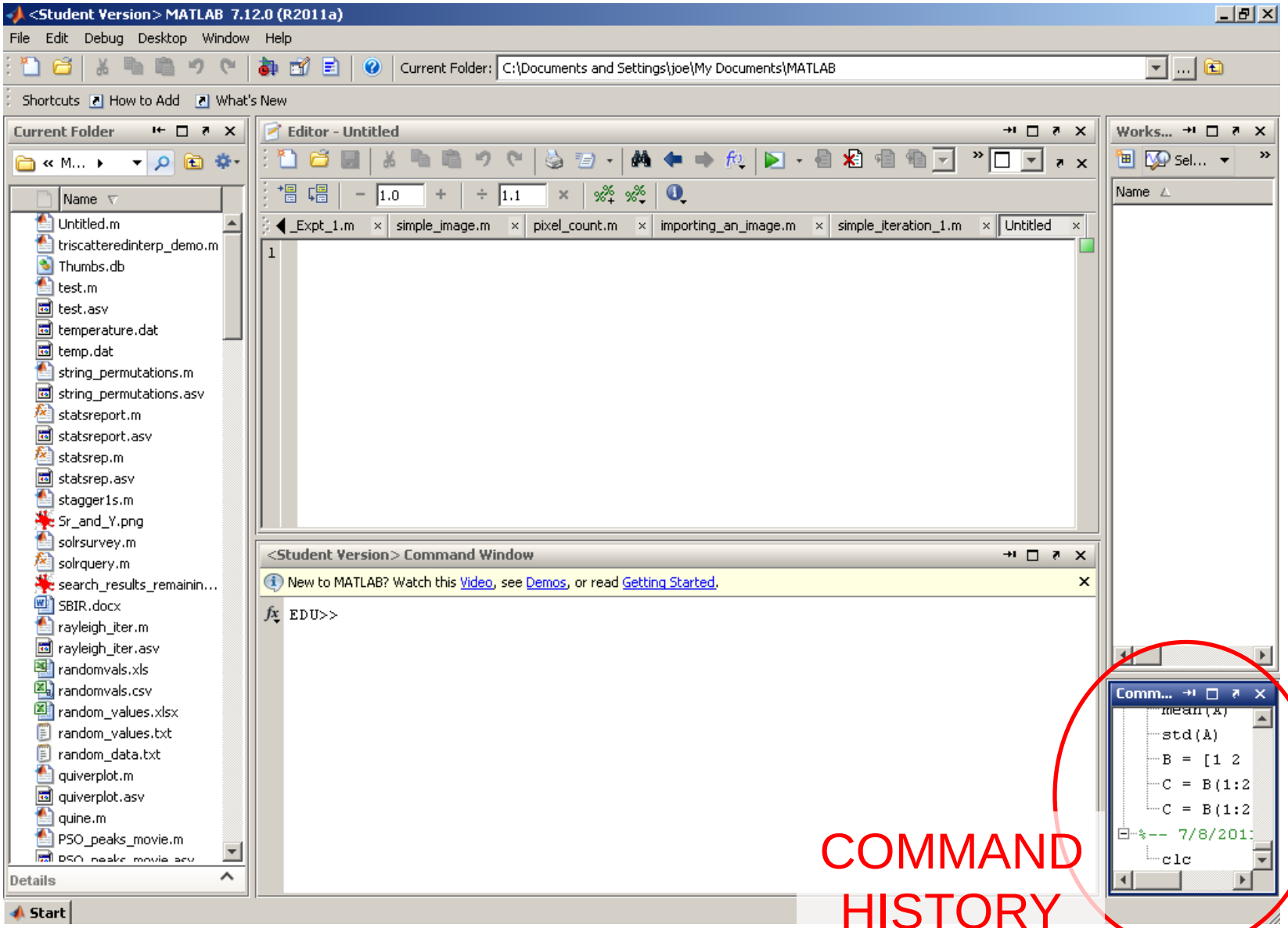


THE MATLAB DESKTOP



CURRENT VARIABLES

THE MATLAB DESKTOP



COMMAND HISTORY

CHAPTER 3

ASSIGNMENT and INTRINSIC FUNCTIONS

ASSIGNMENT: VARIABLES

• Think of a labeled box. We can put "stuff" inside that box. "Stuff" here means ***values***.

• Box labels have names written on them.

• Those names enable us to refer to specific boxes, at a later time, as needed – to go straight to them.

• These ***labeled boxes*** are what we call ***variables***. A variable is a labeled memory box.

• Putting "stuff" inside that box is called ***assigning a value to a variable***, or simply, ***assignment***.

ASSIGNMENT: VARIABLES

- "MATLAB variable names must begin with a letter, which may be followed by any combination of letters, digits, and underscores. MATLAB distinguishes between uppercase and lowercase characters, so `A` and `a` are not the same variable."
  (http://www.mathworks.com/help/techdoc/matlab_prog/f0-38052.html)

- Valid variable names:
  ```
  A,   a,   Aa,  abc123,  a_b_c_123
  ```

- Invalid variable names:
  ```
  1A, _abc, ?variable, abc123?
  ```

ASSIGNMENT: VARIABLES

- To do assignment in Matlab:
  1. Write a variable name
  2. Write the "=" symbol
  3. Write the value that you want to store in the variable

- Examples:

```
A = 5                    (an integer value)
a123 = 1.0               (a floating point value)
abc_123 = 1.0e-02        (an exponential value)
myVariable = 'Joe'       (a string value)
```

ASSIGNMENT: VARIABLES

Rules of Assignment:

- The "=" symbol ***DOES NOT MEAN EQUALS***! It means assignment: Assign the ***value on the right*** of the "=" symbol to the ***variable on the left*** of the "=" symbol.
- To access what's "in the box"—that is, the value currently held by the variable—simply type the name of the variable alone on a line, or, on the right side of a "=" symbol. So a variable name written on the right side of a "=" symbol means: "retrieve the value stored in this variable".

ASSIGNMENT: VARIABLES

REMEMBER:

- **Value on the right of "=" gets stored into variable on the left of "=":**

```
var1 = 5.0
```

- Example: Valid assignment (creates var2, assigns it the **value contained in var1**):

```
var2 = var1
```

- Example: Invalid assignment (generates error: **var3 not previously declared** – holds no value)

```
var2 = var3
```

ASSIGNMENT: VARIABLES

- **Rules of Assignment** (cont):
  - Variables can be used in assignment statements to assign values to other variables: Since placing a variable on the right side of "=" retrieves its current value, we can subsequently assign that value to yet another variable:

var1 = 3.0 (assigns the value 3.0 to var1)
var2 = var1 (retrieves 3.0 from var1 and stores that value into var2)

  - We can do math with variables, too:

Examples:

```
var3 = var2 + var1    (here, 3.0 + 3.0)
var4 = var3 * var2    (here, 6.0 * 3.0)
var5 = var4 / var1    (here, 18.0 / 3.0)
var6 = var2 ^ var1    (here, 3.0 ^ 3.0)
```

ASSIGNMENT: VARIABLES

- **Rules of Assignment** (cont):

  - We can also “update” a variable by constantly reassigning new values to it. Updating a variable by adding 1 to it, and then assigning the new value back into the same variable is called “incrementing”. Example:

```
var7 = 1
var7 = var7 + 1
```

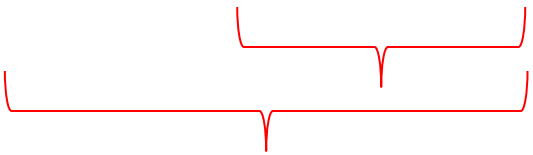
  Incrementing a variable is a VERY IMPORTANT thing to do, because, doing so enables us to **count** effectively.

ASSIGNMENT: VARIABLES

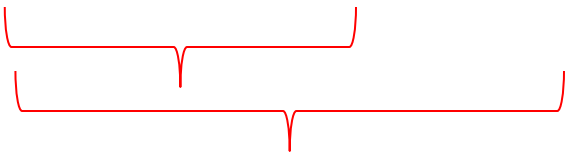
- **Rules of Arithmetic Operator Precedence**:
  - The preceding arithmetic examples raise a question: In what order are the arithmetic operations performed in an assignment statement?
  - Like in algebra: Anything in parentheses first, followed by exponentiation, followed by multiplication/division, followed by addition/subtraction

Examples:

```
var3 = var2 + var1 * var4
```



```
var3 = (var2 + var1) * var4
```

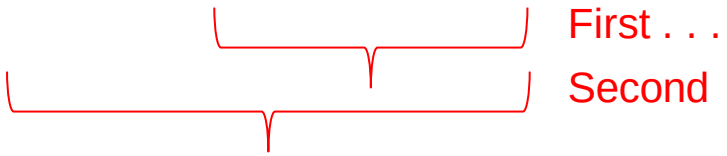


ASSIGNMENT: VARIABLES

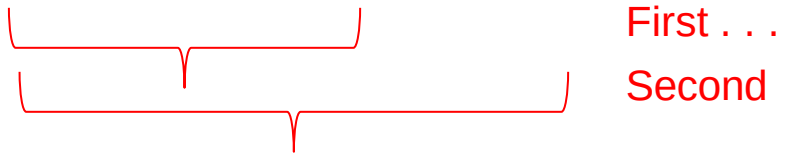
- **Rules of Arithmetic Operator Precedence** :

Examples:

```
var3 = var2 + var1 * var4
```




```
var3 = (var2 + var1) * var4
```



But what if the operators are of equal precedence?

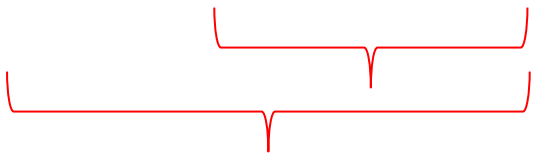
```
var3 = var2 / var1 * var4

       ???
```

ASSIGNMENT: VARIABLES

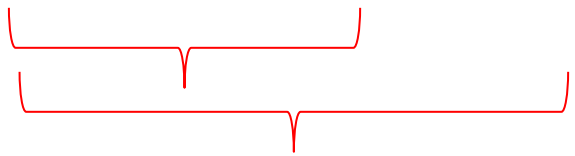
- **Rules of Arithmetic Operator Precedence** :

Examples:

```
var3 = var2 + var1 * var4
```

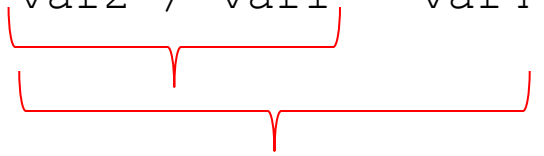



```
var3 = (var2 + var1) * var4
```



When operators are of equal precedence, associate **LEFT TO RIGHT:**

```
var3 = var2 / var1 * var4
```



ASSIGNMENT: VARIABLES

- **Rules of Arithmetic Operator Precedence** :

Examples:

```
var3 = var2 / var1 / var4 / var5 / var6

                          ???
```

```
var3 = var2 * var1 - var4 / var5 + var6

                          ???
```

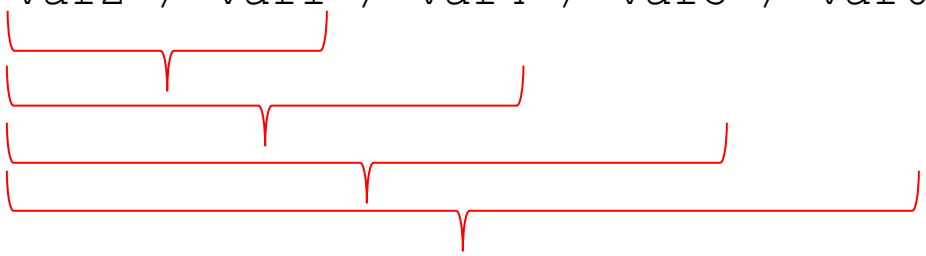
```
var3 = var2 / var1 * var4 / var5 ^ var6

                          ???
```

ASSIGNMENT: VARIABLES

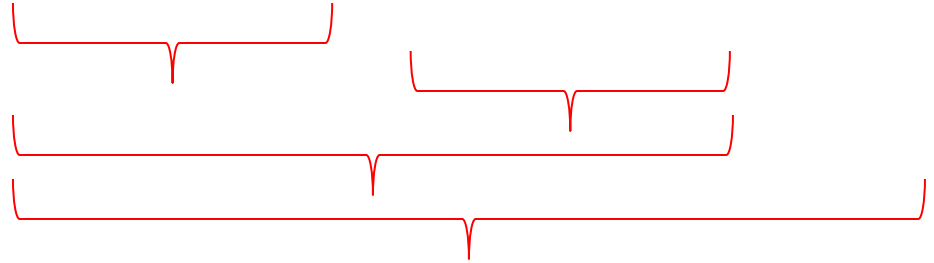
- **Rules of Arithmetic Operator Precedence** :

Examples:

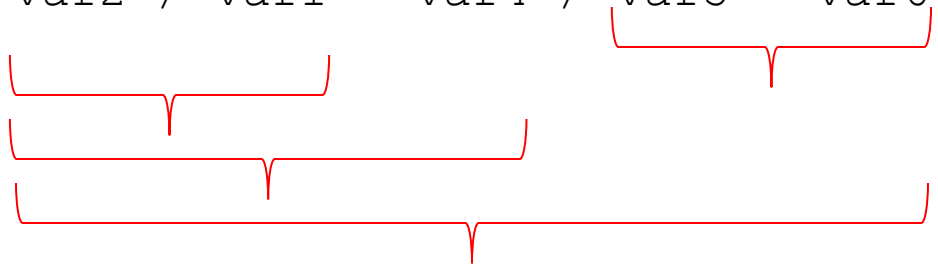
```
var3 = var2 / var1 / var4 / var5 / var6
```



```
var3 = var2 * var1 - var4 / var5 + var6
```



```
var3 = var2 / var1 * var4 / var5 ^ var6
```



APPEARANCE OF OUTPUT

• We can change the way numbers are printed to the screen by using Matlab's "format" command, followed by the appropriate directive, "short" or "long" (the format directive is *persistent*!)

```
>> pi
>> ans = 3.1416

>> format short
>> pi
>> ans = 3.1416

>> format long
>> pi
>> ans = 3.141592653589793

>> sqrt(2)
>> ans = 1.414213562373095
```

SOME BUILT-IN FUNCTIONS

Here are a few of Matlab's built-in (intrinsic) functions, to get you started:

π:

```
>> pi
>> ans = 3.1416
```

sine(x):

```
>> sin(pi)
>> ans = 1.2246e-016
```

e^N :

```
>> exp(1)
>> ans = 2.7183
```

$\sqrt{N}$:

```
>> sqrt(2)
>> ans = 1.4142
```

cosine(x):

```
>> cos(pi)
>> ans = -1
```

natural log (N):

```
>> log(2)
>> ans = 0.6931
```

remainder ($\frac{a}{b}$):

```
>> mod(5,2)
>> ans = 1
```

tangent(x):

```
>> tan(pi)
>> ans = 1.2246e-016
```

base 10 log (N):

```
>> log10(2)
>> ans = 0.3010
```

SOME BUILT-IN FUNCTIONS

We can use Matlab's built-in functions on the right hand side of an assignment statement, to produce a value that we then assign to a variable:

π:

```
>> x = pi
>> x = 3.1416
```

sine(x):

```
>> x = sin(pi)
>> x = 1.2246e-016
```

e^N :

```
>> x = exp(1)
>> x = 2.7183
```

$\sqrt{N}$:

```
>> x = sqrt(2)
>> x = 1.4142
```

cosine(x):

```
>> x = cos(pi)
>> x = -1
```

natural log (N):

```
>> x = log(2)
>> x = 0.6931
```

remainder ($\frac{a}{b}$):

```
>> x = mod(5,2)
>> x = 1
```

tangent(x):

```
>> x = tan(pi)
>> x = 1.2246e-016
```

base 10 log (N):

```
>> x = log10(2)
>> x = 0.3010
```

INTERLUDE: FOCUS ON "MOD"

remainder ($\frac{a}{b}$):

```
>> x = mod(5,2)
>> x = 1
```

The "mod" function is very important. It comes up again and again, and is quite useful.

It is simply this: The **INTEGER remainder** after long division.

Remember long division, and the remainder?

INTERLUDE: FOCUS ON "MOD"

"Ten divided by three is three remainder one"

or

mod(10,3) = 1

"Twelve divided by seven is one remainder five"

or,

mod(12,7) = 5

INTERLUDE: FOCUS ON "MOD" (cont)

"Eight divided by two is three remainder zero"

or

mod(8,2) = 0

"Twenty nine divided by three is nine remainder two"

or,

mod(29,3) = 2

INTERLUDE: FOCUS ON "MOD" (cont)

"Three divided by five is zero remainder three"

or

mod(3,5) = 3

"Eight divided by eleven is zero remainder eight"

or,

mod(8,11) = 8

INTERLUDE: FOCUS ON "MOD" YOUR TURN!

mod(8,3) = ??? (in words, then the value)

mod(4,5) = ??? (in words, then the value)

mod(4,2) = ??? (in words, then the value)

mod(10,7) = ??? (in words, then the value)

mod(10,5) = ??? (in words, then the value)

mod(10,2) = ??? (in words, then the value)

INTERLUDE: FOCUS ON "MOD" YOUR TURN! (ANSWERS)

mod(8,3) : "Eight divided by three is two remainder two"

mod(4,5) : "Four divided by five is zero remainder four"

mod(4,2) : "Four divided by two is two remainder zero"

mod(10,7) : "Ten divided by seven is one remainder three"

mod(10,5) : "Ten divided by five is two remainder zero"

mod(10,2) : "Ten divided by two is five remainder zero"

INTERLUDE: FOCUS ON "MOD"
YOUR TURN! (ANSWERS)

mod(8,3) = 2

mod(4,5) = 4

mod(4,2) = 0

mod(10,7) = 3

mod(10,5) = 0

mod(10,2) = 0

ASSIGNMENT: YOUR TURN!

Example 1: Create a variable called **x** and assign it the value 3. Create another variable called **y** and assign it the value 4. Compute the product of **x** and **y**, and assign the result to a third variable called **z**.

Example 2: Now square **z**, and assign the result to a fourth variable called **a**. Take the base 10 logarithm of **z** and assign that to a fifth variable called **b**. Reassign the value of **b** to **x**. Cube **b**, and assign the result to a sixth variable called **c**.

Example 3: Print out the final values of **x**, **y**, **z**, **a**, **b** and **c**.

ASSIGNMENT: YOUR TURN! (ANSWERS)

Example 1: Create a variable called **x** and assign it the value 3. Create another variable called **y** and assign it the value 4. Compute the product of **x** and **y**, and assign the result to a third variable called **z**.

```
x = 3;
y = 4;
z = x * y;
```

NOTE: A semi-colon at the end of a Matlab statement suppresses output, i.e., tells Matlab to "be quiet!"

ASSIGNMENT: YOUR TURN! (ANSWERS)

Example 2: Now square **z**, and assign the result to a fourth variable called **a**. Take the base 10 logarithm of **z** and assign that to a fifth variable called **b**. Reassign **x** the value of **b**. Cube **b**, and assign the result to a sixth variable called **c**.

```
a = z^2;
b = log10(z);
x = b;
c = b^3;
```

ASSIGNMENT: YOUR TURN! (ANSWERS)

Example 3: Print out the final values of **x**, **y**, **z**, **a**, **b** and **c**.

x
y
z
a
b
c

NOTE: Since a semi-colon at the end of a Matlab statement suppresses output, to get printed output, simply don't put a semi-colon at the end.

CHAPTER 4

VECTORS
and
VECTOR OPERATIONS

VECTORS

• Think of a "VECTOR" as a bunch of values, all lined up (here we have a "**row vector**"):

Vector **A**:

1	2	3	4	5

• We create **row vector** A like this (all three ways of writing the assignment statement are equivalent):

A = [**1 2 3 4 5**];
A = [**1, 2, 3, 4, 5**];
A = [**1:5**];

NOT: A = [1-5];

VECTORS

• Vectors are convenient, because by assigning a vector to a variable, we can manipulate the ENTIRE collection of numbers in the vector, just by referring to the variable name.

• So, if we wanted to add the value 3 to each of the values inside the vector A, we would do this:

A + 3

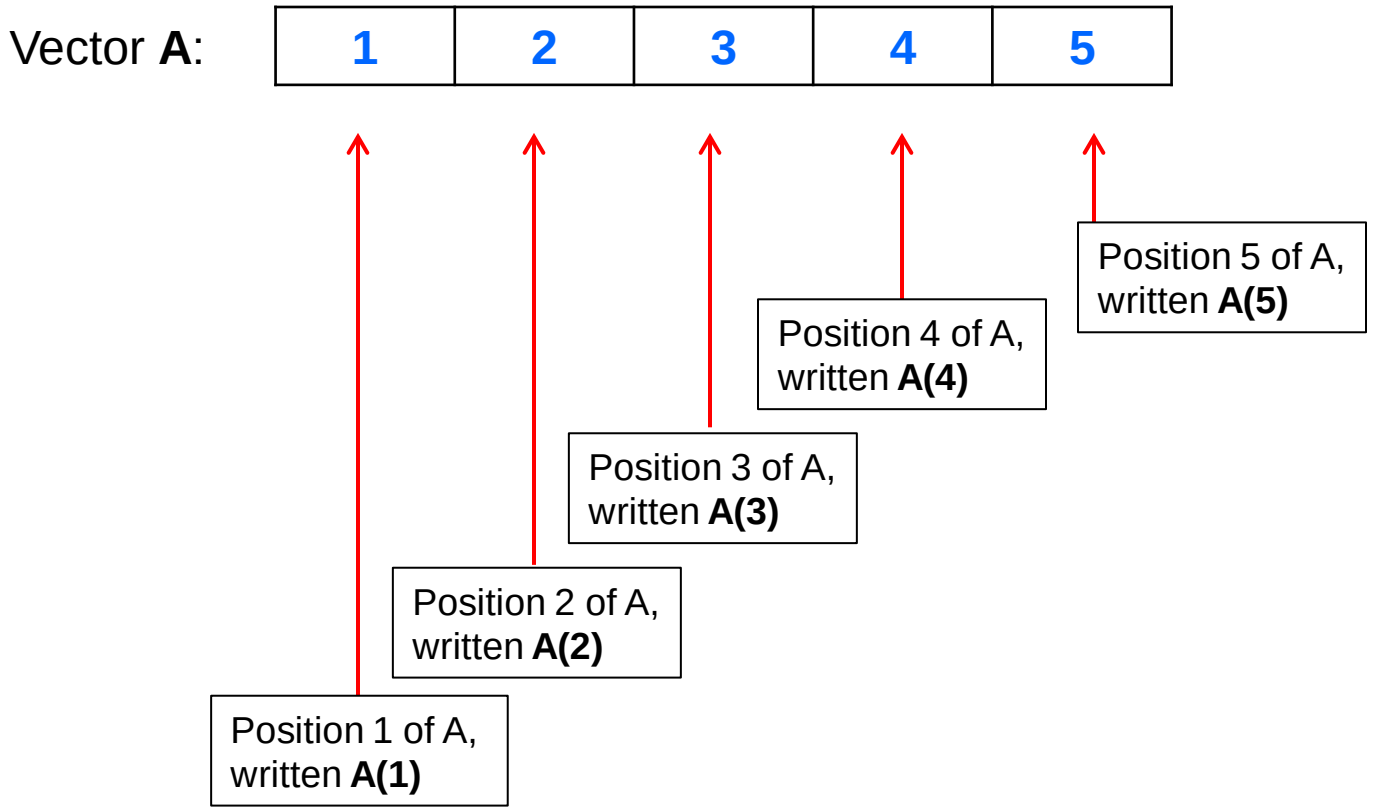
Which accomplishes this:

A + 3:

1+3	**2+3**	**3+3**	**4+3**	**5+3**
4	**5**	**6**	**7**	**8**

VECTORS

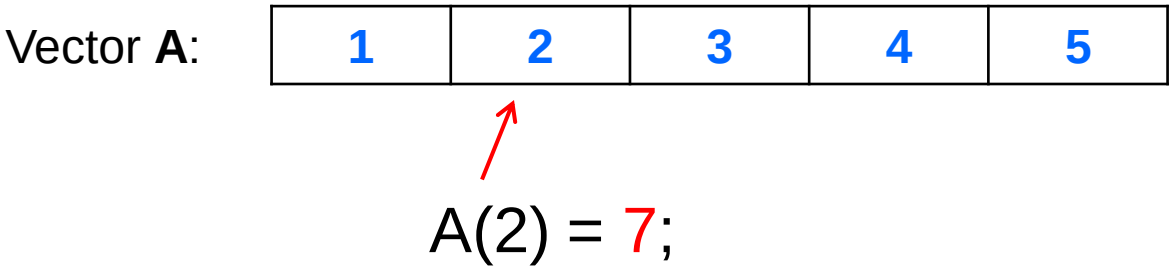
• We can refer to EACH POSITION of a vector, using what's called "subscript notation":



VECTORS

• **KEY POINT**: Each POSITION of a vector can act like an independent variable. So, for example, we can reassign different values to individual positions.

