LEHIGH UNIVERSITY

C Programming II

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Outline

Functions

Functions

- A function is a group of statements that together perform a task.
- Every C program has at least one function, which is main()
- Functions receive either a fixed or variable amount of arguments.
- Functions can only return one value, or return no value (void).
- In C, arguments are **passed by value** to functions
- How to return value? - **Pointers**
- Functions are defined using the following syntax:

```
return_type function_name( parameter list )
{
  body of the function
}
```

- A function **declaration** tells the compiler about a function's name, return type, and parameters.
- A function **definition** provides the actual body of the function.

Function Definition

- **Return Type:** Function's return type is the data type of the value the function returns. When there is no return value, return void.
- **Function Name:** This is the actual name of the function.
- **Parameter:** The parameter list refers to the type, order, and number of the parameters of a function. A function may contain no parameters.
- **Function Body:** The function body contains a collection of statements that define the function behavior.

```
/* function returning the max between two numbers */
int max(int i, int j)
{
  /* local variable declaration */
  int result;

  if (i > j)
    result = i;
  else
    result = j;

  return result;
}
```

Example of using a Function

```c
#include <stdio.h>

/* function declaration */
int max(int i, int j);

int main() {

  /* local variable definition */
  int i = 100, j = 200, maxval;

  /* calling a function to get max value */
  maxval = max(a, b);

  printf( "Max value is : %d\n", maxval );
  return 0;

}


/* function returning the max between two numbers */
int max(int i, int j)
{
  /* local variable declaration */
  int result;

  if (i > j)
    result = i;
  else
    result = j;

  return result;
}
```

Scope Rules: Local & Global Variables I

- A scope is a region of the program where a defined variable can have its existence and beyond that variable can not be accessed.
- **Local Variables:** declared inside a function or block.

  can be used only by statements that are inside that function or block of code.

  Local variables are not known to functions outside their own.
- **Global Variables:** defined outside of a function, usually on top of the program.

  will hold their value throughout the lifetime of your program and,

  they can be accessed inside any of the functions defined for the program.
- A program can have same name for local and global variables but value of local variable inside a function will take preference.

Scope Rules: Local & Global Variables II

```c
#include <stdio.h>

/* global variable declaration */
int a = 20;

int main ()
{
  /* local variable declaration in main function */
  int a = 10;
  int b = 20;
  int c = 0;

  printf ("value of a in main() = %d\n",  a);
  c = sum( a, b);
  printf ("value of c in main() = %d\n",  c);

  return 0;
}

/* function to add two integers */
int sum(int a, int b)
{
  printf ("value of a in sum() = %d\n",  a);
  printf ("value of b in sum() = %d\n",  b);

  return a + b;
}
```

```
value of a in main() = 10
value of a in sum() = 10
value of b in sum() = 20
value of c in main() = 30
```

Initializing Local & Global Variables

- Local Variables are not initialized by the system, the programmer must initialize it.
- Global variables are automatically initialized by the system depending on the data type

Data Type	Initial Default Value
int	0
char	'\0'
float	0
double	0
pointer	NULL

- *It is a good programming practice to initialize variables properly otherwise, your program may produce unexpected results because uninitialized variables will take some garbage value already available at its memory location.*

Arrays

Arrays

- Arrays are special variables which can hold more than one value using the same name with an index.
- Declaring Arrays: `type arrayName [ arraySize ];`

```
/* simply define the arrays */
double balance[10];
float atom[1000];
int index[5];
```

- C array starts its index from 0

[0]	[1]	[2]	[3]	[4]
10	15	14	3	7

index[2] (3rd element of the array) has a value 14

- Initialize arrays with values

```
/* initialize the array with values*/
double atmass[4] = {12.0, 1.0, 1.0, 16.0};
double atmass[] = {12.0, 1.0, 1.0, 16.0};
atmass[0] = 12.0
```

- Access array values via index

```
/* access the array values*/
int current_index = index[i];
double current_value=value[current_cell_index];
```

Array Example

```
#include <stdio.h>

int main ()
{
  int n[ 10 ]; /* n is an array of 10 integers */
  int i,j;

  /* initialize elements of array n to 0 */
  for ( i = 0; i < 10; i++ )
    {
      n[ i ] = i + 100; /* set element at location i to i + 100 */
    }

  /* output each array element's value */
  for (j = 0; j < 10; j++ )
    {
      printf("Element[%d] = %d\n", j, n[j] );
    }

  return 0;
}
```