Before the first assignment:

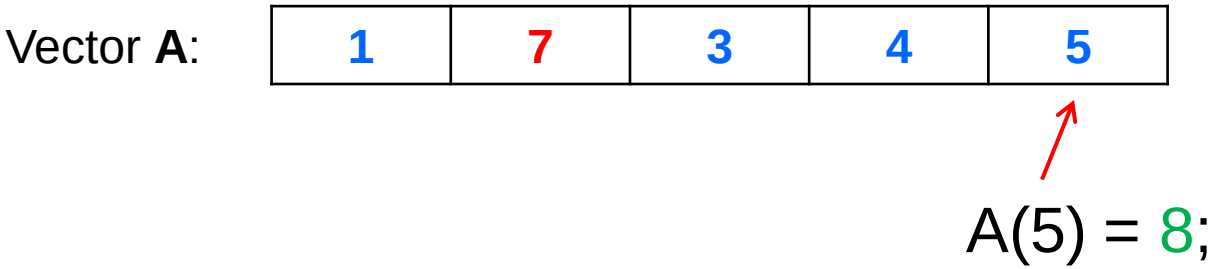


After the first assignment:

VECTORS

• **KEY POINT**: Each POSITION of a vector can act like an independent variable. So, for example, we can reassign different values to individual positions.

Before the second assignment:



After the second assignment:

VECTORS

• **ANOTHER KEY POINT**: Because each position in a vector can act like an independent variable, we can do all the things with vector positions that we can do with independent variables like we did previously with **x**, **y**, **z**, **a**, **b** and **c**.

Vector **A**:

1	7	3	4	8

So, given vector A above, if we type "A(3)" at Matlab's command line, we will get the value **3** returned:

```
EDU>> A(3)
ans =
     3
```

VECTORS: YOUR TURN!

Instructions:

For the next several examples, please try to work out the answers without running the code in Matlab. This is essential, as it will enable you to develop your "Matlab intuition" and also to visualize the sequence of a computation (thus developing your ability to think algorithmically). Furthermore, you will not be allowed to use Matlab software on exams or quizzes and so it's better to get the practice now rather than wait until later! You may, however, use scratch paper to work out answers.

VECTORS: YOUR TURN!

Vector **A**:

1	7	3	4	8

- **Example 4**: If "A(2)" typed at Matlab's command line, what value is printed?

- **Example 5**: If "A(2) + A(3)" is entered at Matlab's command line, what value is printed?

- **Example 6**: If "A(4) * A(5)" is entered at Matlab's command line, what value is printed?

- **Example 7**: If "A * 5" is entered at Matlab's command line, what is printed? Why?

VECTORS: YOUR TURN! ANSWERS

Vector **A**:

1	7	3	4	8

- **Example 4**: If "A(2)" typed at Matlab's command line, what value is printed? **7**

- **Example 5**: If "A(2) + A(3)" is entered at Matlab's command line, what value is printed? **10**

- **Example 6**: If "A(4) * A(5)" is entered at Matlab's command line, what value is printed? **32**

VECTORS: YOUR TURN! ANSWERS

Vector **A**:

1	7	3	4	8

• **Example 7**: If "A * 5" is entered at Matlab's command line, what is printed? Why?

```
EDU>> A*5

ans =

     5    35    15    20    40
```

Each position of A is multiplied by 5.

VECTORS: YOUR TURN!

Vector **A**:

1	7	3	4	8

• **Example 8**: If "A(2) = A(3) * A(4)" typed at Matlab's command line, what does vector A look like now?

• **Example 9**: Assume vector A, as shown above, and also assume that the following sequence is entered at Matlab's command line. What does the vector A look like after this sequence?

```
A(1) = A(2) – ( A(3) + A(4) );
A = A * A(1);
```

VECTORS: YOUR TURN! ANSWERS

Vector **A**:

1	7	3	4	8

- **Example 8**: If "A(2) = A(3) * A(4)" typed at Matlab's command line, what does vector A look like now?

```
EDU>> A(2) = A(3) * A(4)

A =

     1    12     3     4     8
```

VECTORS: YOUR TURN! ANSWERS

Vector **A**:

1	7	3	4	8

• **Example 9**: Assume vector A, as shown above, and also assume that the following sequence is entered at Matlab's command line. What does the vector A look like after this sequence?

```
A(1) = A(2) – ( A(3) + A(4) );
A = A * A(1)
```

```
A =

     0     0     0     0     0
```

VECTOR OPERATIONS

Assume we have a vector, A, as follows:

Vector **A**:	1	7	3	4	8

We can add a single number (a scalar) to every element of A, all at once, as follows:

B = A + 5 =	6	12	8	9	13

We can also multiply every element of A by a single number (a scalar) as follows:

B = A * 5 =	5	35	15	20	40

VECTOR OPERATIONS

Vector **A**:	1	7	3	4	8

We can subtract single number (a scalar) from every element of A, all at once, as follows:

B = A - 5 =	-4	2	-2	-1	3

We can also divide every element of A by a single number (a scalar) as follows:

B = A / 5 =	0.2	1.4	0.6	0.8	1.6

VECTOR OPERATIONS

Vector **A**:

1	7	3	4	8

BUT:

If we want to ***exponentiate*** every element of A by a number (i.e., raise each element of A to a particular power), then we have to write this in a special way, using the ***DOT*** operator:

B = A.^2 =

1	49	9	16	64

NOT: B = A^2

VECTOR OPERATIONS

We can also do mathematical operations on two vectors ***OF THE SAME LENGTH***‡. For example, assume we have two vectors, A and B, as follows:

Vector **A**:	1	7	3	4	8
Vector **B**:	-1	7	10	6	3

Then:

C = A – B =	2	0	-7	-2	5
C = A + B =	0	14	13	10	11

‡: If A and B are not the same length, Matlab will signal an error

VECTOR OPERATIONS

Vector **A**:	1	7	3	4	8
Vector **B**:	-1	7	10	6	3

Multiplication, division, and exponentiation, BETWEEN TWO VECTORS, ELEMENT-BY-ELEMENT, is expressed in the DOT notation:

C = A **.*** B =	-1	49	30	24	24
C = A **./** B =	-1	1	0.3	0.666	2.666
C = A **.^** B =	1^{-1}	7^{7}	3^{10}	4^{6}	8^{3}

Matlab Tutorial Video

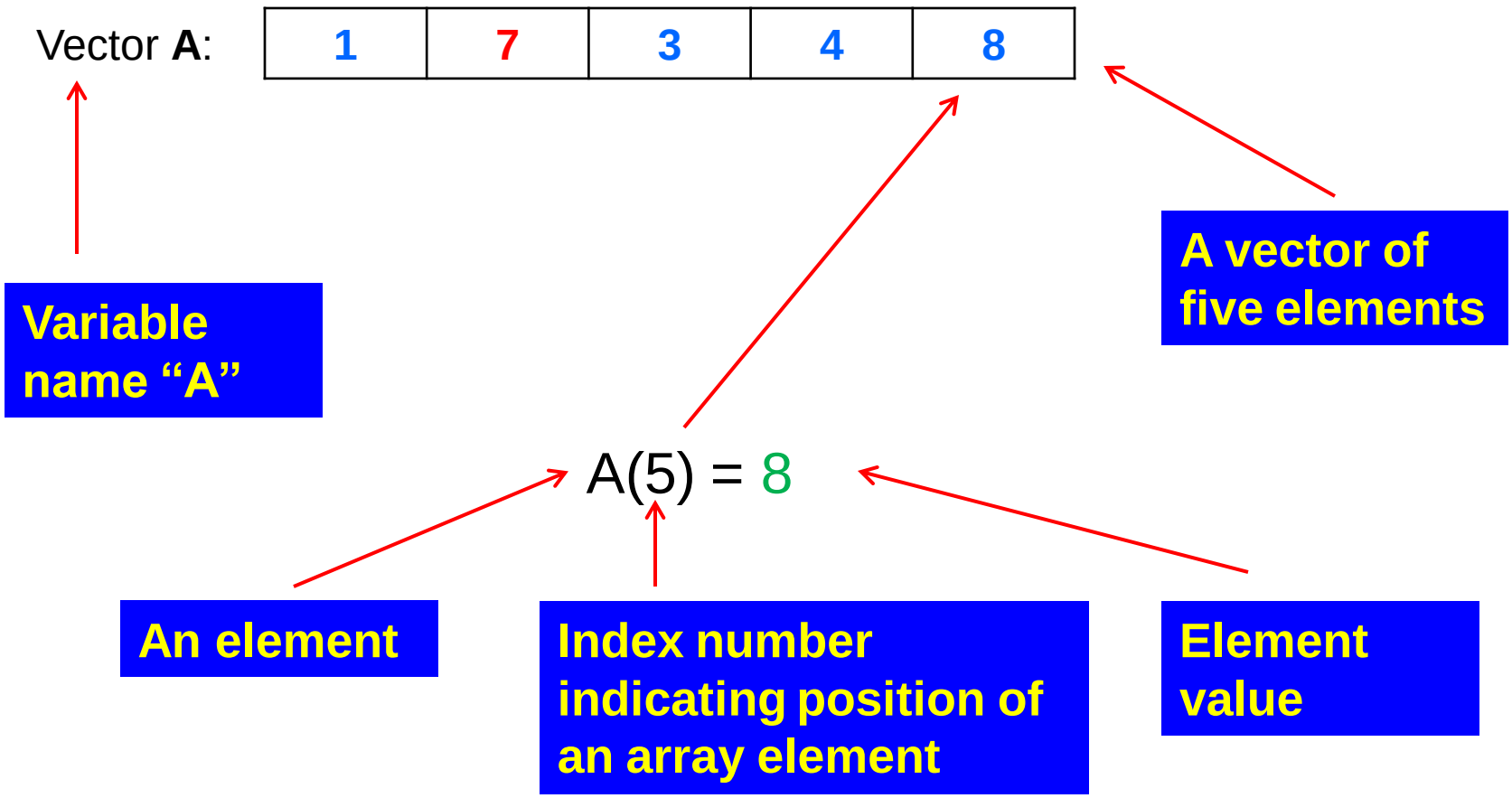
1. Online demo video - Getting Started with Matlab (05:10)
   - http://www.mathworks.com/videos/matlab/getting-started-with-matlab.html

2. Online demo video - Writing a Matlab Program (05:43)
   - http://www.mathworks.com/videos/matlab/writing-a-matlab-program.html

Links are also available at class website resource page:
http://solar.gmu.edu/teaching/2011_CDS130/Resources.html

Short Review of VECTOR

```
>> A=[1,7,3,4,10]  ; %comment: assign values of a vector
```



OTHER USEFUL VECTOR OPERATIONS

Vector **A**:

1	7	3	4	8

e^x of each element of A, where x is an element of A:

```
>> exp(A)
ans =
 1.0e+003 *

    0.0027    1.0966    0.0201    0.0546    2.9810
```

Square root of each element of A:

```
>> sqrt(A)
ans =
    1.0000    2.6458    1.7321    2.0000    2.8284
```

OTHER USEFUL VECTOR OPERATIONS

Vector **A**:

1	7	3	4	8

Natural logarithm of each element of A:

```
>> log(A)
ans =
         0    1.9459    1.0986    1.3863    2.0794
```

Base ten logarithm of each element of A:

```
>> log10(A)
ans =
         0    0.8451    0.4771    0.6021    0.9031
```

OTHER USEFUL VECTOR OPERATIONS

Vector **A**:

1	7	3	4	8

Cosine of each element of A (elements interpreted as radians):

```
 >> cos(A)
ans =
    0.5403    0.7539   -0.9900   -0.6536   -0.1455
```

Sine of each element of A (elements interpreted as radians):

```
 >> sin(A)
ans =
    0.8415    0.6570    0.1411   -0.7568    0.9894
```

OTHER USEFUL VECTOR OPERATIONS

Vector **A**:

1	7	3	4	8

Mean (average) of ALL elements of A:

```
 >> mean(A)
ans =
    4.6000
```

Standard deviation of ALL elements of A:

```
 >> std(A)
ans =
    2.8810
```

VECTORS: VARIABLE INDEXING

Let's say that I wanted to create a vector A containing all the odd integers between 1 and 10 (inclusive). How would I do this?

Here's one way:

A = [1, 3, 5, 7, 9];

I can simply list them all out. BUT, we could do this another way . . .

VECTORS: VARIABLE INDEXING

I could do it this way:

A = [1:2:10]

This says, “Begin at 1, then to generate all the remaining values in the vector, keep adding 2 to the previous value. Stop when we reach 10. Don’t add the value if it exceeds 10.” So . . .

Begin at 1:

A = [1]

VECTORS: VARIABLE INDEXING

Add 2 to the previous value (i.e., to 1) to generate the next value:

A = [1, 1+2]

Add 2 to the previous value (i.e., to 3) to generate the next value:

A = [1, 3, 3+2]

Add 2 to the previous value (i.e., to 5) to generate the next value:

A = [1, 3, 5, 5+2]

VECTORS: VARIABLE INDEXING

Add 2 to the previous value (i.e., to 7) to generate the next value:

A = [1, 3, 5, 7, 7+2]

Then . . . add 2 to the previous value (i.e., to 9) to generate the next value??

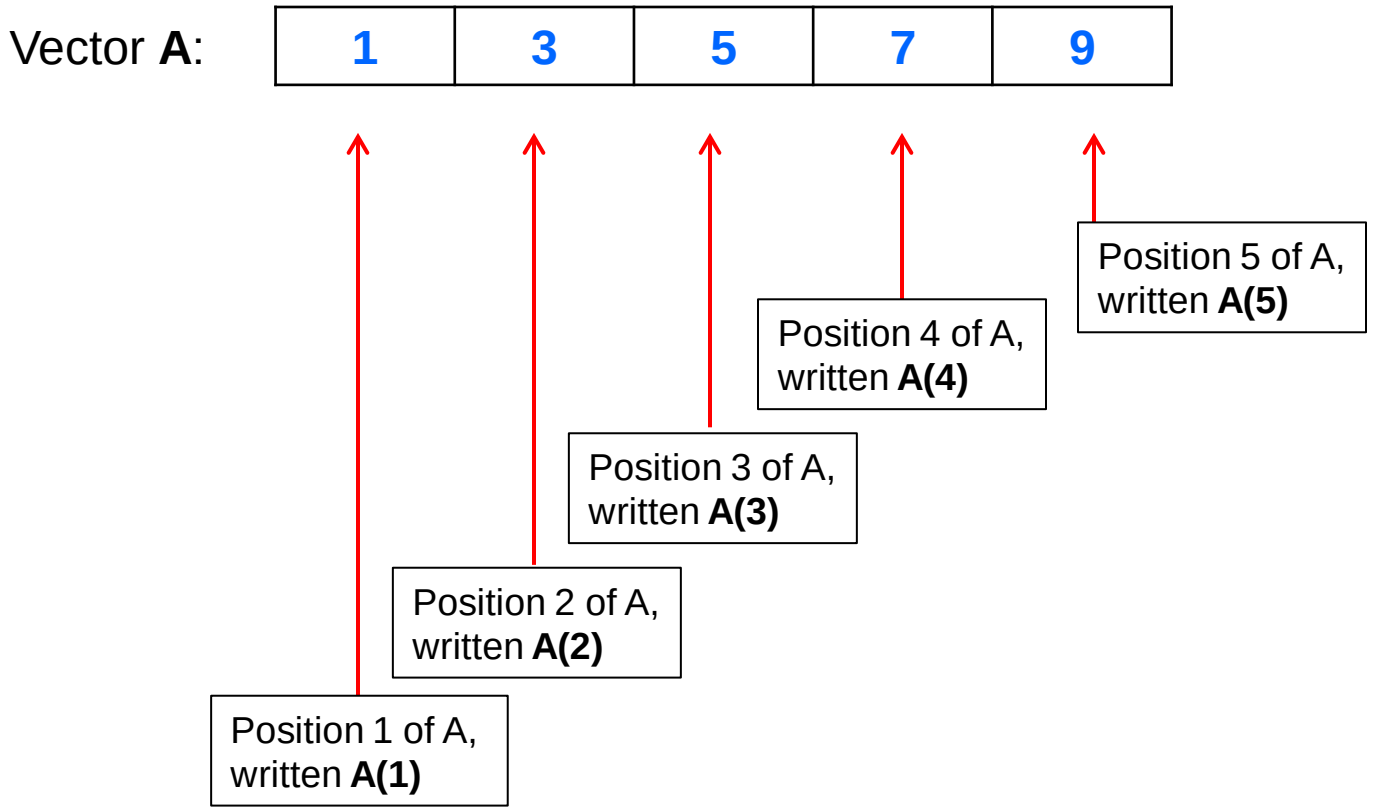
A = [1, 3, 5, 7, 9, **9+2**]

WAIT! 9+2 = 11 and 11 > 10, which is the end of the vector. So since we must stop at 10, we DO NOT insert 11 into the vector A. Thus, the vector A is now constructed as desired:

A = [1, 3, 5, 7, 9]

VECTORS: VARIABLE INDEXING

NOTE WHAT WE NOW HAVE:



VECTORS: VARIABLE INDEXING

THUS:

Vector **A**:

1	3	5	7	9

A(1)=1 A(2)=3 A(3)=5 A(4)=7 A(5)=9

VECTORS: VARIABLE INDEXING

WHAT'S THE ADVANTAGE of doing it this way? Why not list out all the members of the vector? Isn't it easier that way?

Actually, no. What if I wanted to create a vector B containing all the odd, positive integers between, say, 1 and 1000 (inclusive). How would I do that? I could list them out, one by one, but that's pretty tedious (not to mention time consuming). Here's how to do it all in one statement:

```
B = [1:2:1000];
```

Remember to end with a semi-colon, or else you're going to see a LOT of output!

That's it!

VECTORS: VARIABLE INDEXING

How about creating a vector C containing all the even, positive integers between 1 and 1000 (inclusive). How would I do that?

Begin at 2 and then add 2:

```
C = [2:2:1000];
```

We can start anywhere we want. We start at 2 because of course, 1 is odd and will not be a member of the vector! The vector will begin with the value 2.

VECTORS: VARIABLE INDEXING

Let's say that I want to find the average of all the even, positive integers between 1 and 1000. How would I do that?

Here's how:

```
C = [2:2:1000];
mean(C)
```

That's it!

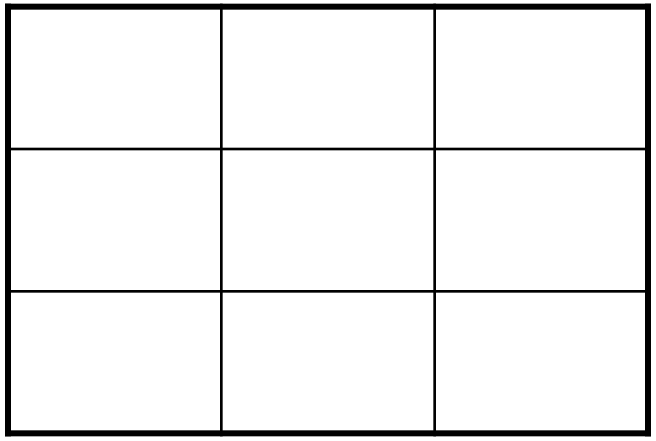
CHAPTER 5

MATRICES (ARRAYS)
and
MATRIX OPERATIONS

MATRICES (ARRAYS)

• Think of a MATRIX as a partitioned box: The box itself has a label (its variable name), and, we can store MULTIPLE things inside the box, each inside its own partition:

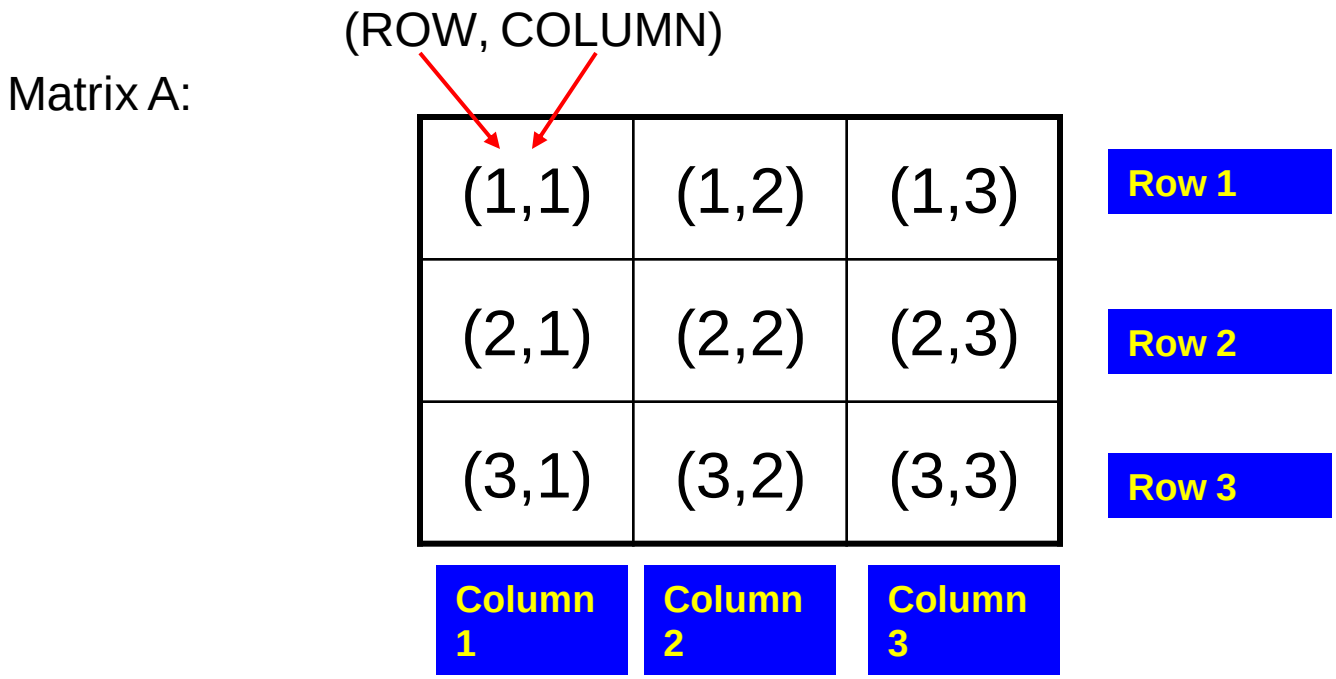
Matrix A:



• We can manipulate the ENTIRE COLLECTION at once, just by referring to the matrix's variable name.

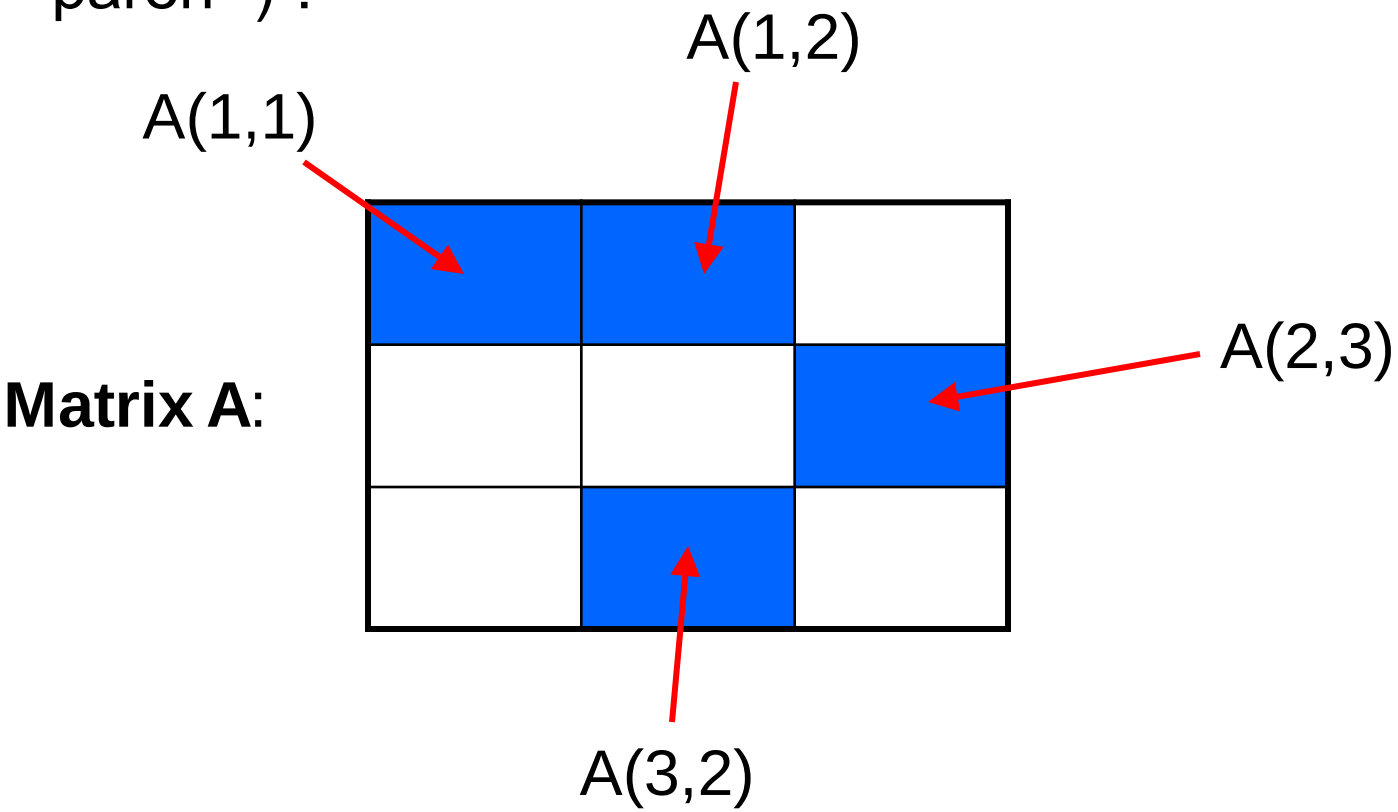
MATRICES (ARRAYS)

- A matrix has **DIMENSIONS**: In the 2 dimensional case, rows and columns.
- Each partition is referred to by both its row number and its column number.
- **Rule**:
  - In Matlab, both row and column numbers **START AT 1**:



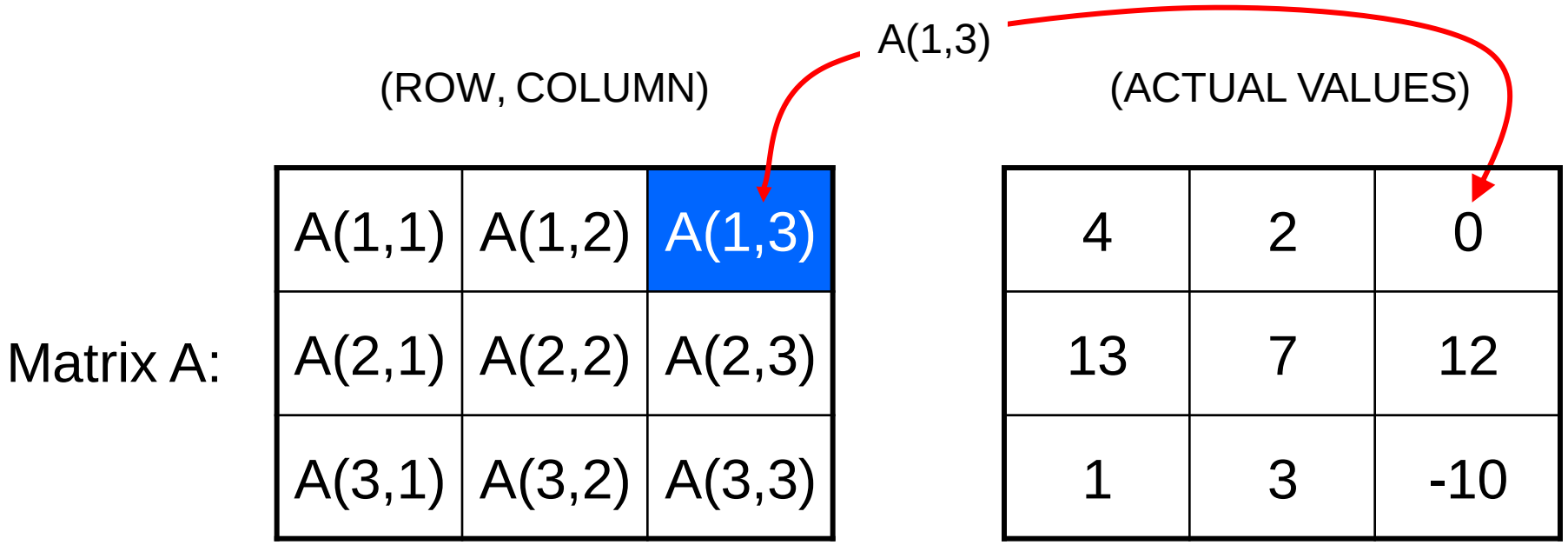
MATRICES (ARRAYS)

• We can access individual partitions (called "elements") by writing the matrix name, followed by a left paren "(", the row number, a comma, the column number, and a right paren ")":



MATRICES (ARRAYS)

- **Rule**:
  The name for an individual matrix element acts **just like a variable**.



Typing "`A(1,1)`" at the command line, will result in 4
Typing "`A(2,2)`" at the command line, will result in 7
Typing "`A(3,3)`" at the command line, will result in -10

MATRICES (ARRAYS)

- **Rules**:
  - Each matrix element acts like a variable and so can be used like variables

Matrix A:

(ROW, COLUMN)

A(1,1)	A(1,2)	A(1,3)
A(2,1)	A(2,2)	A(2,3)
A(3,1)	A(3,2)	A(3,3)

(ACTUAL VALUES)

4	2	0
13	7	12
1	3	-10

Examples:

```
varX  =  A(1,1) + A(1,2)   (so, varX = 4 + 2)
varX  =  A(2,2) * A(1,2)   (so, varX = 7 * 2)
varX  =  A(3,1) - A(2,3)   (so, varX = 1 - 12)
varX  =  A(1,2) ^ A(3,2)   (so, varX = 2^3 )
```

MATRICES (ARRAYS)

• As a result, you can assign values to specific matrix elements, too:

Matrix A:

(ROW, COLUMN)		
A(1,1)	A(1,2)	A(1,3)
A(2,1)	A(2,2)	A(2,3)
A(3,1)	A(3,2)	A(3,3)

(NEW VALUES)		
100	2	0
13	200	12
1	3	300

Examples:

```
A(1,1) =  100;
A(2,2) =  200;
A(3,3) =  300;
```

Review: Array and Matrix

Questions:

(1) For array A=[3,4,5,7,10], what is A(4)?

(2) For the following matrix A

2	8	10
9	1	3
6	20	5
14	7	6

(a) How many rows and columns in this matrix?
(b) What is A (2,3)?
(c) What is A (3,2)?

MATRICES (ARRAYS)

- Matrices can be different dimensions.

Here's a 1-D matrix (called a "row vector"):

(ROW, COLUMN)

Matrix B:	B(1,1)	B(1,2)	B(1,3)	B(1,4)	B(1,5)

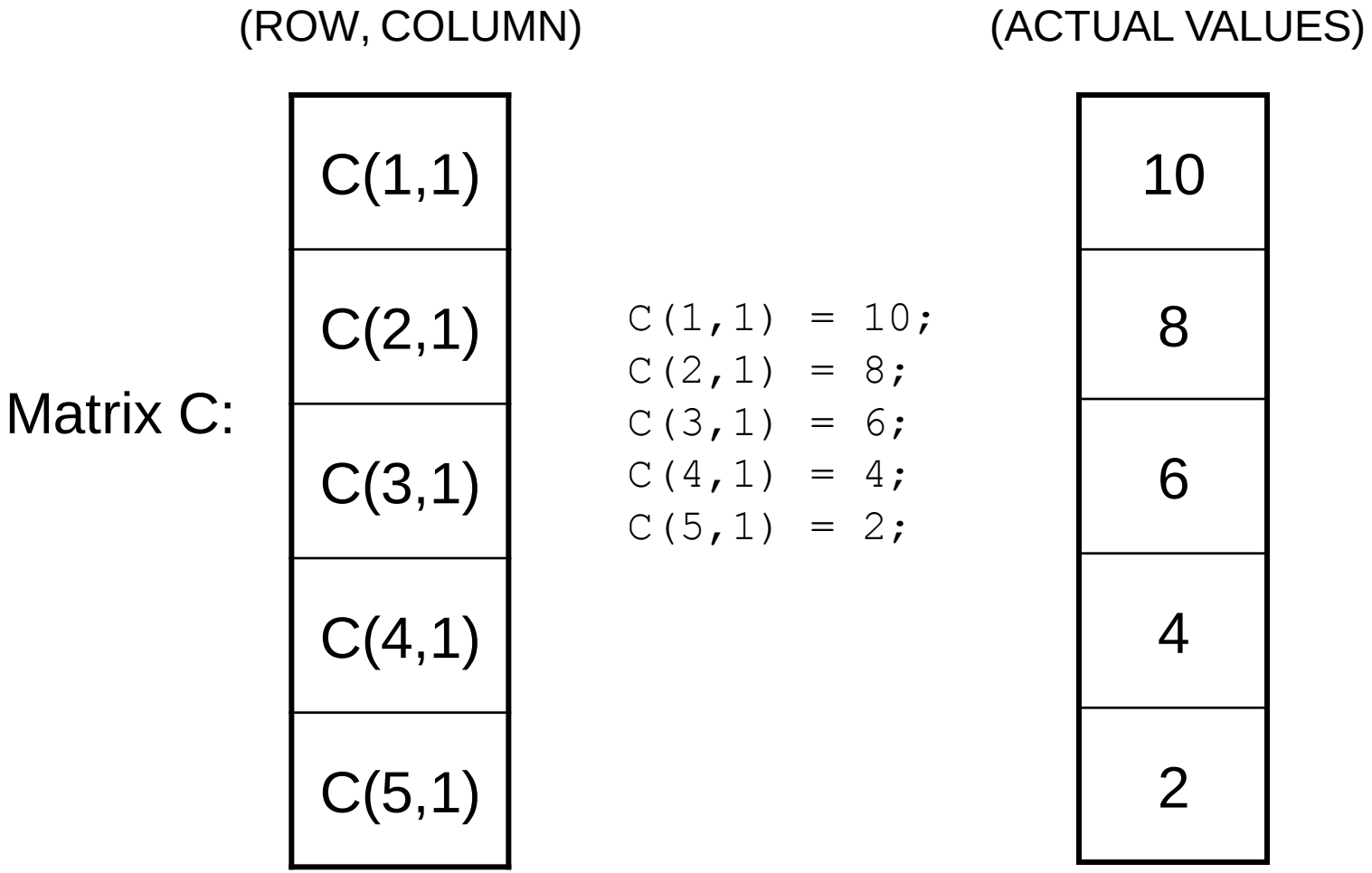
```
B(1,1) = 10;
B(1,2) = 8;
B(1,3) = 6;
B(1,4) = 4;
B(1,5) = 2;
```

(ACTUAL VALUES)

Matrix B:	10	8	6	4	2

MATRICES (ARRAYS)

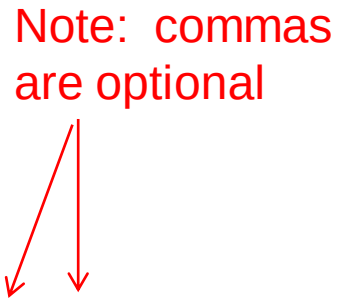
- Another 1-dimensional matrix (called a "column vector"):



MATRICES (ARRAYS)

- **Creating matrices in Matlab (cont)**:
  - **Method #1**: Write it out explicitly (separate rows with a semi-colon):

```
>> D = [1; 2; 3]

D =
        1
        2
        3

>> D = [1, 2, 3; 4, 5, 6; 7, 8, 9]

D =

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



MATRICES (ARRAYS)

- **Creating matrices in Matlab**:
  - **Method #2**: Like variable assignment:
  - Assign the last element in a 1-D matrix, or the "lower right corner element" in a 2-D matrix to be some value.
  - Now you have a matrix filled with zeros and whatever you assigned to the last element:

```
>> D(1,5) = 0

 D =  0     0     0     0     0

 >> D(3,3) = 10

D =   0     0     0
      0     0     0
      0     0    10
```

MATRICES (ARRAYS)

- **Creating matrices in Matlab (cont)**:
  - **Method #2**: Keep assigning pieces to it:

```
>> D(1,1) = 5   ;assigning value to D(1,1)

>> D(1,2) = 6   ;assigning value to D(1,2)

.......

>> D(2,3) = 7   ;assigning value to D(2,3)
```

MATRICES (ARRAYS)

Method #2, while computationally expensive inside Matlab, is nevertheless perfectly suited for inclusion inside a *FOR loop* – particularly when you do not know the exact number of iterations that will be done (and thus, you don't know the exact size of the matrix involved).

FOR loops describe the second topic we will investigate: *ITERATION*.

SOME BASIC MATRIX OPERATIONS

Some of Matlab's built-in (intrinsic) functions work the way we would expect, on an element-by-element basis for an input matrix (here called "A"):

cosine:

```
>> cos(A)
```

returns cosine of each element of A

sqrt

```
>> sqrt(A)
```

returns the sqrt of each element of A

base 10 log:

```
>> log10(A)
```

returns base 10 logarithm of each element of A

sine:

```
>> sin(A)
```

returns sine of each element of A

natural log:

```
>> log(A)
```

returns the natural logarithm of each element of A

Multiplication by a number (scalar):

```
>> A*5
```

returns matrix A with each element multiplied by 5.

BASIC MATRIX OPERATIONS (cont)

Some arithmetic operators also operate this way, and in particular, if give two matrix arguments “A” and “B”, these operators compute on an element-by-element basis:

+ :

```
>> A + B
```

returns a matrix containing the sum of each element of A and its corresponding element in B.

- :

```
>> A - B
```

returns a matrix containing the difference of each element of A and its corresponding element in B.

BASIC MATRIX OPERATIONS (cont)

BUT Multiplication and division operate differently, when we are dealing with a matrix multiplied by a matrix. In order to do element-by-element multiplication or division, we need to use the "dot" operator:

```
>> A .* B
```

returns a matrix containing the product of each element of A and its corresponding element in B.

```
>> A ./ B
```

returns a matrix containing the result of dividing each element of A by its corresponding element in B.

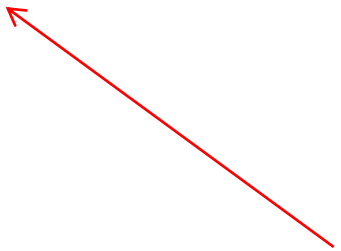
Getting Matlab to "Be Quiet!"

By the way . . .

```
>> D(1,5) = 0

D =   0     0     0     0     0
```

But . . .

```
>> D(1,5) = 0;

>>
```



The appearance of a semi-colon at the end of a statement suppresses output to the screen. Otherwise, Matlab echoes output back to you (rather inconvenient if you have a loop that goes for, say, 1,000 iterations! Loops are up next . . .)

Array and Matrix

Question:

(1) Create a row array with five elements “10,20,30,40,50”

(1) Create a column array with five elements “10,20,30,40,50”

Array and Matrix

Answer:

```
>> A=[10,20,30,40,50]  ;row array

>>A=[10;20;30;40;50]   ;column array
```

Array and Matrix

Question:

(1) Create a 3 X 3 matrix A with the following elements

1	2	3
4	5	6
7	8	9

(2) Create a matrix B, and B=A*10

(3) Calculate A+B, A-B, A multiply B (element by element), A divide B (element by element)

Array and Matrix

Answer:

```
>>A=[1,2,3;4,5,6;7,8,9]  %explicit method

>> A(3,3) = 0                % element assignment method
>> A(1,1)=0
>> A(1,2)=1
>> A(1,3)=3
>>A(2,1)=4
>>A(2,2)=5
>>A(2,3)=6
>>A(3,1)=7
>>A(3,2)=8
>>A(3,3)=9
```

Array and Matrix

Answer (continued):

```
>> B=A*10

>> A+B

>>A-B

>>A.*B  %comment: use “.”operator, different from
     A*B

>>A./B  %comment: use “.”operator
```

Array and Matrix

Question:

Create a 11 X 11 matrix A with all elements equal 50?
Then change the value at the center to 100?

Array and Matrix

Answer:

```
>> A(11,11)=0 %create an 11 X 11 matrix with all
      elements equal to 0

>>A=A+10       % all elements in A are added by 10

>>A(6,6)=100  %element A(6,6) is assigned to 100
```

CHAPTER 6

ITERATION I: FOR LOOPS

ITERATION

• Often times, we'll want to repeat doing something again, and again, and again, and again…maybe millions of times…or maybe, just enough times to access and change each element of a matrix.

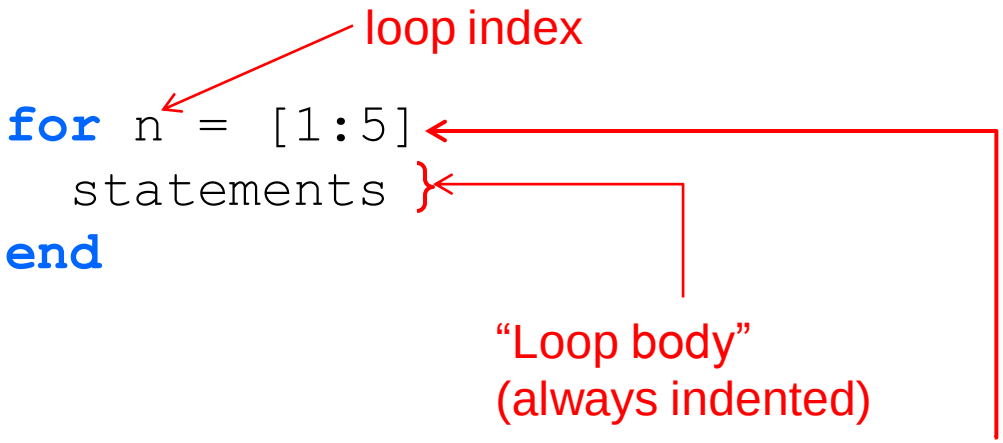
• Computers, of course, are great at doing things over and over again

• This is called *ITERATION*.

• Iteration is executed with a *FOR loop,* or, with a *WHILE loop.*

ITERATION (FOR loops)

• **Syntax**: ***As shown, and always the same***. **NOTE**: The keywords FOR and END come in a pair—***never one without the other***.



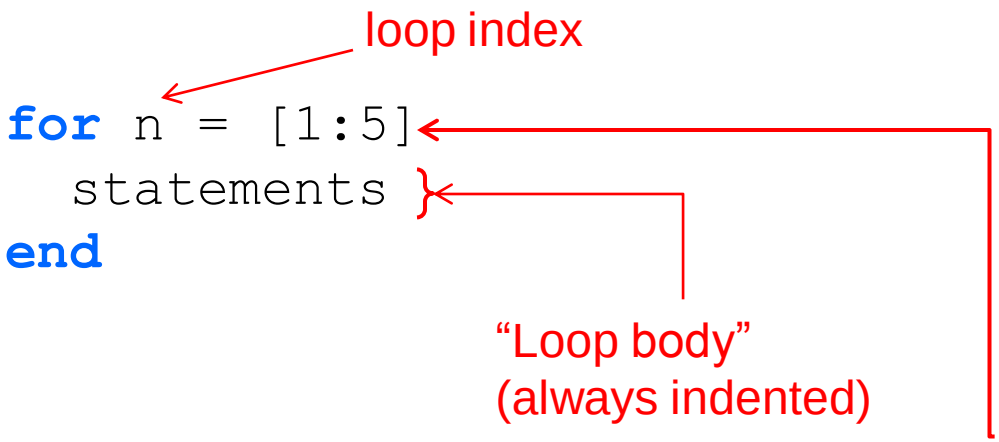
•**What's happening**:

- n first assigned the value 1
- the statements are then executed
- END is encountered
- END sends execution back to the top
- Repeat: n = 2, 3, 4, 5
- Is n at the end of the list? Then STOP.

SIDE NOTE:
n = [1:5]
same as
n = [1,2,3,4,5],
same as
n = 1:5

ITERATION (FOR loops)

• **Syntax**: ***As shown, and always the same***. **NOTE**: The keywords FOR and END come in a pair—***never one without the other***.



• **Key Features**:
  - The FOR loop executes for a finite number of steps and then quits.
  - Because of this feature, it's hard to have an infinite loop with a FOR loop.
  - You can NEVER change a FOR loop's index counter (here, called "n").

SIDE NOTE:
n = [1:5]
same as
n = [1,2,3,4,5],
same as
n = 1:5
Can be **any** values, not limited to 1-5!

ITERATION (FOR loops)

• So, a FOR loop is doing "implicit assignment" to the loop index n: each time "through the loop" (or, one "trip"), the loop index n has a particular value (which can't be changed by you, only by the FOR loop). After the trip is complete (when execution reaches END), the loop index is reassigned to the next value in the 1-D matrix, from left to right. When the rightmost (last) value is reached, the FOR loop stops executing.

And then statements AFTER the FOR loop (following the END keyword) are executed -- that is, the FOR loop "exits".

ITERATION (FOR loops) – YOUR TURN!

Instructions:

For the next several examples, please try to work out the answers without running the code in Matlab. This is essential, as it will enable you to develop your "Matlab intuition" and also to visualize the sequence of a computation (thus developing your ability to think algorithmically). Furthermore, you will not be allowed to use Matlab software on exams or quizzes and so it's better to get the practice now rather than wait until later! You may, however, use scratch paper to work out answers.

ITERATION (FOR loops) – YOUR TURN!

Example 10:

```
for  n = [1:5]
     n
end
```

This will print out the value of n, for each iteration of the loop. Why? Because the statement `n` is NOT terminated with a semi-colon:

```
ans =  1
ans =  2
ans =  3
ans =  4
ans =  5
```

ITERATION (FOR loops) – YOUR TURN!

Example 11:

```
for  n = [1:5]
     n^2
end
```

This FOR loop will print out:

```
ans =  1
ans =  4
ans =  9
ans =  16
ans =  25
```

ITERATION (FOR loops) – YOUR TURN!

Example 12:

```
for  n = [1:5]
     n^3 - 5
end
```

What will this FOR loop print out?