Accessing C arrays

- C arrays are a sequence of elements with contiguous addresses.
- There is no bounds checking in C.
- Be careful when accessing your arrays
- Compiler will not give you error, you will have *undefined* runtime behavior:

```c
#include <stdio.h>

int main() {

  int index[5]={5, 4, 6, 3, 1};

  int a=3;

  /* undefined behavior */

  printf("%d\n",index[5]);

}
```

Multidimensional Arrays

- General form of multidimensional array

```
type name[size1][size2]...[sizeN];
```

- Declaring 2D and 3D arrays:

```
float array2d[4][5];
double array3d[2][3][4];
```

- Initializing multidimensional arrays

```
int a[3][4] = {{/* 2D array is composed of 1D arrays*/
  {0, 1, 2, 3} ,    /*  initializers for row indexed by 0 */
  {4, 5, 6, 7} ,    /*  initializers for row indexed by 1 */
  {8, 9, 10, 11}    /*  initializers for row indexed by 2 */
  };
```

	col0	**col1**	**col2**	**col3**
row0	a[0][0]=0	a[0][1]=1	a[0][2]=2	a[0][3]=3
row1	a[1][0]=4	a[1][1]=5	a[1][2]=6	a[1][3]=7
row2	a[2][0]=8	a[2][1]=9	a[2][2]=10	a[2][3]=11

- C arrays are **row major** order i.e. in memory, the C array appears as

a[0][0]	a[0][1]	a[0][2]	a[0][3]	a[1][0]	a[1][1]	· · ·	a[1][3]	a[2][0]	· · ·	a[2][3]

Example: Arrays

```
#include <stdio.h>
#include <time.h>
#include <stdlib.h>

int main () {
  /* Program to calculate the sum, min and max of an integer array */
  int i, sum, min, max, n=11  ;
  int a[] = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9};

  sum = max = 0.0 ; min = 10.0 ;
  /* Initialize array */

  /* Find sum, min and max */
  for (i = 0 ; i < n ; i++ ) {
    sum += a[i] ;
    if (a[i] > max ) max = a[i];
    if (a[i] < min ) min = a[i];
  }

  printf("The max value is: %d\n", max);
  printf("The min value is: %d\n", min);
  printf("The sum value is: %d\n", sum);
  return 0;

}
```

Strings in C I

- Strings in C are a special type of array: array of characters terminated by a null character '\0'.

```
/* define string */
char str[7]={'H', 'E', 'L', 'L', 'O', '!', '\0'};
char str1="HELLO!";
```

- Memory presentation of above defined string in C/C++:

str[]	[0]	[1]	[2]	[3]	[4]	[5]	[6]
	'H'	'E'	'L'	'L'	'O'	'!'	'\0'

- C uses built-in functions to manipulate strings:

```
/* C sample string functions */
strcpy(s1, s2); /* Copies string s2 into string s1.*/
strcat(s1, s2); /* Concatenates string s2 onto the end of string s1. */
strlen(s1); /* Returns the length of string s1. */
strcmp(s1, s2); /* Returns 0 if s1 and s2 are the same; less than 0 if
s1<s2; greater than 0 if s1>s2. */
```

Strings in C II

```
#include <stdio.h>
#include <string.h>

int main ()
{
  char str1[12] = "Hello";
  char str2[12] = "World";
  char str3[12];
  int  len ;

  /* copy str1 into str3 */
  strcpy(str3, str1);
  printf("strcpy( str3, str1) :  %s\n", str3 );

  /* concatenates str1 and str2 */
  strcat( str1, str2);
  printf("strcat( str1, str2):   %s\n", str1 );

  /* total lenghth of str1 after concatenation */
  len = strlen(str1);
  printf("strlen(str1) :  %d\n", len );

  return 0;
}
```

Pointers

Pointers

- Pointers are a very important part of the C programming language.
- They are used in many ways, such as:
  - Array operations (e.g., while parsing strings)
  - Dynamic memory allocation
  - Sending function arguments by reference
  - Generic access to several similar variables
  - Malloc data structures of all kinds, especially trees and linked lists
  - Efficient, by-reference "copies" of arrays and structures, especially as function parameters
- Necessary to understand memory and address $\cdots$ and the C programming language.