```
ans =  ?
ans =  ?
ans =  ?
ans =  ?
ans =  ?
```

ITERATION (FOR loops) – YOUR TURN!

Example 12:

```
for  n = [1:5]
     n^3 - 5
end
```

What will this FOR loop print out?

```
ans =  -4
ans =  3
ans =  22
ans =  59
ans =  120
```

ITERATION (FOR loops) – YOUR TURN!

Example 13:

```
counter = 1;
for  n = [1:5]
    counter = counter + n
end
```

What will this FOR loop print out?

```
counter =  ?
counter =  ?
counter =  ?
counter =  ?
counter =  ?
```

Why, all of a sudden, "counter" and NOT "ans"?

ITERATION (FOR loops) – YOUR TURN!

Example 13:

```
counter = 1;
for  n = [1:5]
    counter = counter + n
end
```

What will this FOR loop print out?

```
counter =  2
counter =  4
counter =  7
counter =  11
counter =  16
```

Why, all of a sudden, "counter" and NOT "ans"?

ITERATION (FOR loops) – YOUR TURN!

Example 14:

```
counter = 1;
for  n = [1:5]
    counter = counter - n
end
```

What will this FOR loop print out?

```
counter =  ?
counter =  ?
counter =  ?
counter =  ?
counter =  ?
```

ITERATION (FOR loops) – YOUR TURN!

Example 14:

```
counter = 1;
for  n = [1:5]
    counter = counter - n
end
```

What will this FOR loop print out?

```
counter =  0
counter =  -2
counter =  -5
counter =  -9
counter =  -14
```

ITERATION (FOR loops) – YOUR TURN!

Example 15:

```
counter = 1;
for  n = [1:5]
    counter = counter*n
end
```

What will this FOR loop print out?

```
counter =  ?
counter =  ?
counter =  ?
counter =  ?
counter =  ?
```

ITERATION (FOR loops) – YOUR TURN!

Example 15:

```
counter = 1;
for  n = [1:5]
    counter = counter*n
end
```

What will this FOR loop print out?

```
counter =  1
counter =  2
counter =  6
counter =  24
counter =  120
```

ITERATION (FOR loops) – YOUR TURN!

Example 16:

```
A = [5 4 3 2 1];
for  n = [1:5]
    A(1,n)
end
```

What will this FOR loop print out?

```
ans  =  ?
ans  =  ?
ans  =  ?
ans  =  ?
ans  =  ?
```

ITERATION (FOR loops) – YOUR TURN!

Example 16:

```
A = [5 4 3 2 1];
for  n = [1:5]
     A(1,n)
end
```

What will this FOR loop print out?

```
ans =  5
ans =  4
ans =  3
ans =  2
ans =  1
```

ITERATION (FOR loops) – YOUR TURN!

Example 17:

```
A = [5 4 3 2 1];
counter = 0;
for  n = [1:5]
     A(1,n)= A(1,n) + counter;
     counter = counter + 1;
end
A
```

What will print out?

```
A  =  ?
```

ITERATION (FOR loops) – YOUR TURN!

Example 17:

```
A = [5 4 3 2 1];
counter = 0;
for  n = [1:5]
     A(1,n)= A(1,n) + counter;
     counter = counter + 1;
end
A
```

What will print out?

```
A =
     5     5     5     5     5
```

ITERATION
(FOR loops with variable indexing, I)

• **Syntax**: In the case of variable indexing, the loop index steps forward by an amount other than 1:

```
for n = [1:2:15]
   statements
end
```

• **Key Features**:

  • In this FOR loop, the index variable `n` first takes on the value 1 and then, each trip through the loop, it is increased by 2, up to the limit 15. What this means is that the index variable `n` takes on the following values: 1, 3, 5, 7, 9, 11, 13, 15

ITERATION
(FOR loops with variable indexing, II)

• **Syntax**: In this second case of variable indexing, the loop index steps ***backward*** by an amount other than 1:

```
for n = [15:-2:1]
  statements
end
```

• **Key Features**:

  • In this second FOR loop, the index variable `n` first takes on the value 15 and then, each trip through the loop, it is ***decreased*** by 2, down to the limit 1. What this means is that the index variable `n` takes on the following values: 15, 13, 11, 9, 7, 5, 3, 1

ITERATION
(FOR loops with variable indexing, III)

• **Syntax**: In this third case of variable indexing, the loop index steps ***forward,*** but by an amount ***less than*** 1:

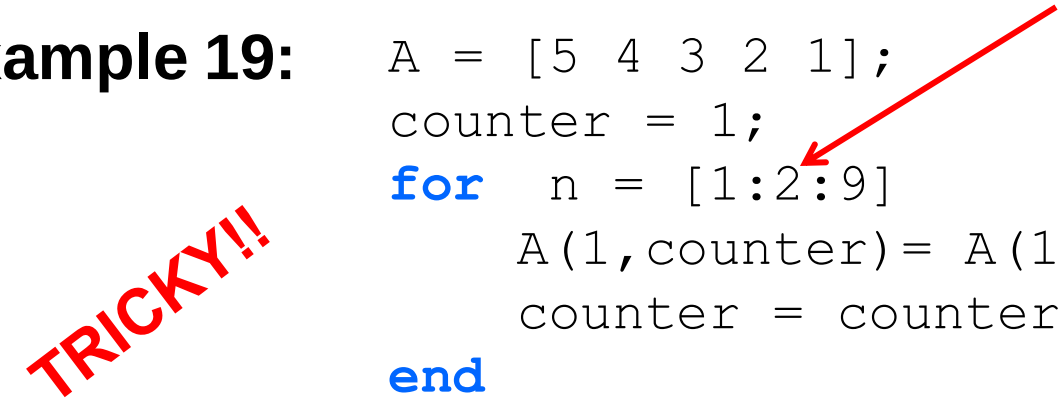
```
for n = [0.1: 0.1 : 1.0]
  statements
end
```

• **Key Features**:
In this third FOR loop, the index variable `n` first takes on the value 0.1 and then, each trip through the loop, it is ***increased*** by 0.1, up to the limit 1.0. What this means is that the index variable `n` takes on the following values: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 . Thus, the index variable `n` need not be assigned integer values! Furthermore, we could do the above in reverse, too, as follows: `n = [1.0: -0.1 : 0.1]`

ITERATION
(FOR loops; variable indexing)—YOUR TURN

Example 19:

```
A = [5 4 3 2 1];
counter = 1;
for  n = [1:2:9]
    A(1,counter)= A(1,counter) + n;
    counter = counter + 1;
end
A
```



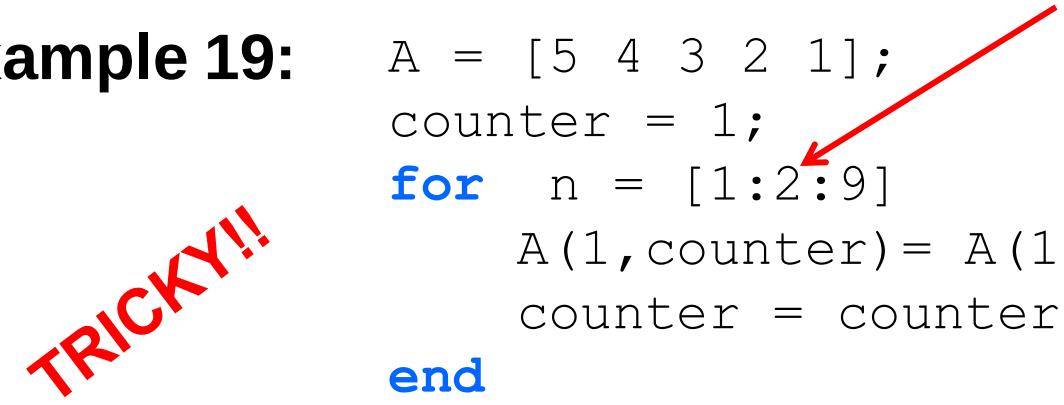
What will print out?

A = ?

ITERATION
(FOR loops; variable indexing)—YOUR TURN

Example 19:

```
A = [5 4 3 2 1];
counter = 1;
for  n = [1:2:9]
    A(1,counter)= A(1,counter) + n;
    counter = counter + 1;
end
A
```



What will print out?

```
A =
     6     7     8     9    10
```

ITERATION (FOR loops)

Study the preceding discussions and example problems **VERY CAREFULLY** to ensure that you understand completely what each FOR loop is doing, AND WHY!

These problems are VERY REPRESENTATIVE of those you might encounter in the future . . .

CHAPTER 7

Write a Matlab Program

Matlab Tutorial Video

1. Online demo video - Writing a Matlab Program (05:43)
   - http://www.mathworks.com/videos/matlab/writing-a-matlab-program.html

Links are also available at class website resource page:
http://solar.gmu.edu/teaching/2011_CDS130/Resources.html

Write a Matlab program

Exercise: create a Matlab program file named as "prey.m" with the following codes. Make sure that you save the file and run the code without an error.

```
clear
R(1)=100.0   %initial population of rabbits
F(1)=20.0    %initial population of foxs
BR_rabbit=0.5     %birth rate of rabbit
DR_rabbit_INT=0.02   %death date of rabbit (prey) due to interaction
DR_fox=0.1     %death rate of fox
BR_fox_INT= 0.001 % birth rate of fox (predator) due to interaction

for i=1:40
  R(i+1)=R(i)+BR_rabbit*R(i)-DR_rabbit_INT*R(i)*F(i)
  F(i+1)=F(i)-DR_fox*F(i)+BR_fox_INT*F(i)*R(i)
end

figure(1); plot(R,'*')
figure(2); plot(F,'-')
```

CHAPTER 8

BASIC GRAPHS AND PLOTS

Sample

scientific model:

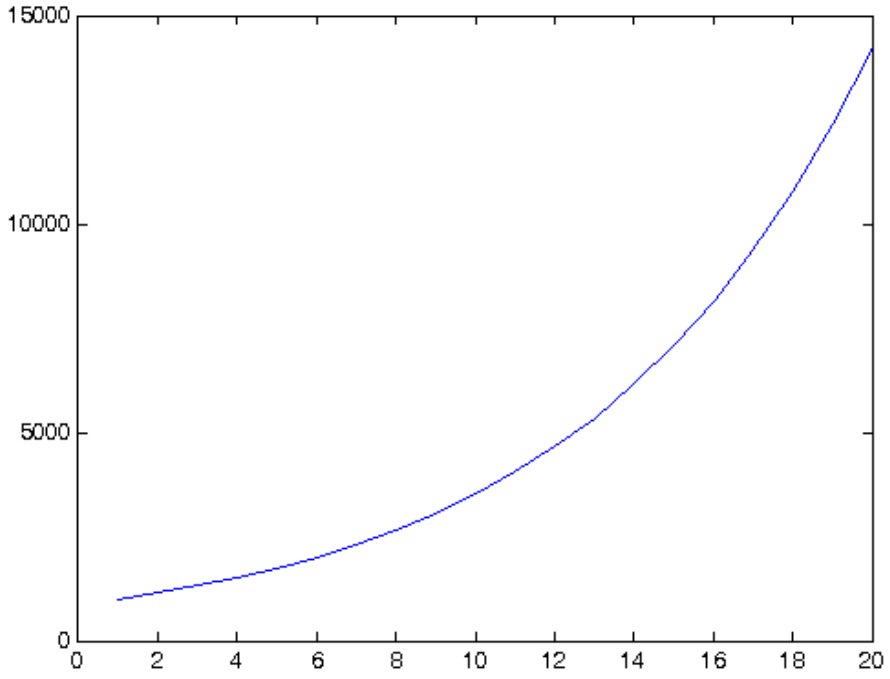
Every year your bank account balance increases by 15%.
The initial balance in the first year is $1000.
What are the balances in 20 years?

```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
B
```

BASIC GRAPHS and PLOTS

Let's begin by creating the graph on the right with the Matlab code on the left . . .

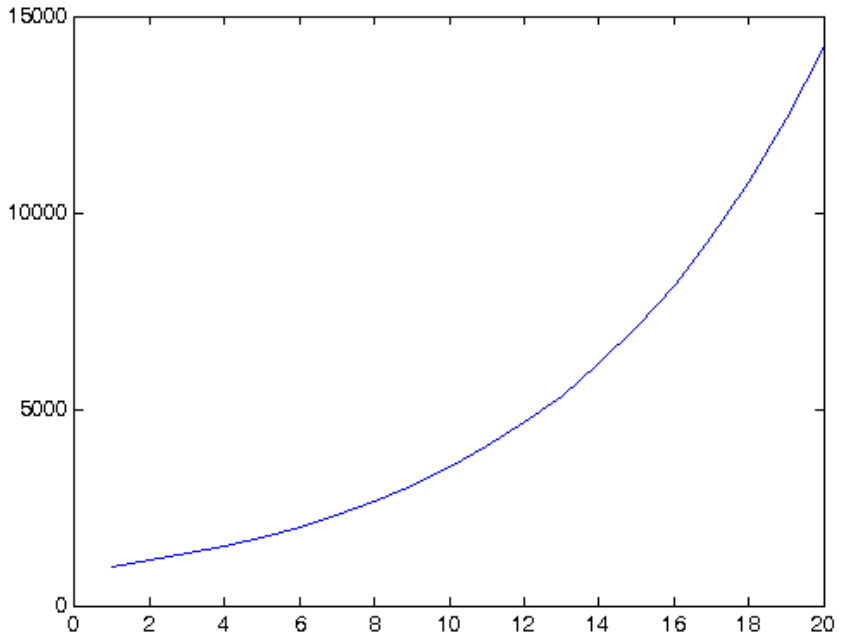
```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
plot(B)
```



BASIC GRAPHS and PLOTS

First, give the graph a name (internal to Matlab) by using the **figure** command:

```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
figure(1)
plot(B)
```

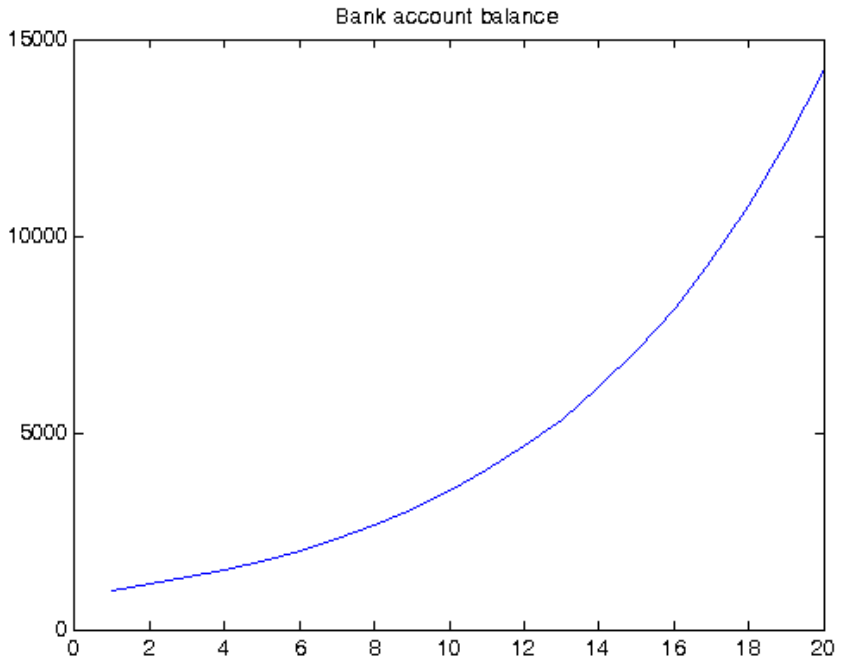


When you re-run this code, there's no visible effect, but the plot now has a name (meaning it won't be overwritten later!)

BASIC GRAPHS and PLOTS

Next, give the graph a title
by using the **title** command:

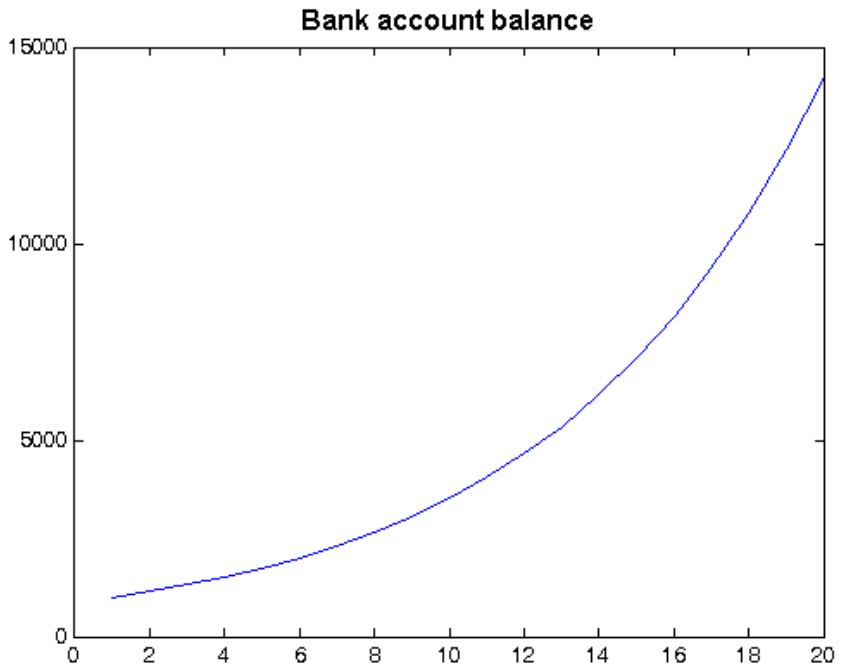
```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
figure(1)
plot(B)
title('Bank account balance')
```



BASIC GRAPHS and PLOTS

Change the title's font: continue on next line and use the **FontName, FontSize** and **FontWeight** commands:

```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
figure(1)
plot(B)
title('Bank account balance', ...
   'FontName', 'Arial', ...
   'FontSize', 12, ...
   'FontWeight', 'Bold')
```

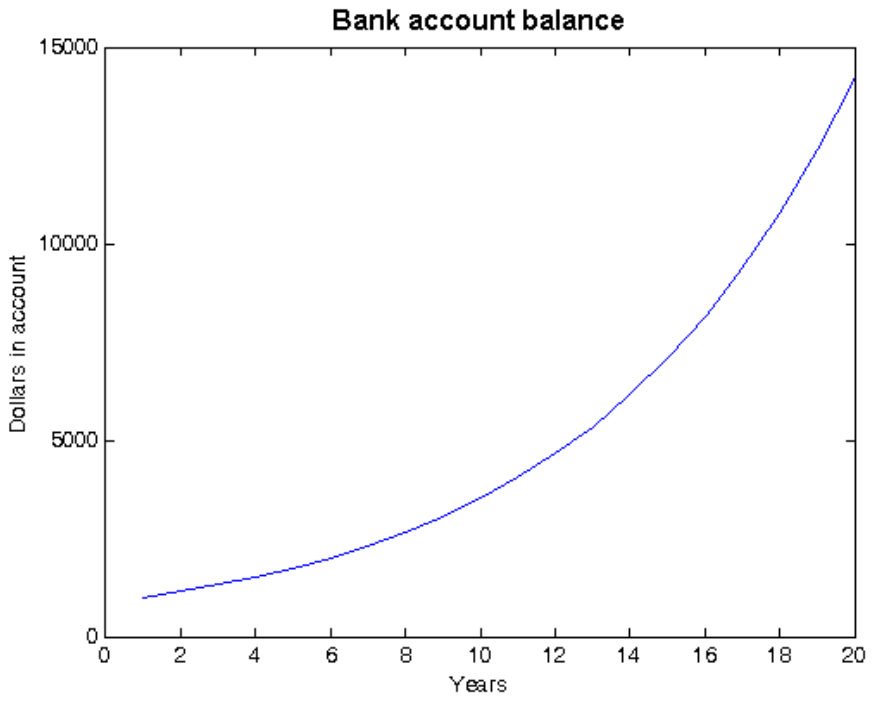


Continue on the next line with three dots in a row

BASIC GRAPHS and PLOTS

Add X and Y axis labels:
use the **xlabel** and **ylabel** commands:

```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
figure(1)
plot(B)
title('Bank account balance', ...
   'FontName', 'Arial', ...
   'FontSize', 12, ...
   'FontWeight', 'Bold')
xlabel('Years')
ylabel('Dollars in account')
```

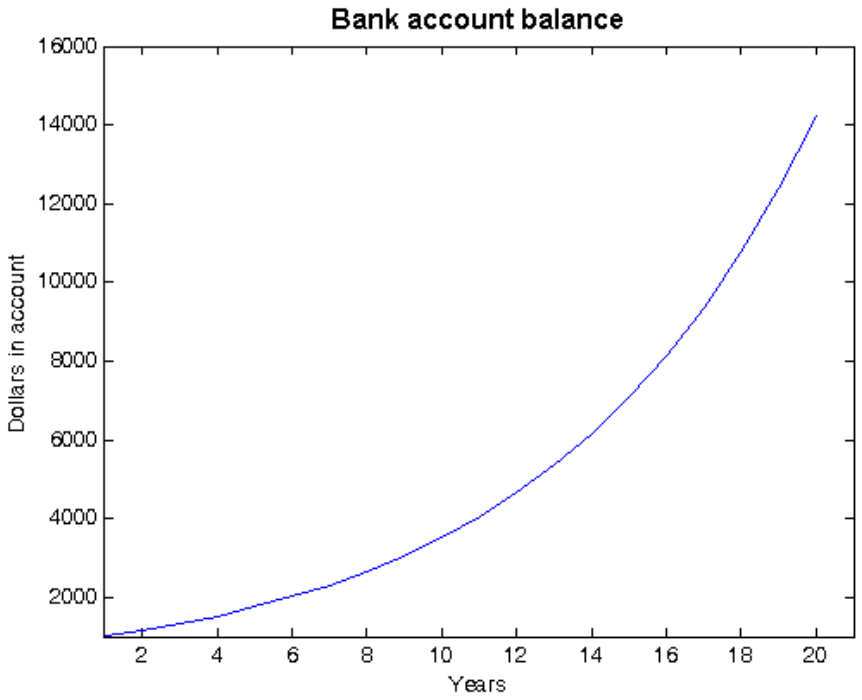


You can also change X and Y axis fonts, sizes, etc, just like for the title

BASIC GRAPHS and PLOTS

Change X and Y axis ranges:
use the **xlim** and **ylim** commands:

```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
figure(1)
plot(B)
title('Bank account balance', ...
   'FontName', 'Arial', ...
   'FontSize', 12, ...
   'FontWeight', 'Bold')
xlabel('Years')
ylabel('Dollars in account')
xlim([1 21])
ylim([1000 16000])
```

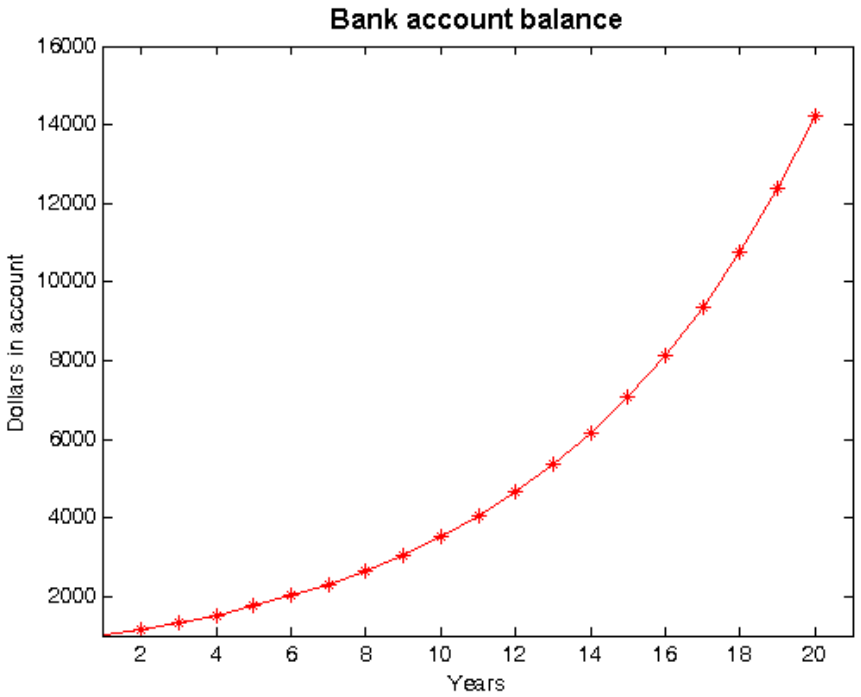


BASIC GRAPHS and PLOTS

Now, change the plot:

Let it have a red line and * datamarkers:

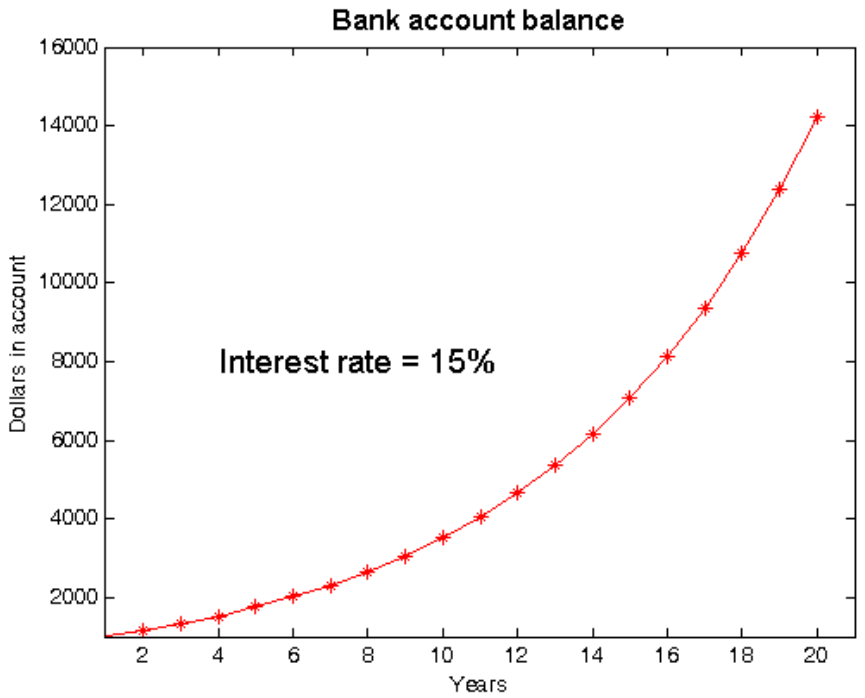
```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
figure(1)
plot(B,'-*r')
title('Bank account balance', ...
   'FontName', 'Arial', ...
   'FontSize', 12, ...
   'FontWeight', 'Bold')
xlabel('Years')
ylabel('Dollars in account')
xlim([1 21])
ylim([1000 16000])
```



BASIC GRAPHS and PLOTS

Finally, insert some text annotation on the graph using the **text** command, and control its properties:

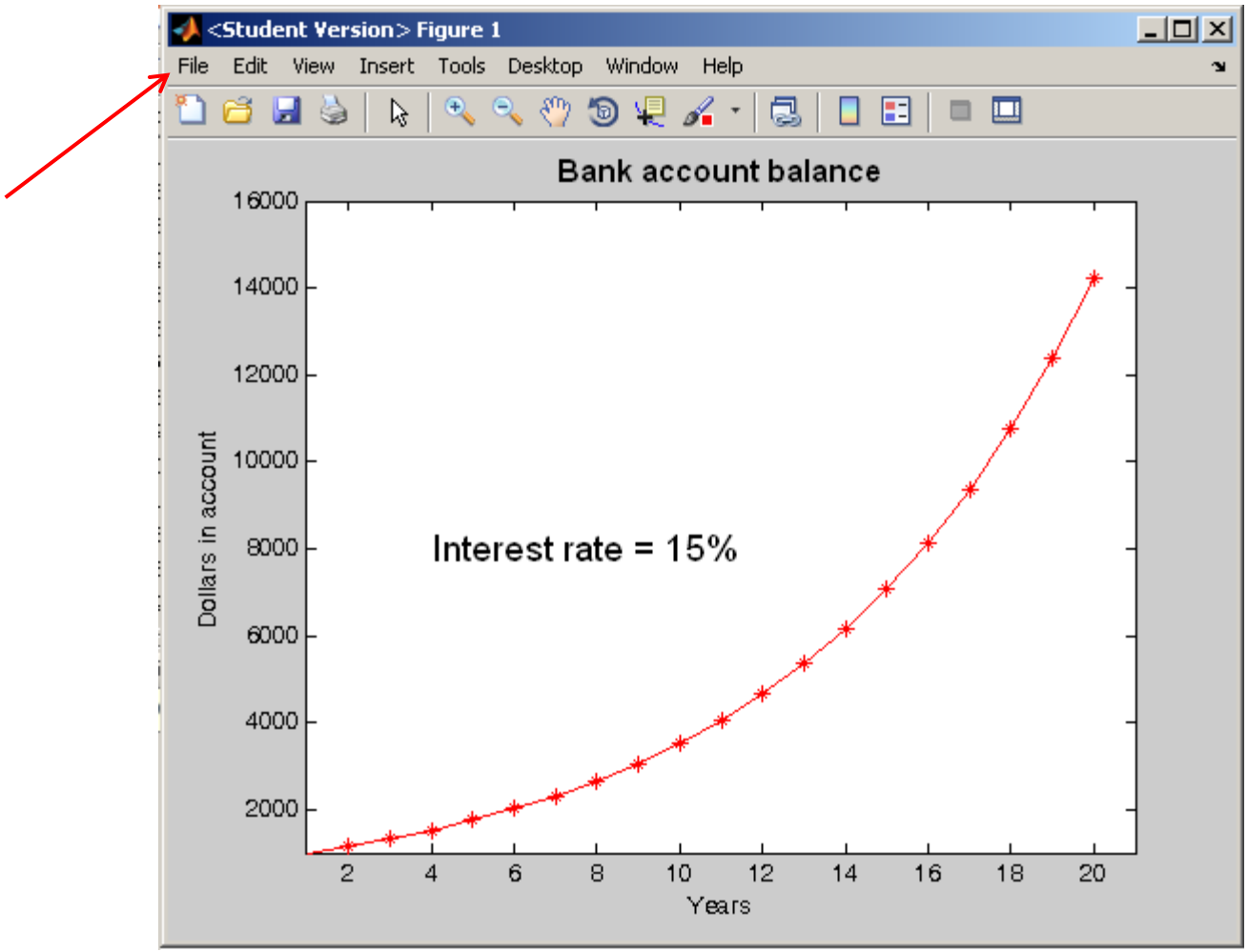
```
clear
B(1)=1000;
rate = 0.15;
for i = [1:19]
   B(i+1) = B(i)+rate*B(i);
end
figure(1)
plot(B,'-*r')
title('Bank account balance',
...
   'FontName', 'Arial', ...
   'FontSize', 12, ...
   'FontWeight', 'Bold')
xlabel('Years')
ylabel('Dollars in account')
xlim([1 21])
ylim([1000 16000])
text(4,8000,'Rate = 15%', ...
'FontName','Arial', ...
'FontSize',14)
```



Again, font size, weight, etc. can be controlled just like the title command

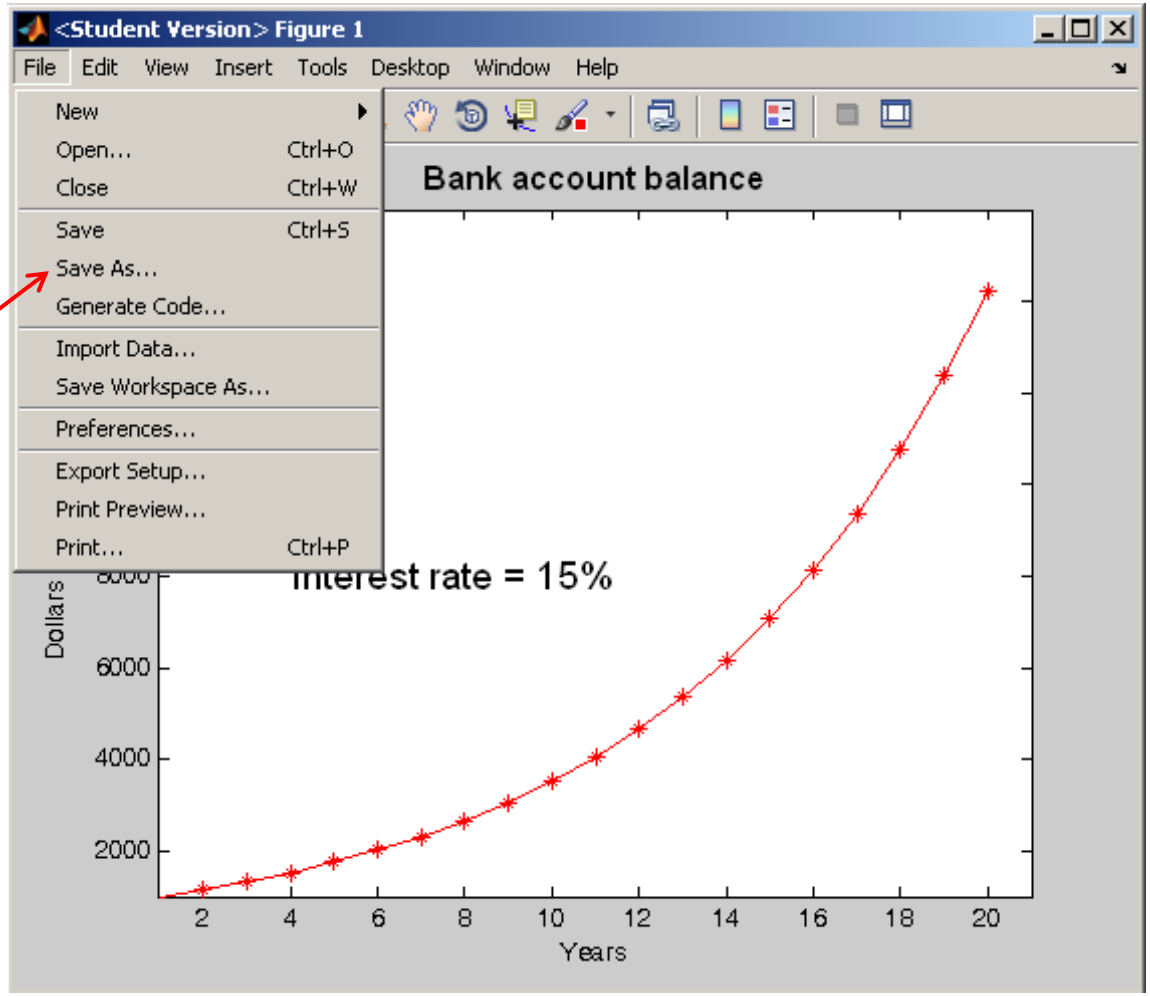
BASIC GRAPHS and PLOTS

Now, switch to the window containing the figure and click on “File”:



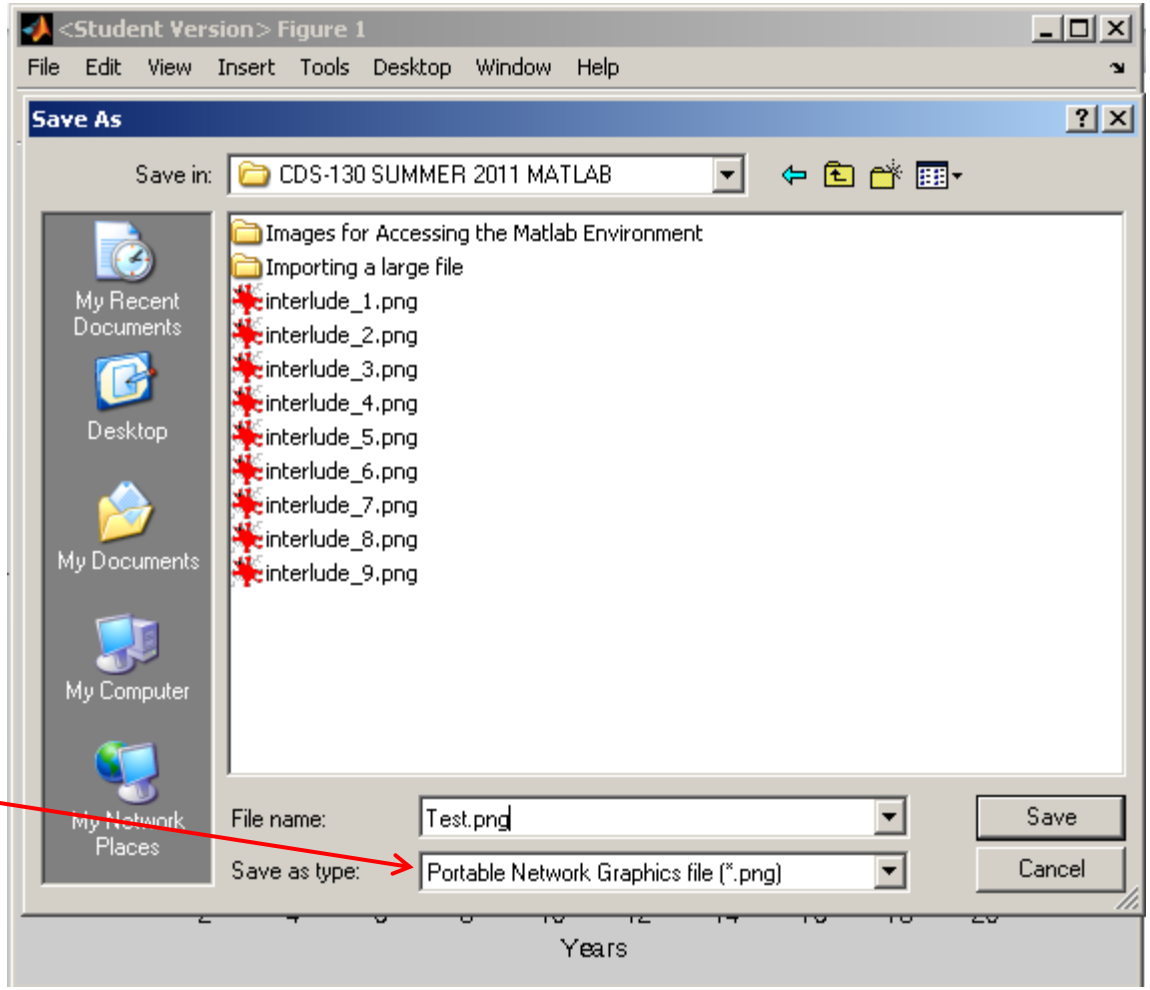
BASIC GRAPHS and PLOTS

Select “Save As”:



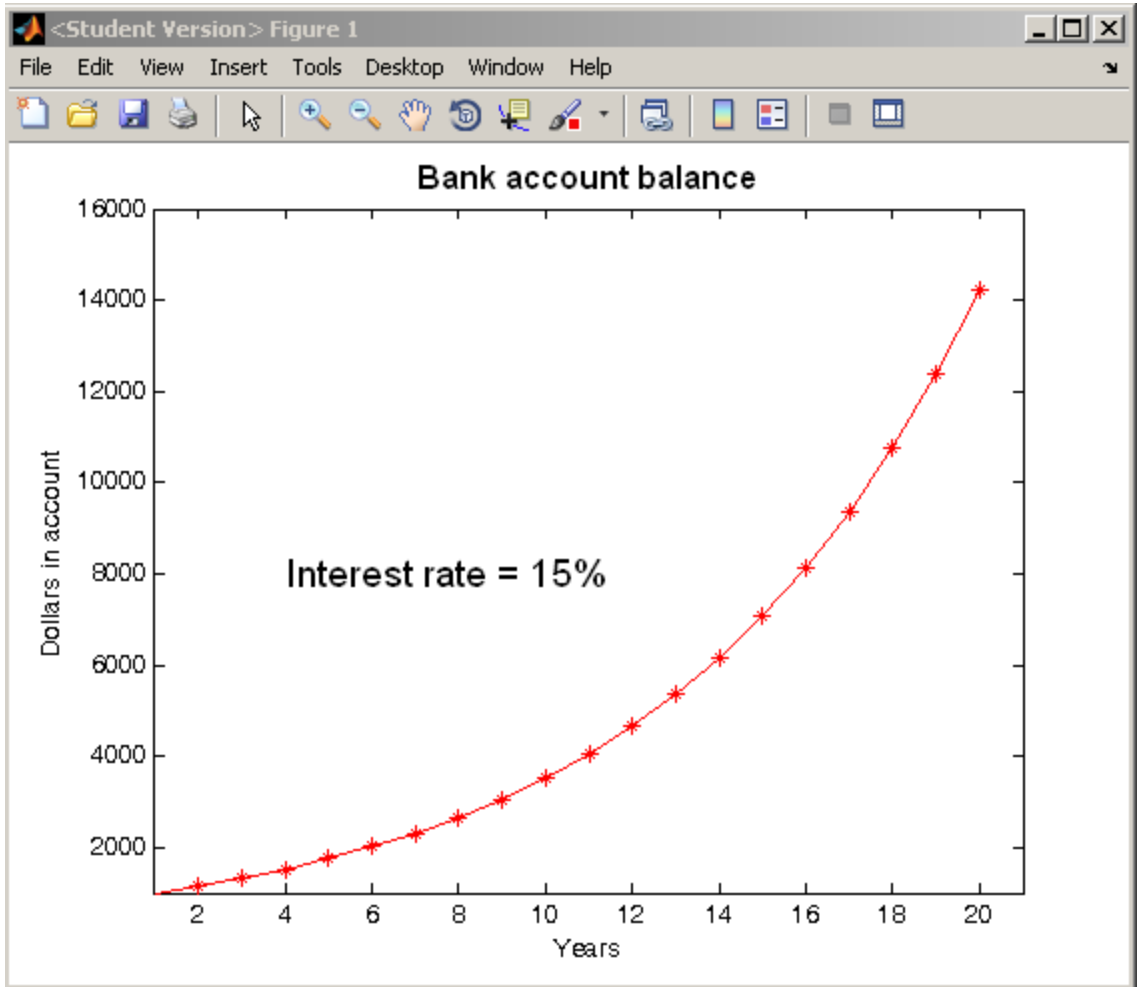
BASIC GRAPHS and PLOTS

Navigate to the directory where you want to save the file, enter a filename, and ensure “Save as Type” is “PNG”:



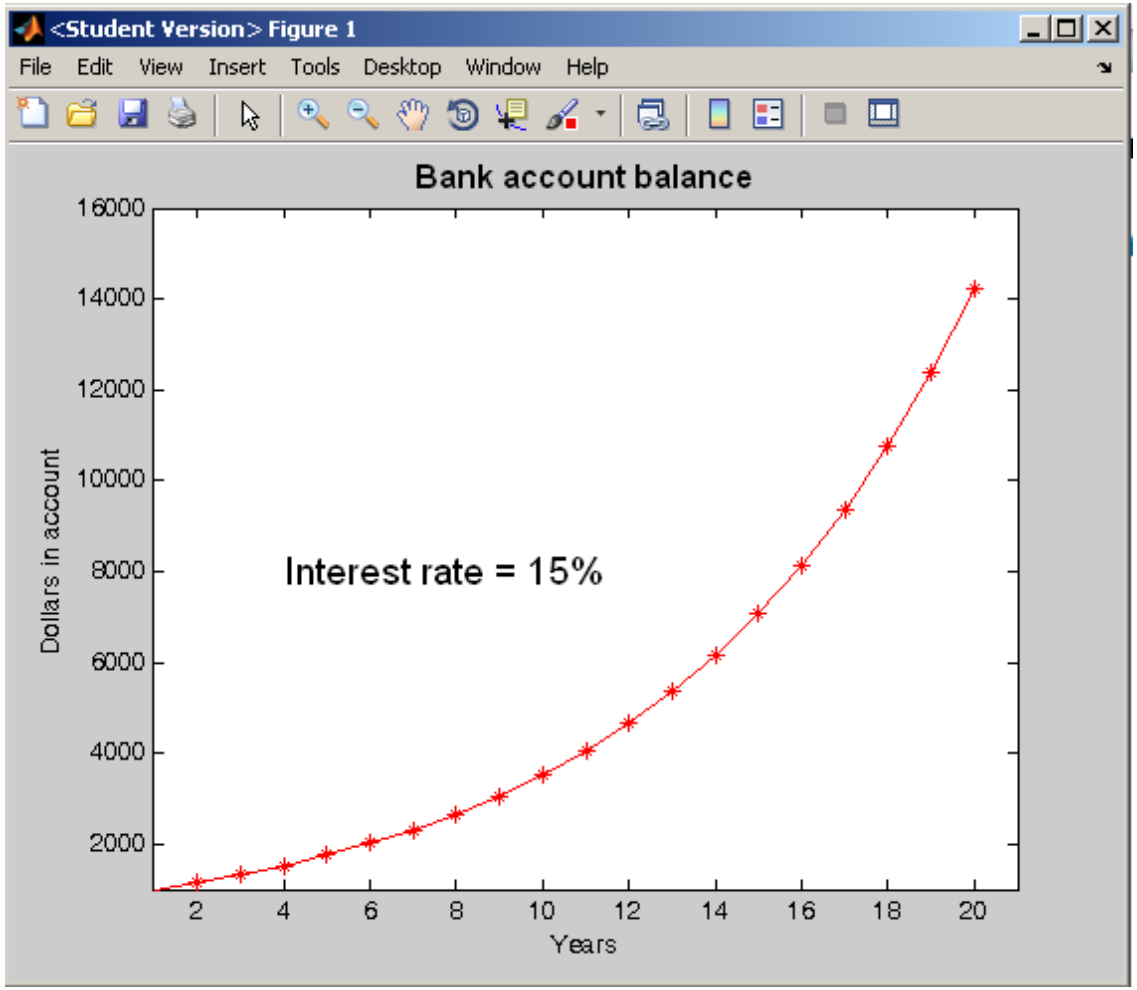
BASIC GRAPHS and PLOTS

You'll be taken back to the figure. It will flash white for an instant:



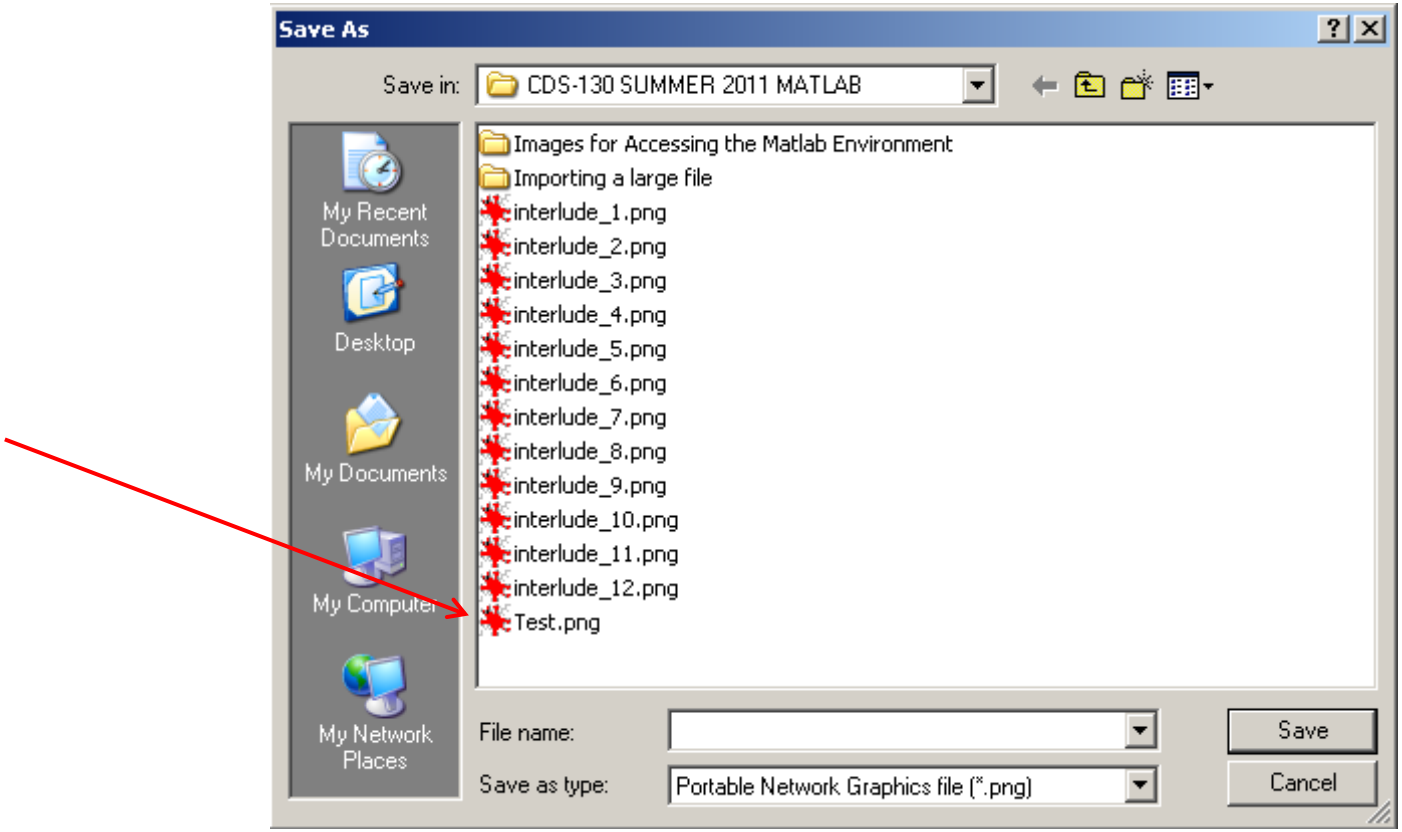
BASIC GRAPHS and PLOTS

And then it will return to its “normal self”, with a grey background. The image has been saved . . .



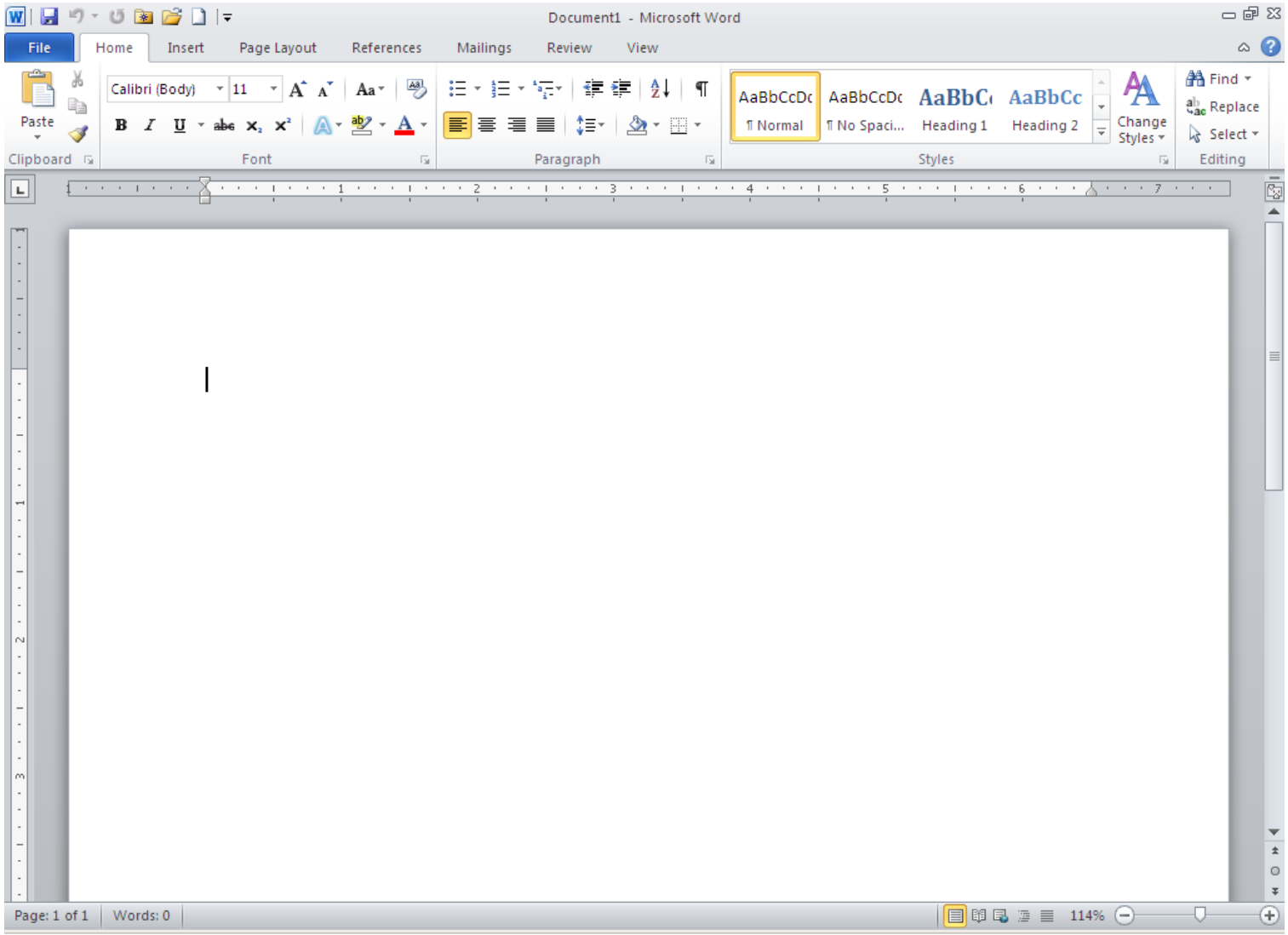
BASIC GRAPHS and PLOTS

Which you can now verify by inspecting the directory structure:



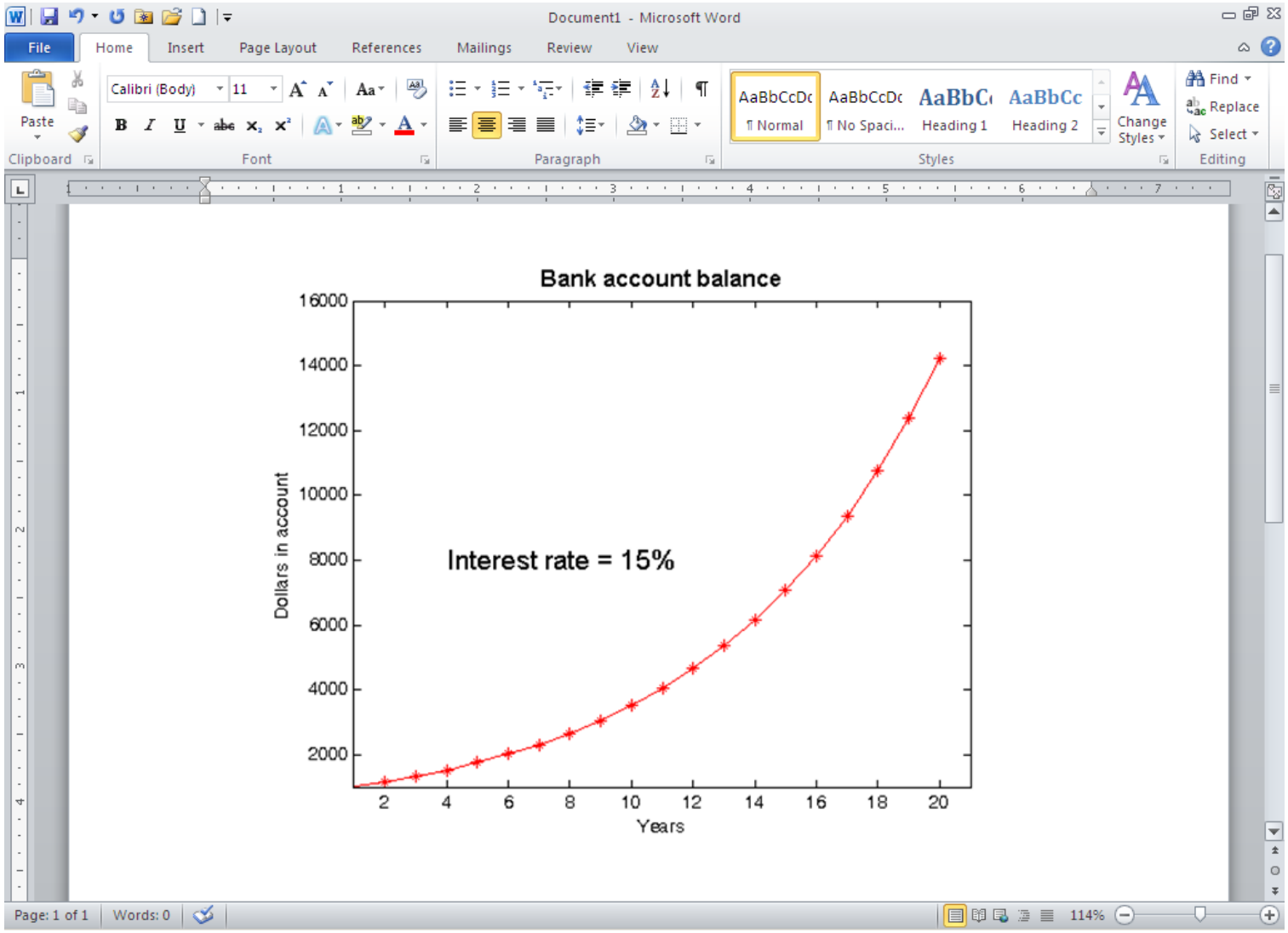
BASIC GRAPHS and PLOTS

Now you can open Microsoft Word:



BASIC GRAPHS and PLOTS

And paste your .PNG graph right onto the page:



CHAPTER 9

ITERATION II: DOUBLE-NESTED FOR LOOPS (DNFL)

ITERATION:
Double Nested FOR Loops (DNFL)

Now we come to a very important syntactic structure, the ***Double Nested FOR Loop*** (aka, “DNFL”)

This is important precisely because double nested FOR loops enable us to “walk through” a two dimensional matrix, element by element.

This is the basis for ***image processing algorithms***.

ITERATION: DNFL

• **Syntax**: ***As shown, and always the same*** (except for the end limit of the indexes `m` and `n`, which could be any number other than 3—and frequently will be!)