What is a Pointer

- A pointer is essentially a **variable** whose value is the address of another variable.
- Since it is a variable, it must be declared before use.
- Pointer "points" to a specific part of the memory.
- How to define pointers?

```
/* type: pointer's base type
var-name: name of the pointer variable.
asterisk *:designate a variable as a pointer */
type *pointer_var_name;
```

- Examples

```
int *i_ptr; /* pointer to an integer */
double *d_ptr; /* pointer to a double */
float *f_ptr; /* pointer to a float */
char *ch_ptr; /* pointer to a character */
int **p_ptr; /* pointer to an integer pointer */
```

Pointer Rules

- There are two prefix unary operators to work with pointers.

```
& /*"address of" operator */
* /*"dereferencing" operator */
```

- Use ampersand "**&**" in front of a variable to access it's address, this can be stored in a pointer variable.
- Use asterisk "*****" in front of a pointer you will access the value at the memory address pointed to (**dereference** the pointer).
- Example

```
int a = 8;
int *p;
/* point p to a */
p = &a;
/* dereference pointer p */
*p = 10;
```

Part of symbol table

var_name	var_address	var_value
a	bff5a400	8
p	bff5a3f6	bff5a400

Pointer to variables and dereference pointers

```c
/* pointer_rules.c */

#include <stdio.h>

int main() {

  int a = 6, b = 10;
  int *p;

  printf("\nInitial values:\n\tthe value of a is %d, value of b is %d\n", a, b);
  printf("the address of a is : %p, address of b is : %p\n", &a, &b);
  p = &a; /* point p to a */
  printf("\nafter \"p = &a\":\n");
  printf("\tthe value of p is %p, value at that address is %d\n", p, *p);
  p = &b; /* point p to b */
  printf("\nafter \"p = &b\":\n");
  printf("\tthe value of p is %p, value at that address is %d\n", p, *p);
  /* dereference pointer p */
  *p = 6, p = &a, *p = 10 ;
  printf("\nafter dereferencing the pointer:\n");
  printf("\tthe value of a is %d, value of b is %d\n", a, b);
  return 0;
}
```

Never dereference an uninitialized pointer!

- In order to dereference the pointer, pointer must have a valid value (address).
- What is the problem for the following code?

```
int *ptr;
*ptr = 3;
```

- Again, you will have **undefined behavior** at runtime, you are operating on unknown memory space.
- Typically error: "Segmentation fault", possible illegal memory operation
- **Always initialize your variables before use!**

var_name	var_address	var_value
ptr	0x22aac0	0xXXXX
	0xXXXX	3

NULL Pointer

- Memory address 0 has special significance, if a pointer contains the null (zero) value, it is assumed to point to nothing, defined as NULL in C.
- Set the pointer to NULL if you do not have exact address to assign to your pointer.
- A pointer that is assigned NULL is called a null pointer.

```
/* set the pointer to NULL 0 */
int *ptr = NULL;
```

- Before using a pointer, ensure that it is not equal to NULL:

```
if (ptr != NULL) {
  /* make use of pointer1 */
  /* ... */
  }
```

Pointers and Functions I

- In C, arguments are passed by value to functions: changes of the parameters in functions do **not** change the parameters in the calling functions.
- Take a look at the below example, what are the values of a and b after we called swap(a, b);

```
/* this is the main calling function */

int main() {

  int a = 2;
  int b = 3;

  printf("Before: a = %d and b = %d\n", a, b );
  swap( a, b );
  printf("After: a = %d and b = %d\n", a, b );

}

/* this is function, pass by value */
void swap(int p1, int p2) {

  int t;

  t = p2, p2 = p1, p1 = t;
  printf("Swap: a (p1) = %d and b(p2) = %d\n", p1, p2 );

}
```

Pointers and Functions II

- The values of a and b do not change after calling swap(a,b)
- **Pass by value means the called function's parameter will be a copy of the caller's passed argument**. The value of the caller and called functions will be the same, but the identity (the variable) is different - caller and called function each has its own copy of parameters

```
/* this is function, pass by reference */
void swap_by_reference(int *p1, int *p2) {

  int t;

  t = *p2, *p2 = *p1, *p1 = t;
  printf("Swap: a (p1) = %d and b(p2) = %d\n", *p1, *p2);

}


/* call by-address function */
swap_by_reference( &a, &b );
```

- The most frequent use of pointers in C is for walking efficiently along arrays.
- **Remember, array name is the first element address of the array (it is a constant)**

Pointers and Functions III

```
int *p=NULL; /* define an integer pointer p*/
/* array name represents the address of the 0th element of the array
    */
int a[5]={1,2,3,4,5};
/* for 1d array, below 2 statements are equivalent */
p = &a[0]; /* point p to the 1st array element (a[0])'s address */
p = a; /* point p to the 1st array element (a[0])'s address */
*(p+1); /* access a[1] value */
*(p+i); /* access a[i] value */
p = a+2; /* p is now pointing at a[2] */
p++; /* p is now at a[3] */
p--; /* p is now back at a[2] */
```

- Recall 2D array structure: combination of 1D arrays

```
int a[2][2]={{1,2},{3,4}};
```

- The 2D array contains 2 1D arrays: array a[0] and array a[1]
- a[0] is the address of a[0][0], i.e:
  - a[0] ⇔ &a[0][0]
  - a[1] ⇔ &a[1][0]
- **Array a** is then actually an **address array** composed of a[0], a[1], i.e. a ⇔ &a[0]

Walk through array with pointer

```
#include <stdio.h>

const int MAX = 3;

int main () {

  int a_i[] = {10, 20, 30};
  double a_f[] = {0.5, 1.5, 2.5};
  int i;
  int *i_ptr;
  double *f_ptr;

  /* let us have array address in pointer */
  i_ptr = a_i;
  f_ptr = a_f;

  /* use the ++ operator to move to next location */
  for (i=0; i<MAX; i++,i_ptr++,f_ptr++ ) {
    printf("adr a_i[%d] = %8p\t", i, i_ptr );
    printf("adr a_f[%d] = %8p\n", i, f_ptr );
    printf("val a_i[%d] = %8d\t", i, *i_ptr );
    printf("val a_f[%d] = %8.2f\n", i, *f_ptr );
  }
  return 0;

}
```

Dynamic memory allocation using pointers

- For situations that the size of an array is unknown, we must use pointers to dynamically manage storage space.
- C provides several functions for memory allocation and management.
- Include <stdlib.h> header file to use these functions.
- Function prototype:

```
/* This function allocates a block of num bytes of memory and
     return
a pointer to the beginning of the block. */
void *malloc(int num);
/* This function release a block of memory block specified by
address. */
void free(void *address);
```

Example of 1D dynamic array

```c
/* dynamic_1d_array.c */

#include <stdio.h>
#include <stdlib.h>

int main(void) {

  int n;
  int* i_array; /* define the integer pointer */
  int j;

  /* find out how many integers are required */
  printf("Input the number of elements in the array:\n");
  scanf("%d",&n);

  /* allocate memory space for the array */
  i_array = (int*)malloc(n*sizeof(int));

  /* output the array */
  for (j=0;j<n;j++) {
    i_array[j]=j; /* use the pointer to walk along the array */
    printf("%d ",i_array[j]);
  }

  printf("\n");
  free((void*)i_array); /* free memory after use*/
  return 0;
}
```

File Input/Output

Opening & Closing Files

- Opening Files: use the `fopen( )` function to create a new file or to open an existing file, this call will initialize an object of the type FILE

```
FILE *fopen( const char * filename, const char * mode );
```

  - `filename` is string literal, which you will use to name your file and access `mode` can have one of the following values:

Mode	Description
r	Read Only, file pointer is at beginning of file
w	Write Only, file pointer is at beginning of file
a	Append, if file exists, file pointer is at end of file
r+	Read & Write
w+	first truncate the file to zero length if it exists otherwise create the file if it does not exist.
a+	creates file if it does not exist. The reading will start from the beginning but writing can only be appended.

- Closing Files: use the `fclose( )` function.

```
int fclose( FILE *fp );
```

  - The `fclose( )` function returns zero on success, or EOF if there is an error in closing the file.
  - This function actually, flushes any data still pending in the buffer to the file, closes the file, and releases any memory used for the file.
  - The EOF is a constant defined in the header file stdio.h.

Writing Files

- simplest function to write individual characters to a stream:

```
int fputc( int c, FILE *fp );
```

- function `fputc()` writes the character value of the argument 'c' to the output stream referenced by `fp`.
- returns the written character written on success otherwise EOF if there is an error.
- to write a null-terminated string to a stream:

```
int fputs( const char *s, FILE *fp );
```

- function `fputs()` writes the string 's' to the output stream referenced by `fp`.
- returns a non-negative value on success, otherwise EOF is returned in case of any error.
- You can use `int fprintf(FILE *fp,const char *format, ...)` function as well to write a string into a file.