```
for m = [1:3]
    for n = [1:3]
        statements
    end
end
```

inner loop

outer loop

ITERATION: DNFL

```
for m = [1:3]
    for n = [1:3]
        statements
    end
end
```

inner loop

outer loop

What's happening:

- `m` is assigned the value 1
- `n` is assigned the value 1
- the `statements` are executed
- the first **`end`** is encountered, sending execution to the top of the inner loop . More to do? If not, then . . .
- the second **`end`** is encountered, sending execution to the top of the outer loop. More to do? If not, then EXIT the outer loop and program execution continues onward, immediately following the second end statement.

ITERATION: DNFL

```
for m = [1:3]
    m
    for n = [1:3]
        n
    end
end
```

inner loop

outer loop

Simple example: When the above code is run, we get the following output . . .

```
m = 1
n = 1
n = 2
n = 3
```

First iteration outer; inner iterates 3 times

```
m = 2
n = 1
n = 2
n = 3
```

Second iteration outer; inner iterates 3 times

```
m = 3
n = 1
n = 2
n = 3
```

Third iteration outer; inner iterates 3 times

ITERATION: DNFL – YOUR TURN!

Instructions:

For the next several examples, please try to work out the answers without running the code in Matlab. This is essential, as it will enable you to develop your "Matlab intuition" and also to visualize the sequence of a computation (thus developing your ability to think algorithmically). Furthermore, you will not be allowed to use Matlab software on exams or quizzes and so it's better to get the practice now rather than wait until later! You may, however, use scratch paper to work out answers.

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 1;
b = 1;
for m = [1:3]
    for n = [1:3]
        a
        b
    end
end
```

What is printed out by the above Double Nested FOR loop?

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 1;
b = 1;
for m = [1:3]
    for n = [1:3]
        a
        b
    end
end
```

What is printed out by the above Double Nested FOR loop?

a = 1
b = 1
(repeated nine times)

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 1;
b = 1;
for m = [1:3]
    for n = [1:3]
        a = a + 1;
        b = b + a
    end
end
```

What is printed out by the above Double Nested FOR loop?
(You can use a calculator)

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 1;
b = 1;
for m = [1:3]
    for n = [1:3]
        a = a + 1;
        b = b + a
    end
end
```

When m = 1	When m = 2	When m = 3
b = 3	b = 15	b = 36
b = 6	b = 21	b = 45
b = 10	b = 28	b = 55

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 1;
b = 1;
for m = [1:3]
    for n = [1:3]
        a = a + b;
        b = b + a
    end
end
```

BIG NUMBERS

What is printed out by the above Double Nested FOR loop?
(You can use a calculator)

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 1;
b = 1;
for m = [1:3]
    for n = [1:3]
        a = a + b;
        b = b + a
    end
end
```

BIG NUMBERS

When m = 1	When m = 2	When m = 3
b = 3	b = 55	b = 987
b = 8	b = 144	b = 2584
b = 21	b = 377	b = 6765

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 2;
b = 3;
for m = [1:3]
    for n = [1:3]
        a = a + b;
        b = b + 1
    end
end
```

TINY BIT TRICKY!!

What is printed out by the above Double Nested FOR loop?
(You can use a calculator—HINT: IF you really, really need one!)

ITERATION: DNFL – YOUR TURN!

Example:

```
a = 2;
b = 3;
for m = [1:3]
    for n = [1:3]
        a = a + b;
        b = b + 1
    end
end
```

TINY BIT TRICKY!!

When m = 1	When m = 2	When m = 3
b = 4	b = 7	b = 10
b = 5	b = 8	b = 11
b = 6	b = 9	b = 12

ITERATION: DNFL – YOUR TURN!

Example:

```
A(3,3) = 0;
for m = [1:3]
    for n = [1:3]
        A(m,n) = m;
    end
end
A
```

What is printed out by the above Double Nested FOR loop?

ITERATION: DNFL – YOUR TURN!

Example:

```
A(3,3) = 0;
for m = [1:3]
    for n = [1:3]
        A(m,n) = m;
    end
end
A
```

```
A =

     1     1     1
     2     2     2
     3     3     3
```

ITERATION: DNFL – YOUR TURN!

Example:

```
A(3,3) = 0;
for m = [1:3]
    for n = [1:3]
        A(m,n) = n;
    end
end
A
```

What is printed out by the above Double Nested FOR loop?

ITERATION: DNFL – YOUR TURN!

Example:

```
A(3,3) = 0;
for m = [1:3]
    for n = [1:3]
        A(m,n) = n;
    end
end
A
```

```
A =

     1     2     3
     1     2     3
     1     2     3
```

ITERATION: DNFL – YOUR TURN!

Example:

```
A = [1, 2, 3; 4, 5, 6; 7, 8, 9];
for m = [1:3]
    for n = [1:3]
        A(m,n) = m - n;
    end
end
A
```

What is printed out by the above Double Nested FOR loop?

ITERATION: DNFL – YOUR TURN!

Example:

```
A = [1, 2, 3; 4, 5, 6; 7, 8, 9];
for m = [1:3]
    for n = [1:3]
        A(m,n) = m - n;
    end
end
A
```

```
A =

     0    -1    -2
     1     0    -1
     2     1     0
```

ITERATION: DNFL – YOUR TURN!

Example:

```
A = [1, 2, 3; 4, 5, 6; 7, 8, 9];
for m = [1:3]
    for n = [1:3]
        A(m,n) = m*n + 1;
    end
end
A
```

What is printed out by the above Double Nested FOR loop?

ITERATION: DNFL – YOUR TURN!

Example:

```
A = [1, 2, 3; 4, 5, 6; 7, 8, 9];
for m = [1:3]
    for n = [1:3]
        A(m,n) = m*n + 1;
    end
end
A
```

```
A =

     2     3     4
     3     5     7
     4     7    10
```

ITERATION: DNFL – YOUR TURN!

Example:

```
A = [1, 2, 3; 4, 5, 6; 7, 8, 9];
B = [1 -2  2; 2 -2 3; 3 -3 4];
C(3,3) = 0;
for m = [1:3]
    for n = [1:3]
        C(m,n) = A(m,n) - B(m,n);
        C(m,n) = C(m,n)*(-1);
    end
end
C
```

What is printed out by the above Double Nested FOR loop?

ITERATION: DNFL – YOUR TURN!

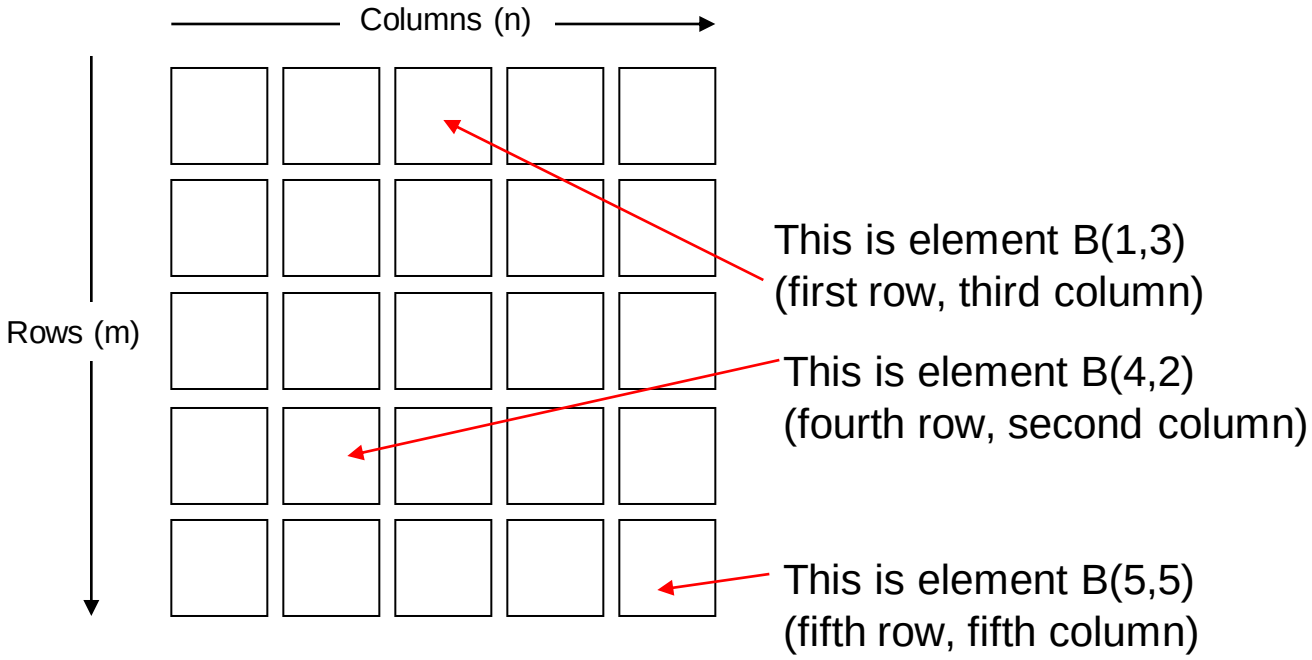
Example:

```
A = [1, 2, 3; 4, 5, 6; 7, 8, 9];
B = [1 -2  2; 2 -2 3; 3 -3 4];
C(3,3) = 0;
for m = [1:3]
    for n = [1:3]
        C(m,n) = A(m,n) - B(m,n);
        C(m,n) = C(m,n)*(-1);
    end
end
C
```

```
C =

     0    -4    -1
    -2    -7    -3
    -4   -11    -5
```

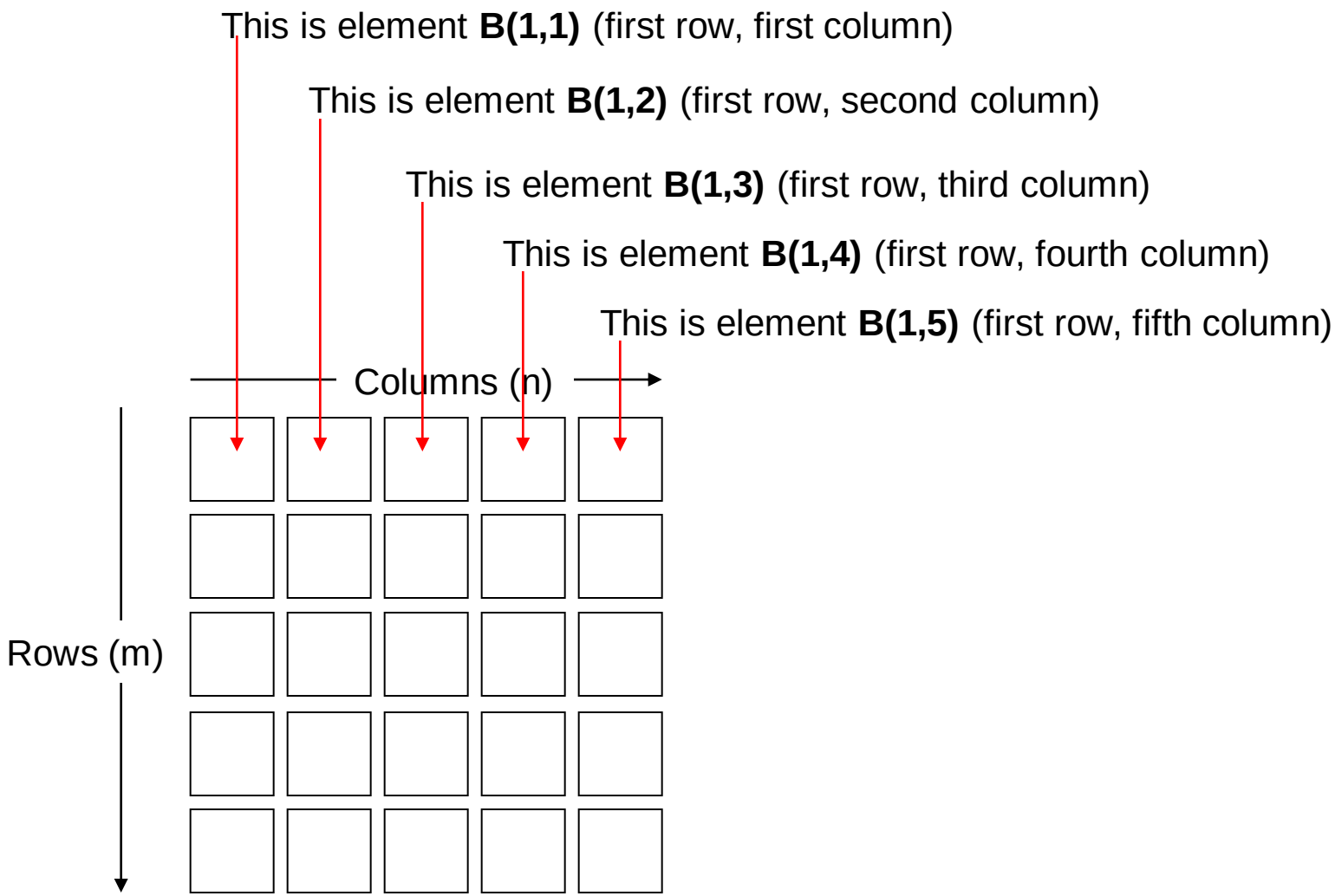
DNFL: Accessing Pieces of a Matrix

A two dimensional array called “B”