Reading Files

- simplest function to read a single character from a file:

```
int fgetc( FILE * fp );
```

- `getc()|` unction reads a character from the input file referenced by `fp`.
- return value is the character read, or in case of any error it returns EOF.
- functions to read a string from a stream:

```
char *fgets( char *buf, int n, FILE *fp );
```

- function `fgets()` reads up to $n - 1$ characters from the input stream referenced by `fp`.
- It copies the read string into the buffer buf, appending a null character to terminate the string.

Example: Writing & Reading a File

```c
#include <stdio.h>

main()
{
  FILE *fp;

  fp = fopen("/tmp/test.txt", "w+");
  fprintf(fp, "This is testing for fprintf...\n
        ");
  fputs("This is testing for fputs...\n", fp);
  fclose(fp);
}
```

```c
#include <stdio.h>

main()
{
  FILE *fp;
  char buff[255];

  fp = fopen("/tmp/test.txt", "r");
  fscanf(fp, "%s", buff);
  printf("1 : %s\n", buff );

  fgets(buff, 255, (FILE*)fp);
  printf("2: %s\n", buff );

  fgets(buff, 255, (FILE*)fp);
  printf("3: %s\n", buff );
  fclose(fp);

  }
```

Preprocessor

C Preprocessor I

- The C Preprocessor is not part of the compiler, but is a separate step in the compilation process.
- In simplistic terms, a C Preprocessor is just a text substitution tool and they instruct compiler to do required pre-processing before actual compilation.
- All preprocessor commands begin with a pound symbol (#).
- It must be the first nonblank character, and for readability, a preprocessor directive should begin in first column.

Directive	Description
#define	Substitutes a preprocessor macro
#include	Inserts a particular header from another file
#undef	Undefines a preprocessor macro
#ifdef	Returns true if this macro is defined
#ifndef	Returns true if this macro is not defined
#if	Tests if a compile time condition is true
#else	The alternative for #if
#elif	#else an #if in one statement
#endif	Ends preprocessor conditional
#error	Prints error message on stderr
#pragma	Issues special commands to the compiler, using a standardized method

C Preprocessor II

- replace instances of MAX_ARRAY_LENGTH with 20

```
#define MAX_ARRAY_LENGTH 20
```

- get stdio.h from System Libraries and add the text to the current source file.

```
#include <stdio.h>
```

- get myheader.h from the local directory and add the content to the current source file.

```
#include "myheader.h"
```

- undefine existing FILE_SIZE and define it as 42.

```
#undef FILE_SIZE
```

```
#define FILE_SIZE 42
```

- define MESSAGE only if MESSAGE isn't already defined.

```
#ifndef MESSAGE
#define MESSAGE "You wish!"
#endif
```

C Preprocessor III

- process the statements enclosed if DEBUG is defined.

```
#ifdef DEBUG
/* Your debugging statements here */
#endif
```

- This is useful if you pass the -DDEBUG flag to gcc compiler at the time of compilation.

Exercise

Calculate Area and Circumference

- Write a code to read a radius from standard input and calculate area and circumference of a circle of that radious

Algorithm 1 Pseudo code for calculating area and circumference

program AREACIRCUM
    Define π
    $r \leftarrow$ some number
    $a = \pi r^2$
    $c = 2\pi r$
end program AREACIRCUM

Roots of Quadratic Equation

- Solve the quadratic equation $ax^2 + bx + c = 0$

$$x = \frac{-b \pm \sqrt{(}b^2 - 4ac)}{2a}$$

Algorithm 2 Pseudo Code for Solving Quadratic Equation

program ROOTS
    read a, b, c from standard input
    $d \leftarrow b^2 + 4ac$
    $x \leftarrow (-b + \sqrt{d})/2a$ and $x \leftarrow (-b - \sqrt{d})/2a$
end program ROOTS

Fibonacci Numbers

- In mathematical terms, the sequence F_n of Fibonacci numbers is defined by the recurrence relation

$$F_n = F_{n-1} + F_{n-2},$$

with seed values

$$F_0 = 0; F_1 = 1.$$

- Calculate the first n Fibonacci Numbers.