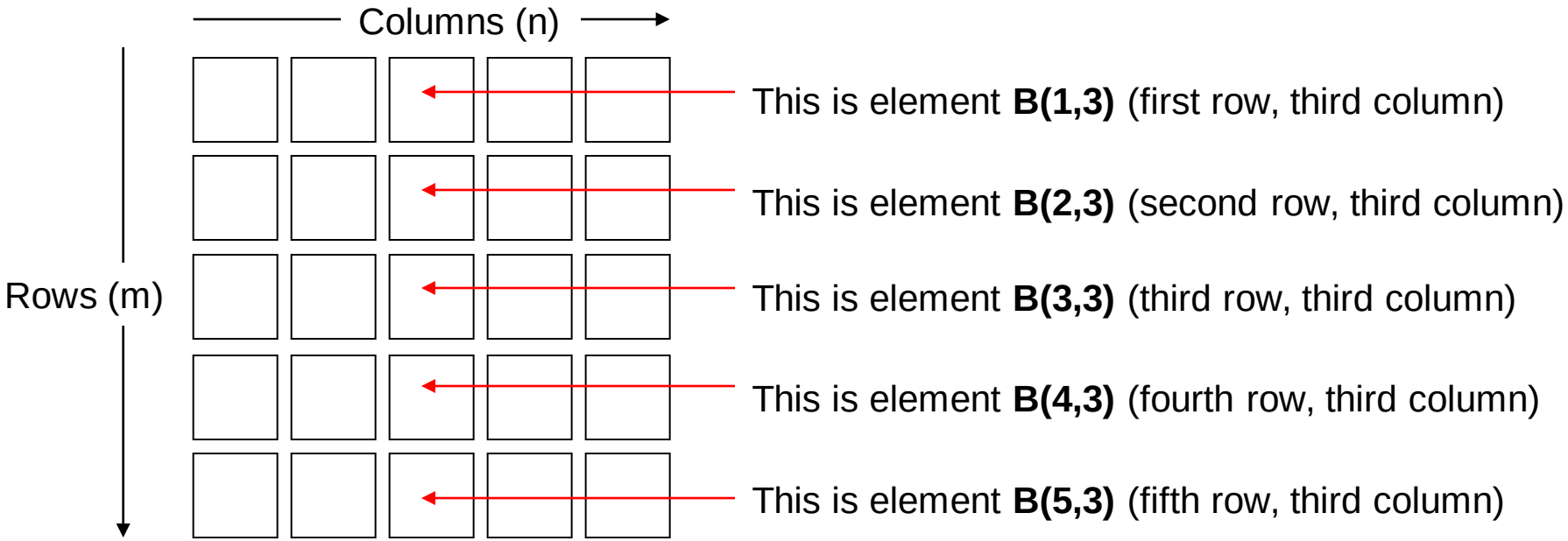


“B” is a 5x5 array: 5 rows by 5 columns

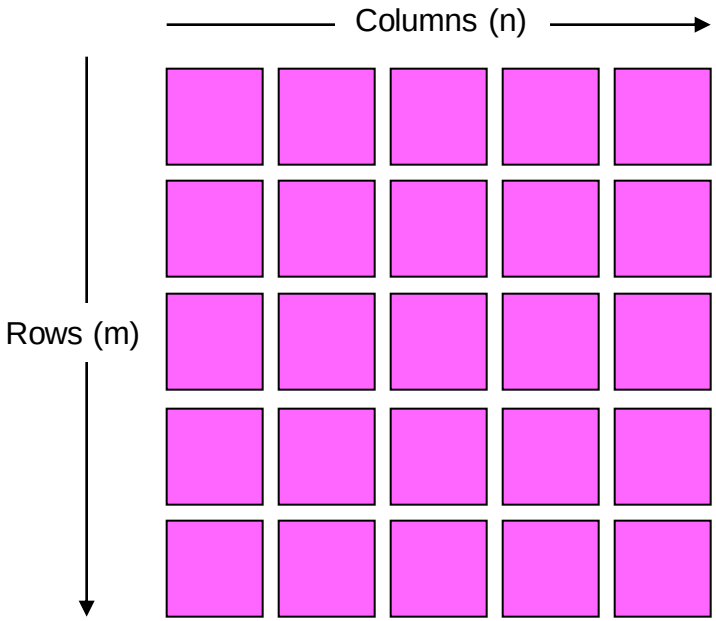
DNFL: Accessing Pieces of a Matrix



DNFL: Accessing Pieces of a Matrix



DNFL: Accessing Pieces of a Matrix

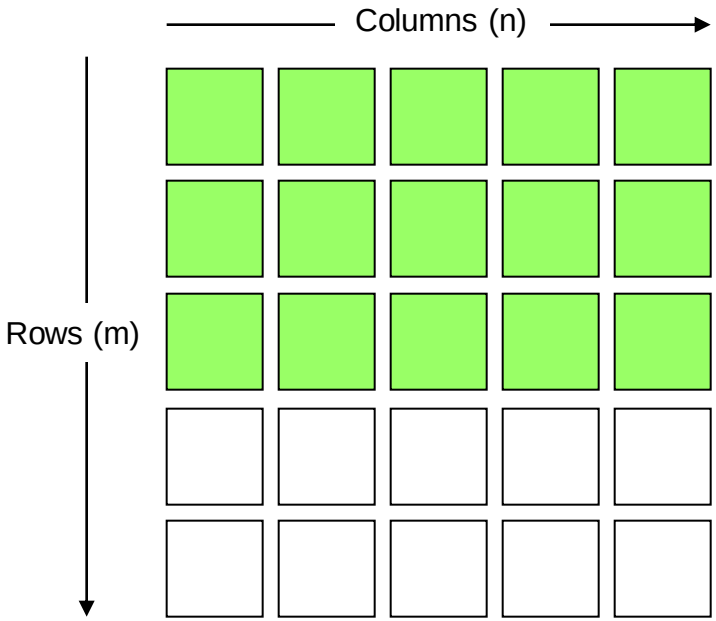


Accessing all the pink colored elements (and in this case, printing them out):

```
for m = 1:5        <-- or, m = [1:5]
    for n = 1:5    <-- or, n = [1:5]
        B(m, n)
    end
end
```

Notice that to access a particular row, we vary the row index m. To access a particular column, we vary the column index, n. In this case, varying m and n each from 1 to 5 will enable us to access ALL ELEMENTS of the ENTIRE ARRAY B (in this case, print them out): We're going down 5 rows and across 5 columns.

DNFL: Accessing Pieces of a Matrix

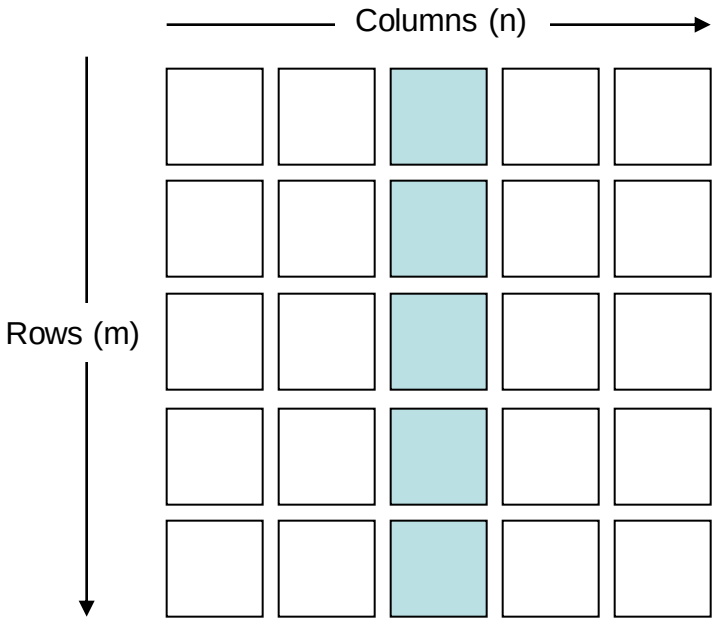


Accessing all the green colored elements (and in this case, printing them out):

```
for m = 1:3        <-- or, m = [1:3]
    for n = 1:5    <-- or, n = [1:5]
        B(m,n)
    end
end
```

Here, to access a particular row, we vary the row index m and to access a particular column, we vary the column index n. In this second case, we vary m from 1 to 3, and n from 1 to 5. Doing so will allow us to access (and in this case print out), all the green colored elements.

DNFL: Accessing Pieces of a Matrix

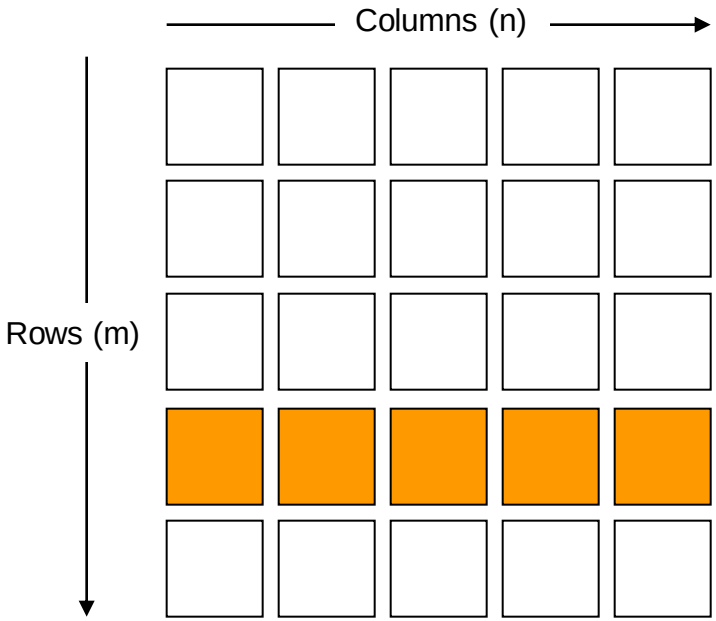


Accessing all the blue colored elements (and in this case, printing them out):

```
for m = 1:5        <-- or, m = [1:5]
    B(m,3)
end
```

In this third case we keep the column index, n, held constant and vary the row index m. Since we vary m and hold n constant, we are able to selectively print out the third column of the array B.

DNFL: Accessing Pieces of a Matrix

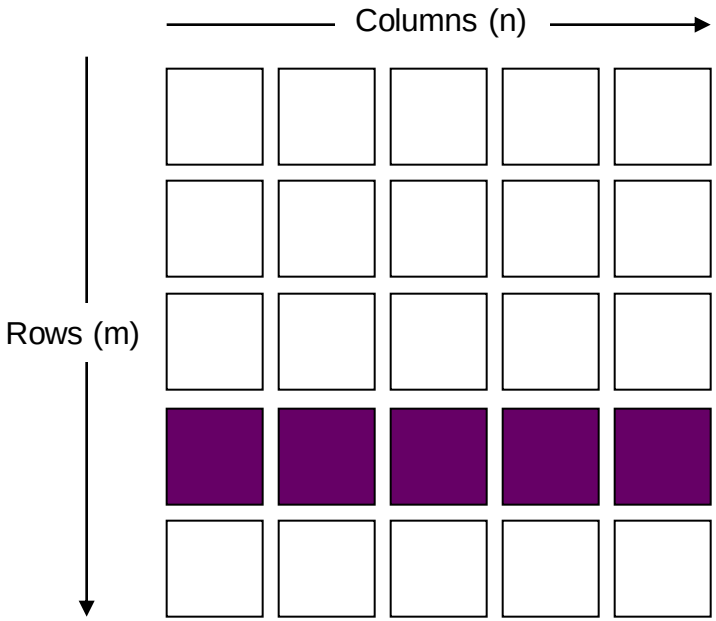


Accessing all the orange colored elements (and in this case, printing them out):

```
for n = 1:5        <-- or, n = [1:5]
    B(4, n)
end
```

Now, we vary the column index n while keeping the row index m held constant. By doing so, we can selectively print out an entire row from the array B.

DNFL: Accessing Pieces of a Matrix

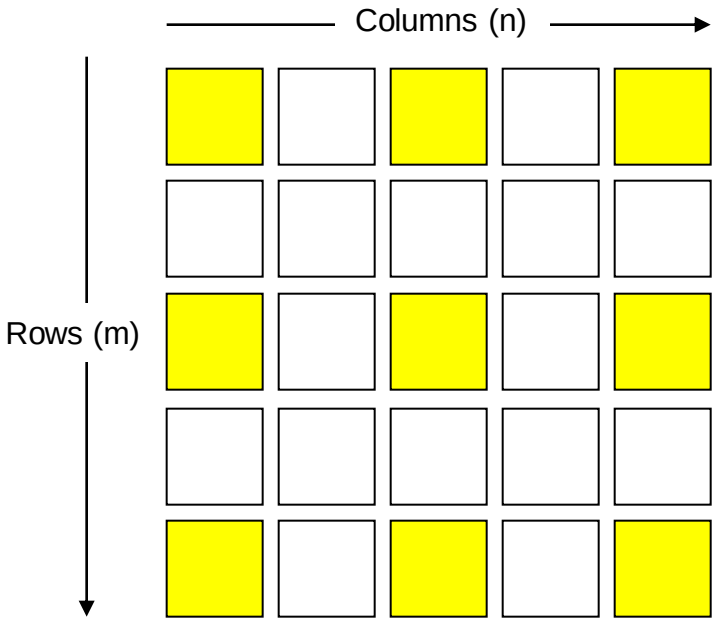


Resetting the value of all the violet colored elements:

```
for n = 1:5        <-- or, n = [1:5]
    B(4, n) = 10;
end
```

In this example, we keep the row index m held constant at 4, and vary the column index n from 1 to 5. Doing so enables us to selectively access each of the elements in row 4 of array B. Each time we access an element of this row, we set it's value to 10. Now, whatever value was previously located in each of the fourth row elements is lost because the FOR loop assigns each element of row 4 to a new value: 10.

DNFL: Accessing Pieces of a Matrix



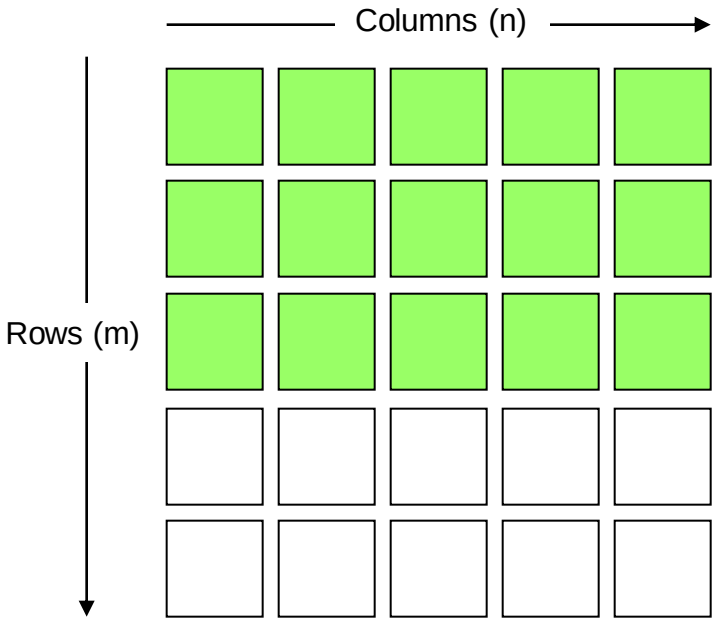
Accessing the value of all the yellow colored elements and printing them out:

```
for m = [1, 3, 5]
    for n = [1, 3, 5]
        B(m, n)
    end
end
```

Here, the FOR loop assigns the row index m and the column index n to values from the list, as we know. But those values aren't necessarily in sequential order. The result is that we access NONSEQUENTIAL elements of array B. In this case, we access the yellow elements, and print them out.

DNFL: Accessing Pieces of a Matrix

Let's return, for a moment, to an earlier situation…



Accessing all the green colored elements (and in this case, printing them out):

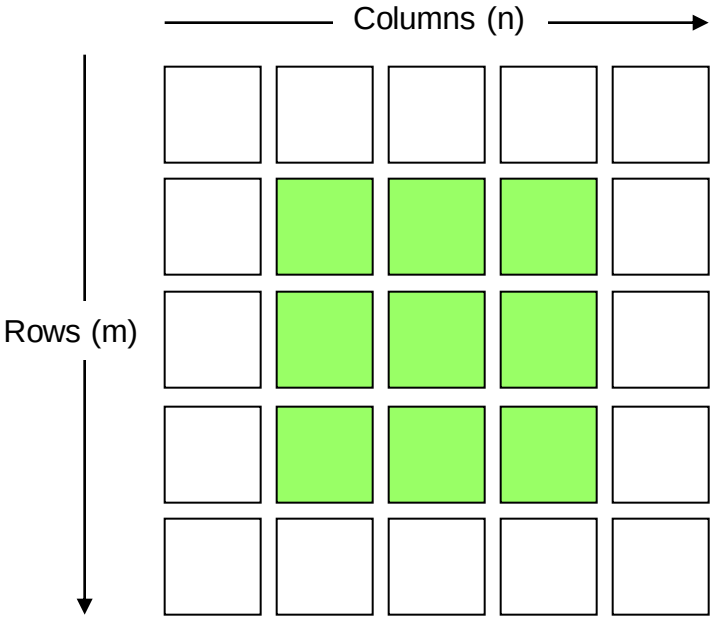
```
for m = 1:3        <-- or, m = [1:3]
    for n = 1:5    <-- or, n = [1:5]
        B(m,n)
    end
end
```

Here's a much easier way to access the green colored elements, and, avoids the above DNFL:

C = B(1:3, 1:5)

Says: "Take rows 1-3 and columns 1-5 of B and assign them to C."
Note **comma**, NOT semicolon!

DNFL: Accessing Pieces of a Matrix



In this case, to access the green elements, we could write:

C = B(2:4, 2:4)

Says: “Take rows 2-4 and columns 2-4 of B and assign them to C.” Again, note **comma**, NOT semicolon!

CHAPTER 10

CONDITIONALS: IF STATEMENTS

IF STATEMENTS (Conditionals)

- **Syntax #1**: ***As shown, for first variant***.

NOTE: The keywords `if` and `end` come in a pair—***never one without the other***.

```
if(test)
   statements
end
```

"IF body"
(always indented)

What's happening in the first variant:

- IF checks `test` to see if `test` is **TRUE**
- if `test` is **TRUE**, then `statements` are executed
- if `test` is **FALSE**, then nothing happens,
  and program execution continues immediately after the `end` statement.

SIDE NOTE: A LOGICAL TEST

IF STATEMENTS (Conditionals)

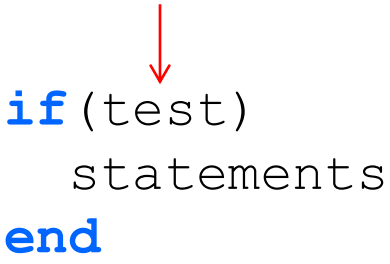
- **What is this thing, "`test`", all about?**

```
if(test)
   statements
end
```

- `test` is what's called a "logical test", or, "conditional". It's like asking the question, "Is this statement true?"
- Logical tests evaluate to a single truth value: either TRUE, or FALSE (never both!)
- The formal name for a `test` that evaluates to either TRUE or to FALSE, is a **PREDICATE**.

IF STATEMENTS (Conditionals)

- **What is this thing, "`test`", all about?**



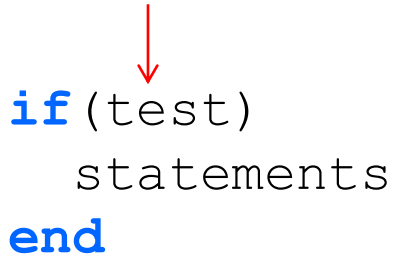
```
if(test)
   statements
end
```

- The predicate is (usually) composed of a LHS and a RHS featuring "logical operators" and "relational operators":

(logical connective)	&&	means	"AND"
(logical connective)	||	means	"OR"
(logical connective)	~	means	"NOT"
(relational operator)	>	means	"Greater than"
(relational operator)	<	means	"Less than"
(relational operator)	>=	means	"Greater-than-or-equal-to"
(relational operator)	<+	means	"Less-than-or-equal-to"
(relational operator)	==	means	"Equal-to"
(relational operator)	~=	means	"NOT Equal-to"

IF STATEMENTS (Conditionals)

- **What is this thing, "`test`", all about?**



- So a complete `test` (or predicate) usually has a left hand side, one or more logical connectives and/or relational operators, and a right hand side.

- **The complete `test` asks a question that is answered only TRUE or FALSE (or if you prefer, "yes" or "no") – <u>BUT NEVER BOTH</u> (called, the "Law of the Excluded Middle")**

- Example predicate: The `test (x < y)` asks the question, "**Is x less than y?**" There is ONLY one answer to this question: YES (true) or NO (false).

IF STATEMENTS (Conditionals)

- **What is this thing, "`test`", all about?**

```
if(test)
   statements
end
```

Predicate Example	Relational Operator	Equivalent Question(s)
(x > y)	>	Is x greater than y?
(x <= y)	<=	Is x less-than-or-equal-to y?
(x >= y)	>=	Is x greater-than-or-equal-to y?
(x == y)	==	Is x equal to y?

IF STATEMENTS (Conditionals)

- **What is this thing, "`test`", all about?**

```
if(test)
   statements
end
```

Predicate Example	Relational / Logical / Relational Sequence	Equivalent Question(s)
`(x == y)&&(a == b)`	`==, &&, ==`	`Is x equal to y AND is a equal to b?`
`(x == y)||(a < b)`	`==, ||, <`	`Is x equal to y OR is a less than b?`
`(x ~= y)&&(a >= 0)`	`~=, &&, >=`	`Is x NOT equal to y AND is a greater-than-or-equal-to 0?`

How we write "NOT"

IF STATEMENTS (Conditionals)—Your Turn !

Instructions:

For the next several examples, please try to work out the answers without running the code in Matlab. This is essential, as it will enable you to develop your "Matlab intuition" and also to visualize the sequence of a computation (thus developing your ability to think algorithmically). Furthermore, you will not be allowed to use Matlab software on exams or quizzes and so it's better to get the practice now rather than wait until later! You may, however, use scratch paper to work out answers.

IF STATEMENTS (Conditionals)—Your Turn !

Example 31:

```
c = 1;
a = 1;
b = 2;
if(a + b < 3)
  c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

IF STATEMENTS (Conditionals)—Your Turn !

Example 31:

```
c = 1;
a = 1;
b = 2;
if(a + b < 3)
   c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

No, it will not: a + b is equal to 3 and not less than 3!

IF STATEMENTS (Conditionals)—Your Turn !

Example 32:

```
c = 1;
a = pi;
b = 2;
if(cos(a*b) == 1)
  c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

IF STATEMENTS (Conditionals)—Your Turn !

Example 32:

```
c = 1;
a = pi;
b = 2;
if(cos(a*b) == 1)
  c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

Yes: cosine(2*π) is equal to 1

IF STATEMENTS (Conditionals)—Your Turn !

Example 33:

```
c = 1;
a = pi;
b = 2;
if(cos(a*b) == 1 && a < b)
  c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

IF STATEMENTS (Conditionals)—Your Turn !

Example 33:

```
c = 1;
a = pi;
b = 2;
if(cos(a*b) == 1 && a < b)
  c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

No: Although cosine(2*π) is equal to 1,
a is NOT less than b (rather: π > 2),
and so BOTH CONDITIONS ARE NOT TRUE TOGETHER,
which is what is required by AND,
and so the statements bounded
by IF and END will not execute!

IF STATEMENTS (Conditionals)—Your Turn !