Algorithm 3 Pseudo Code to calculate sequence of Fibinacci Numbers

---

program FIBONACCI
  $n \leftarrow$ a number > 5
  $f0 \leftarrow 0$, $f1 \leftarrow 1$
  do $i \leftarrow 2 \cdots n$
    $fn \leftarrow f0 + f1$, $f0 \leftarrow f1$, $fn \leftarrow f1$
  end do
end program FIBONACCI

Factorial

- Calculate factorial and double factorial of a number

Algorithm 4 Pseudo Code for Factorial

program FACTORIAL
  $n \leftarrow$ a number
  do $i \leftarrow n, n-1, n-2 \cdots 1$
    $f = f * i$
  end do
end program FACTORIAL

Calculate GCD & LCM I

- In mathematics, the greatest common divisor (gcd) of two or more integers, when at least one of them is not zero, is the largest positive integer that divides the numbers without a remainder.
- Using Euclid's algorithm

$$gcd(a, 0) = a$$
$$gcd(a, b) = gcd(b, a\%b)$$

- In arithmetic and number theory, the least common multiple of two integers a and b is the smallest positive integer that is divisible by both a and b.

$$lcm(a, b) = \frac{\mid a \cdot b \mid}{gcd(a, b)}$$

Calculate GCD & LCM II

Algorithm 5 Pseudo Code to calculate gcd

program GCDLCM
  $a, b \leftarrow$ two integers
  do while $b \neq 0$
    $t \leftarrow v, v \leftarrow u\%v, u \leftarrow t$
  end do
  $gcd \leftarrow |u|$
  $lcm \leftarrow |a \cdot b|/gcd$
end program GCDLCM

Calculate pi by Numerical Integration I

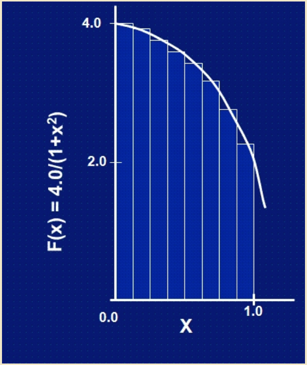
- We know that

$$\int_0^1 \frac{4.0}{(1+x^2)}\,dx = \pi$$

- So numerically, we can approxiate pi as the sum of a number of rectangles

$$\sum_{i=0}^{N} F(x_i)\Delta x \approx \pi$$

Meadows et al, A "hands-on" introduction to OpenMP, SC09



Calculate pi by Numerical Integration II

Algorithm 6 Pseudo Code for Calculating Pi

program CALCULATE_PI
    $step \leftarrow 1/n$
    $sum \leftarrow 0$
    do $i \leftarrow 0 \cdots n$
        $x \leftarrow (i + 0.5) * step; sum \leftarrow sum + 4/(1 + x^2)$
    end do
    $pi \leftarrow sum * step$
end program

SAXPY

- SAXPY is a common operation in computations with vector processors included as part of the BLAS routines

  $y \leftarrow \alpha x + y$

- Write a SAXPY code to multiply a vector with a scalar.

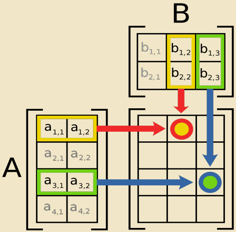
Algorithm 7 Pseudo Code for SAXPY

program SAXPY
  $n \leftarrow$ some large number
  $x(1:n) \leftarrow$ some number say, 1
  $y(1:n) \leftarrow$ some other number say, 2
  $a \leftarrow$ some other number ,say, 3
  do $i \leftarrow 1 \cdots n$
    $y_i \leftarrow y_i + a * x_i$
  end do
end program SAXPY

Matrix Multiplication I

- Most Computational code involve matrix operations such as matrix multiplication.
- Consider a matrix **C** which is a product of two matrices **A** and **B**:

  Element *i,j* of **C** is the dot product of the i^{th} row of **A** and j^{th} column of **B**
- Write a MATMUL code to multiple two matrices.



Matrix Multiplication II

Algorithm 8 Pseudo Code for MATMUL

```
program MATMUL
    m, n ← some large number ≤ 1000
    Define a_mn, b_nm, c_mm
    a_ij ← i + j; b_ij ← i − j; c_ij ← 0
    do i ← 1 ··· m
        do j ← 1 ··· m
            c_i,j ← Σ_{k=1}^{n} a_i,k * b_k,j
        end do
    end do
end program MATMUL
```