Example 34:

```
c = 1;
a = pi;
b = 2;
if(cos(a*b) == 0 || a > b)
  c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

IF STATEMENTS (Conditionals)—Your Turn !

Example 34:

```
c = 1;
a = pi;
b = 2;
if(cos(a*b) == 0 || a > b)
  c = c + 1;
end
```

Question: Will `c` be incremented by 1? Why or why not?

Yes: Although cosine(2*π) is NOT equal to 0, in this case, we're dealing with an OR, which means either the first condition OR the second condition can be true, and then the entire test is considered true. That happens here.

IF STATEMENTS (Conditionals)—Your Turn !

Example 35:

```
c = 1;
for m = 1:3
    if(m <= m^2)
        c = c + 1;
    end
end
c
```

Question: What final value of `c` is printed out?

IF STATEMENTS (Conditionals)—Your Turn !

Example 35:

```
c = 1;
for m = 1:3
    if(m <= m^2)
        c = c + 1;
    end
end
c
```

Question: What final value of `c` is printed out?

c = 4

IF STATEMENTS (Conditionals)—Your Turn !

Example 36:

```
a = 0;
c = 1;
for m = 1:3
    for n = 1:3
        if(m > n)
            c = c + 1;
            a = c;
        end
    end
end
a
```

Question: What final value of `a` is printed out?

IF STATEMENTS (Conditionals)—Your Turn !

Example 36:

```
a = 0;
c = 1;
for m = 1:3
    for n = 1:3
        if(m > n)
            c = c + 1;
            a = c;
        end
    end
end
a
```

Question: What final value of `a` is printed out?

a = 4

IF STATEMENTS (Conditionals)

• **IF STATEMENT Syntax #2**: ***As shown, for second variant***. **NOTE**: The keywords `if` and `end` come in a pair—***never one without the other***.

```
if(test)
   statements }
else
   other stmts }
end
```

"IF bodies" (always indented)

SIDE NOTE: A LOGICAL TEST

What's happening in the second variant:

- IF checks `test` to see if `test` is **TRUE**
- if `test` is **TRUE**, then `statements` are executed
- if `test` is **FALSE**, then `other stmts` are executed, and overall program execution continues immediately after the `end` statement.

IF STATEMENT Syntax #2: A way to select between TRUE and FALSE:

```
(assume a and b were
 previously assigned)

if(cos(a*b) == 0)
  c = c + 1;
else
  c = c - 1;
end
```

What happens now depends upon whether `cos(a*b) == 0` evaluates to TRUE or to FALSE: If to TRUE, then the statement `c = c + 1;` is executed but if FALSE, then the statement `c = c - 1;` is executed instead.

IF STATEMENT Syntax #2: ILLUSTRATION

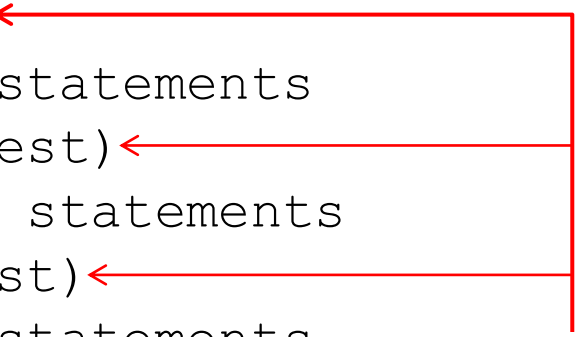
```
(assume a and b were
 previously assigned)

A(5,5) = 0.0;
A = (A + 2)/2.0;
if(cos(a*b) == 0)
   c = c + 1;
else
   for m = [1:5]
      for n = [1:5]
         A(m,n) = A(m,n)/2.0
      end
   end
end
```

Here, an **entire** double nested FOR loop is executed if `cos(a*b) == 0` is false! If not, the variable `c` is incremented instead.

IF STATEMENTS (Conditionals)

• **IF STATEMENT Syntax #3**: ***As shown, for third variant***. **NOTE**: The keywords **`if`** and **`end`** come in a pair—***never one without the other***. **`elseif`** doesn't need an **`end`** statement:

```
if(first test)
  first set of statements
elseif(second test)
  second set of statements
elseif(third test)
  third set of statements
     .
     .
     .
end
```



Multiple tests MEANS multiple outcomes are possible!

IF STATEMENTS (Conditionals)

IF STATEMENT Syntax #3: ILLUSTRATION 1

(assume a, b and c were previously assigned)

```
A(5,5) = 0.0;
A = (A + 2)/2.0;
if(cos(a*b) == 0)
  c = c + 1;
elseif(cos(a*b) < 0)
  for m = [1:5]
     for n = [1:5]
        A(m,n) = A(m,n)/2.0
     end
  end
elseif(cos(a*b) > 0)
  c = c - 1;
end
```

IF STATEMENT Syntax #3: ILLUSTRATION 2

WOW!! A Multi-Branch IF that covers eight possibilities!

```
(assume matrix A  and variables a, b and c were all
previously assigned)

if(A(1,1) == 0 && A(1,2) == 0 && A(1,3) == 0)
   c = c + 1;
elseif(A(1,1) == 0 && A(1,2) == 0 && A(1,3) == 1)
   c = c - 1;
elseif(A(1,1) == 0 && A(1,2) == 1 && A(1,3) == 0)
   c = a*b;
elseif(A(1,1) == 0 && A(1,2) == 1 && A(1,3) == 1)
   c = a/b
elseif(A(1,1) == 1 && A(1,2) == 0 && A(1,3) == 0)
   c = cos(a)*b
elseif(A(1,1) == 1 && A(1,2) == 0 && A(1,3) == 1)
   c = a*cos(b)
elseif(A(1,1) == 1 && A(1,2) == 1 && A(1,3) == 0)
   c = log(a*b)
elseif(A(1,1) == 1 && A(1,2) == 1 && A(1,3) == 1)
   c = a^b
end
```

IF STATEMENT Syntax #3 ILLUSTRATIONS 1 & 2

The purpose of ILLUSTRATIONS 1 & 2 was to demonstrate to you that by using Syntax #3 (and also Syntax #1 and #2), it is possible to build up some very complex program capability! The ability of a program to evaluate conditionals and then select from a (possibly) wide range of available processing options – based on the outcome of the conditional evaluation – is what's enabled by the IF statement and its variations.

IF STATEMENTS (Conditionals)

Example 37:

```
a = 0;
c = 0;
for m = 1:3
    for n = 1:3
        if(m <= n)
            c = c + 1;
        end
        if(c > a)
            a = a + 1;
        end
    end
end
a
```

TRICKY!!

Question: What final value of `a` is printed out?

IF STATEMENTS (Conditionals)

Example 37:

```
a = 0;
c = 0;
for m = 1:3
    for n = 1:3
        if(m <= n)
            c = c + 1;
        end
        if(c > a)
            a = a + 1;
        end
    end
end
a
```

TRICKY!!

Question: What final value of `a` is printed out?

a = 6

IF STATEMENTS (Conditionals)

Example 38:

```
a = 0;
c = 1;
for m = 1:3
    for n = 1:3
        if(m <= n && c ~= a)
            c = c + 1;
        end
        if(c > a^2)
            a = a + 1;
        end
    end
end
a
```

VERY TRICKY!!

Question: What final value of `a` is printed out?

a = 6

IF STATEMENTS (Conditionals)

Example 38:

```
a = 0;
c = 1;
for m = 1:3
    for n = 1:3
        if(m <= n && c ~= a)
            c = c + 1;
        end
        if(c > a^2)
            a = a + 1;
        end
    end
end
a
```

VERY TRICKY!!

Question: What final value of `a` is printed out? **a = 3**

CHAPTER 11

RANDOM NUMBERS

GENERATING RANDOM NUMBERS

There are two Matlab random number commands you need to know. The first command, `rand`, generates a single, random, real value distributed uniformly between 0.0 and 1.0 (including 0.0 but EXCLUDING 1.0):

```
EDU>> rand

ans =  0.7922
```

If we use `rand` on *the right hand side* of an assignment statement, we can capture the random value into a variable:

```
EDU>> randnum = rand

randnum =  0.9058
```

GENERATING RANDOM NUMBERS

Actually, using `rand`, we can generate an entire matrix of random numbers distributed uniformly between 0.0 and 1.0 (including 0.0 but EXCLUDING the 1.0). We do this by giving `rand` an integer argument N. `rand` interprets this to mean, "*Generate an NxN matrix of random values between 0.0 and 1.0*" :

```
EDU>> A = rand(3)

A =

    0.8147    0.9134    0.2785
    0.9058    0.6324    0.5469
    0.1270    0.0975    0.9575
```

GENERATING RANDOM NUMBERS

The second command, `randi`, generates a single random integer, uniformly distributed between 1 and *upperlimit* (INCLUSIVE, where you specify the value of *upperlimit*):

`randi(`*`upperlimit`*`)`

We can use it to generate a random integer from 1 to *upperlimit*. Again, if we use it in an assignment statement, we can capture the random integer into a variable:

```
EDU>> randint = randi(100)

randint =  92
```

GENERATING RANDOM NUMBERS

Wait a minute . . . are the values generated by rand REALLY uniformly distributed?

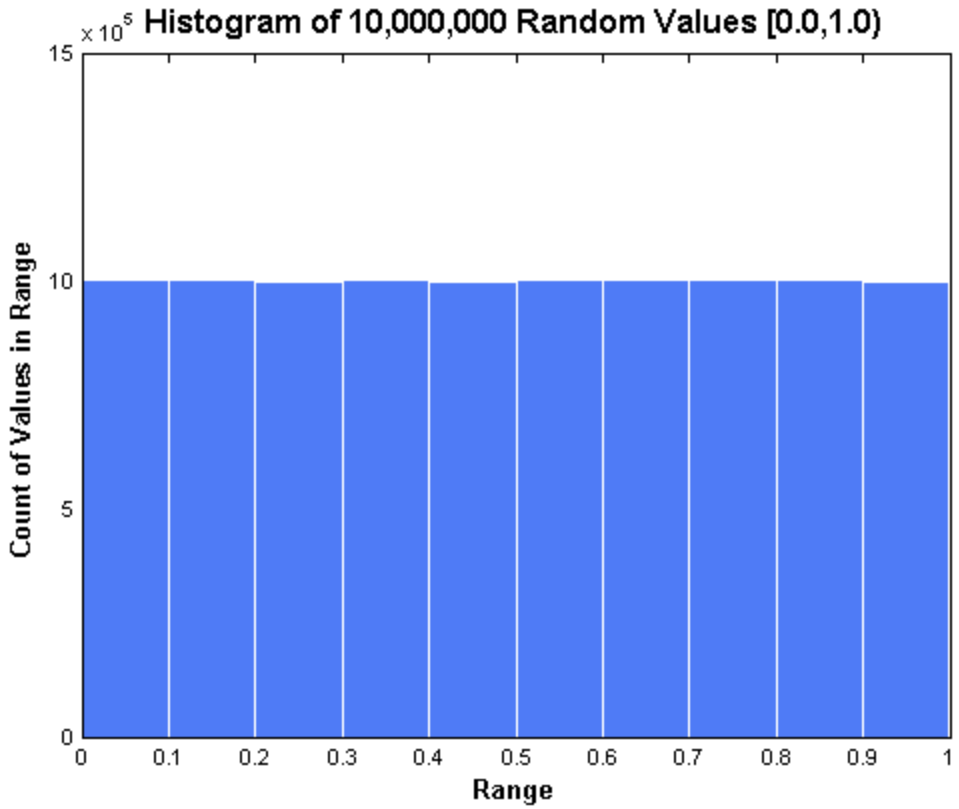
Good question. There are several ways to check. Let's generate ten million of them and then work with them:

```
A = [1:10000000];
for m = 1:10000000
    A(m) = rand;
end
```

Now we have ten million random numbers, stored in the matrix A.

GENERATING RANDOM NUMBERS

One way to check the distribution – visually – is to plot a histogram of it:



Not bad!

GENERATING RANDOM NUMBERS

A much better way, however, is to compute some basic statistics. Using the function `mean` we can compute the mean of the distribution. We would expect it to be very close to 0.5 in this case. We'll use `format long` in order to get a better idea:

```
EDU>> format long
EDU>> mean(A)

ans =

   0.499999906493784
```

Which is pretty close to 0.5, as we expect.

CHAPTER 12

ITERATION III: WHILE LOOPS

ITERATION (WHILE loops)

• **Syntax**: ***As shown, and always the same***. **NOTE**: The keywords WHILE and END come in a pair—***never one without the other***.

```
while (test)
   statements
end
```

"Loop body"
(always indented)

•**What's happening**:

- WHILE loop ***test*** occurs (NO loop index!)
- if ***test*** is **TRUE**, then the loop continues
- `statements` inside executed
- END sends execution back to the top
- repeat: WHILE loop ***test*** occurs . . .
- stops executing `statements` only when test is ***FALSE . . . so, COULD GO ON FOREVER*** !!

SIDE NOTE: A LOGICAL TEST, and NOT a list of values like the FOR loop!

ITERATION (WHILE loops)

• **Syntax**: ***As shown, and always the same***. **NOTE**: The keywords WHILE and END come in a pair—***never one without the other***.

```
while (test)
   statements
end
```

"Loop body"
(always indented)

•**Comments**:

- Because of the "endless" feature, WHILE loops require a LOT of care in their use.
- In general, anything that can be done with a WHILE loop, can be done with a FOR loop.
- So why use WHILE loops? Convenience!

SIDE NOTE: A LOGICAL TEST, and NOT a list of values like the FOR loop!

ITERATION (WHILE loops)–the "test"

- **What is this thing, "test", all about?**

```
while (test)
   statements
end
```

- ***test*** is what's called a "logical test", or, "conditional". It's like asking the question, "Is this statement true?"
- Logical tests evaluate to a single truth value: either TRUE, or FALSE (never both!)

ITERATION (WHILE loops)–the "test"

- **What is this thing, "test", all about?**

```
while (test)
   statements
end
```

- The "test" is (usually) composed of a LHS and a RHS with a "logical connective" in between:

&&	means	"AND"
||	means	"OR"
~	means	"NOT"
>	means	"Greater than"
<	means	"Less than"
>=	means	"Greater-than-or-equal-to"
<+	means	"Less-than-or-equal-to"
==	means	"Equal-to" (~= means "NOT Equal-to")

ITERATION (WHILE loops)–the "test"

- **What is this thing, "test", all about?**

```
while (test)
   statements
end
```

- So a complete test (usually) has a left hand side, one or more logical connectives, and a right hand side.
- **The complete test asks a question that is answered TRUE or FALSE.**

- Example: The test `(x < y)` asks the question, "**Is x less than y?**"

ITERATION (WHILE loops)–the "test"

- **What is this thing, "test", all about?**

```
while (test)
   statements
end
```

(test) Example	Logical Connective(s)	Equivalent Question(s)
(x > y)	>	Is x greater than y?
(x <= y)	<=	Is x less-than-or-equal-to y?
(x >= y)	>=	Is x greater-than-or-equal-to y?
(x == y)	==	Is x equal to y?

ITERATION (WHILE loops)–the "test"

- **What is this thing, "test", all about?**

```
while (test)
   statements
end
```

(test) Example	Logical Connective(s)	Equivalent Question(s)
`(x == y) && (a == b)`	`==, &&, ==`	Is x equal to y AND is a equal to b?
`(x == y) || (a < b)`	`==, ||, <`	Is x equal to y OR is a less than b?
`(x ~= y) && (a >= 0)`	`~=, &&, >=`	Is x NOT equal to y AND is a greater-than-or-equal-to 0?

How we write "NOT"

ITERATION (WHILE loops)–the "test"

So, this WHILE loop:

```
x = 1;
y = 5;
while (x < y)
    statements
end
```

will continue executing `statements` as long as the test `(x < y)` remains true, that is, as long as x remains less than y.

NOTE: **Since x always remains less than y,** we have that never-ending situation called an **INFINITE LOOP**!

(Usually (but not always) infinite loops are the result of faulty logic and thus, should be avoided!)

ITERATION (WHILE loops)–HELP!!!

HELP!!!

HOW TO I GET OUT OF AN INFINITE LOOP????

Answer: In the Matlab command line window, hit “CRTL-C” a couple of times (hold down CRTL and then hit “C” several times). That should do it. But you may have to wait several seconds for your program to terminate while Matlab keeps grinding…

ITERATION (WHILE loops)–the "test"

- Example WHILE loop:

```
while (test)
   statements
end
```

VERY IMPORTANT TO NOTE: In Matlab, the numerical value 1 also corresponds to "true", and, the numerical value 0 also corresponds to "false".

- So this WHILE loop will execute forever:

```
while (1)
   statements
end
```

***Because the test never evaluates to false*!**

ITERATION (WHILE loops)–the "test"

- This WHILE loop, on the other hand ***will never execute, not even once***:

```
while (0)
   statements
end
```

Remember: In order for the WHILE loop to execute, the test must evaluate to ***true*** (at least once), and for it to stop executing, the test must at some point evaluate to ***false***.

ITERATION (WHILE loops)–the "test"

- Note also that if the test is ***compound***, meaning, put together with a number of different logical connectives, then, the ***entire test*** must evaluate to true for the WHILE loop to execute (and, the entire test must evaluate to false for the WHILE loop to terminate!). In the following example, ***both pieces connected by & must be true*** in order for the entire test to evaluate true:

```
while (x < y && y > 7)
  statements
end
```

(HINT: Remember the rule for AND: "0 in, 0 out"? Well here that means if ***either*** of the conditions connected by && evaluate false (value 0), then the whole test false. So, what's the only way the whole test can evaluate true? Answer: If ***both*** conditions evaluate to true, that is, both have the value 1).

ITERATION (WHILE loops)–the "test"

•In this example, however, ***either piece connected by | must be true*** in order for the entire test to evaluate true:

```
while (x < y || y > 7)
   statements
end
```

(HINT: Remember the rule for OR: "1 in, 1 out"? Well here that means if ***either*** of the conditions connected by || evaluate true, then the whole test is true. So, what's the only way the entire test can evaluate false? Answer: If ***both*** conditions evaluate false.)

ITERATION (WHILE loops)–YOUR TURN!

Example 39:

```
counter = 1;
while (counter < 5)
    counter
    counter = counter + 1;
end
```

This will print out the value of counter, for each iteration of the loop:

```
counter =  1
counter =  2
counter =  3
counter =  4
```

Aha! No `counter = 5` printed out. Why not?

ITERATION (WHILE loops)–YOUR TURN!

Instructions:

For the remaining examples, please try to work out the answers without running the code in Matlab. This is essential, as it will enable you to develop your "Matlab intuition" and also to visualize the sequence of a computation (thus developing your ability to think algorithmically). Furthermore, you will not be allowed to use Matlab software on exams or quizzes and so it's better to get the practice now rather than wait until later! You may, however, use scratch paper to work out answers.

ITERATION (WHILE loops)–YOUR TURN!

Example 40:

```
counter = 1;
while (counter < 5)
    counter
    counter = counter - 1;
end
```

What's printed out when this WHILE loop is executed?

ITERATION (WHILE loops)–YOUR TURN!

Example 40:

```
counter = 1;
while (counter < 5)
    counter
    counter = counter - 1;
end
```

INFINITE LOOP!!!

Actually, a LOT is printed out. An endless amount, so you have to stop execution with multiple presses of "CRTL-C" in Matlab's command window.

ITERATION (WHILE loops)–YOUR TURN!

Example 41:

```
counter = 1;
while (counter > 5)
    counter
    counter = counter + 1;
end
```

What's printed out when this WHILE loop is executed?

ITERATION (WHILE loops)–YOUR TURN!

Example 41:

```
counter = 1;
while (counter > 5)
    counter
    counter = counter + 1;
end
```

NOTHING!!

The WHILE loop never executes because counter is assigned the value 1, and when the WHILE loop test occurs, it fails the very first time.

ITERATION (WHILE loops)–YOUR TURN!

Example 42:

```
counter = 1;
a = 0;
while (counter < 5 && a < 5)
    counter
    counter = counter + 1;
    a = a + 2;
end
```

What's printed out when this WHILE loop is executed?

ITERATION (WHILE loops)–YOUR TURN!

Example 42:

```
counter = 1;
a = 0;
while (counter < 5 && a < 5)
    counter
    counter = counter + 1;
    a = a + 2;
end
```

```
counter =     1
counter =     2
counter =     3
```

ITERATION (WHILE loops)–YOUR TURN!

Example 43:

```
counter = 1;
a = 0;
while (counter < 5 || a < 5)
    counter
    counter = counter + 1;
    a = a + 2;
end
```

What's printed out when this WHILE loop is executed?

ITERATION (WHILE loops)–YOUR TURN!

Example 43:

```
counter = 1;
a = 0;
while (counter < 5 || a < 5)
    counter
    counter = counter + 1;
    a = a + 2;
end
```

```
counter =     1
counter =     2
counter =     3
counter =     4
```

ITERATION (WHILE loops)–YOUR TURN!

Example 44:

```
counter = 1;
a = 0;
b = 4;
while (counter < 5 || b < a)
    counter
    counter = counter + 1;
    b = b - a;
    a = a + 1;
end
```

TRICKY!!

What's printed out when this WHILE loop is executed?

ITERATION (WHILE loops)–YOUR TURN!

Example 44:

```
counter = 1;
a = 0;
b = 4;
while (counter < 5 || b < a)
    counter
    counter = counter + 1;
    b = b - a;
    a = a + 1;
end
```

TRICKY!!

INFINITE LOOP!!!

Actually, a LOT is printed out. An endless amount, so you have to stop execution with multiple presses of "CRTL-C" in Matlab's command window.

ITERATION (WHILE loops)–YOUR TURN!

Example 45:

```
counter = 1;
A = [1:5];
while (A(counter) < 5)
    counter
    counter = counter + 1;
end
```

What's printed out when this WHILE loop is executed?

ITERATION (WHILE loops)–YOUR TURN!

Example 45:

```
counter = 1;
A = [1:5];
while (A(counter) < 5)
    counter
    counter = counter + 1;
end
```

```
counter =     1
counter =     2
counter =     3
counter =     4
```

ITERATION (WHILE loops)–YOUR TURN!

Example 46:

```
counter = 1;
A = [1:5];
while (A(counter) <= 5)
    counter
    counter = counter + 1;
end
```

TRICKY!!

What's happens when this WHILE loop is executed?
WHY?

(HINT: See red arrow, above)

ITERATION (WHILE loops)–YOUR TURN!

Example 46:

```
counter = 1;
A = [1:5];
while (A(counter) <= 5)
    counter
    counter = counter + 1;
end
```

TRICKY!!

```
??? Index exceeds matrix dimensions.

Error in ==> Untitled at 4
while (A(counter) <= 5)
```

ITERATION (WHILE loops)–YOUR TURN!

Example 47:

```
counter = 1;
A = [1:10];
while (A(counter) < 10)
    counter = counter + 1;
    A(counter+1) = A(counter) + 1;
end
A
```

VERY TRICKY!!

What's printed out by the above code? (Note that the WHILE loop itself prints out nothing)

ITERATION (WHILE loops)–YOUR TURN!

Example 47:

```
counter = 1;
A = [1:10];
while (A(counter) < 10)
    counter = counter + 1;
    A(counter+1) = A(counter) + 1;
end
A
```

VERY TRICKY!!

```
A =

     1     2     3     4     5     6     7     8     9    10    11
```

ITERATION (WHILE loops)–YOUR TURN!

Example 48:

```
counter = 5;
A = [1:5];
while (counter > 0)
    A(counter+1) = A(counter) - 1;
    counter = counter - 1;
end
A
```

OMG TRICKY!!

What's printed out by the above code? (Note that the WHILE loop itself prints out nothing)

ITERATION (WHILE loops)–YOUR TURN!

Example 48:

```
counter = 5;
A = [1:5];
while (counter > 0)
    A(counter+1) = A(counter) - 1;
    counter = counter - 1;
end
A
```

OMG TRICKY!!

```
A =

     1     0     1     2     3     4
```

ITERATION (WHILE loops)

Again, ***study*** the preceding WHILE loop examples and problems VERY CAREFULLY to ensure that you understand completely what each loop is doing AND WHY! Also make sure that you know how the "test" works – and why it might sometimes fail and result in an infinite loop.

These problems are VERY REPRESENTATIVE of those you might encounter in the future . . .