Intro to C Programming

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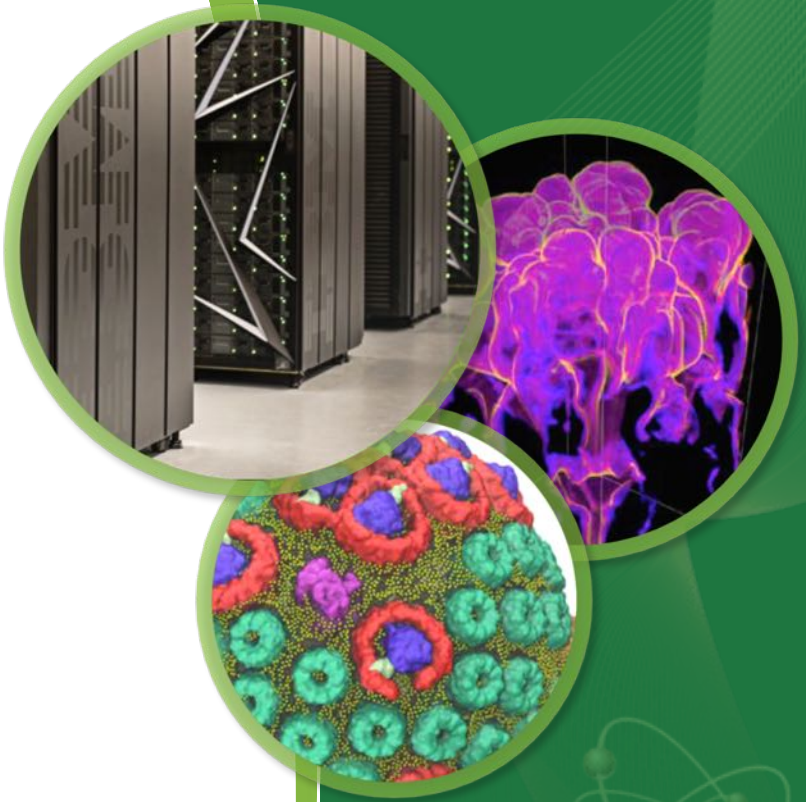

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C Programming Language

- General-purpose programming language initially developed by Dennis Ritchie at Bell Laboratories

- Compiled Language
  - A compiler is a program used to convert high-level code (like C) into machine code

- Many operating systems, as well as Perl, PHP, Python, and Ruby, are written in C.

A Simple C Program (01_simple_c_program/simple.c)

```
#include <stdio.h>

int main(){

    int a = 3;
    printf("The value of this integer is %d\n", a);

    return 0;

}
```

A Simple C Program

C preprocessor directive telling the compiler to include contents of the header file in angle brackets.

```
#include <stdio.h>

int main(){

    int a = 3;

    printf(“The value of this integer is %d\n”, a);

    return 0;

}
```

A Simple C Program

```c
#include <stdio.h>

int main(){

    int a = 3;
    printf("The value of this integer is %d\n", a);

    return 0;

}
```

Declaration of a function called main, which is where execution of the program begins. The "`int`" indicates that the function will return an integer value.

More on functions later…

A Simple C Program

These curly braces indicate the beginning and end of the main function.

```
#include <stdio.h>

int main(){

    int a = 3;
    printf("The value of this integer is %d\n", a);

    return 0;

}
```

A Simple C Program

```
#include <stdio.h>

int main(){

    int a = 3;
    printf("The value of this integer is %d\n", a);

    return 0;

}
```

Defines an integer called "a" and assigns it a value of 3.

More on data types soon…

A Simple C Program

A semicolon is used to indicate the end of each statement.

```
#include <stdio.h>

int main(){

     int a = 3;
     printf("The value of this integer is %d\n", a);

     return 0;

}
```

A Simple C Program

```
#include <stdio.h>

int main(){

    int a = 3;

    printf("The value of this integer is %d\n", a);

    return 0;

}
```

A function, called `printf`, that sends formatted output to stdout (typically the terminal from which the program was run).

This is one of the functions defined in the `stdio.h` header file.

More on `printf` soon…

A Simple C Program

And, of course, a semicolon to indicate the end of the statement.

```
#include <stdio.h>

int main(){

     int a = 3;
     printf("The value of this integer is %d\n", a);

     return 0;

}
```

A Simple C Program

```
#include <stdio.h>

int main(){

    int a = 3;
    printf("The value of this integer is %d\n", a);

    return 0;

}
```

Return value "returned" to the run-time environment.

Typically, a value of 0 indicates a normal/successful exit.

A Simple C Program – Ok, let's compile and run

```
$ cc simple.c

$ ls
a.out simple.c


$ aprun -n1 ./a.out
The value of this integer is 3
```

Compile and link file into executable

- Using the cray compiler wrapper `cc` instead of, say, `pgcc` directly

Executable is named a.out by default

Run program – launched with `aprun`

A Simple C Program – Ok, let's compile and run

```
$ cc -o simple.exe simple.c
```

Compile and link file into executable

```
$ ls
simple.exe simple.c
```

-o is a compiler flag that allows you to name the executable

```
$ aprun -n1 ./simple.exe
The value of this integer is 3
```

Run program

Variables and Basic C Data Types

Variables are named storage areas

- For example, `int a = 5` creates a variable (storage area in memory) named "`a`" and saves the value of `5` in that memory location.
  - Variables of different data types occupy different amounts of memory and can store different ranges of values
- Must be declared before use.

Basic C Data Types

Name	Type	Range of Values	Size (B)
char	Character	ASCII characters	1
int	Integer	-2,147,483,648 to 2,147,483,647	4
float	Decimal (precision to 6 places)	1.2e-38 to 3.4e38	4
double	Decimal (precision to 15 places)	2.3e-308 to 1.7e308	8

Formatted Output with printf Function

Example 1:

```
printf("Hello World");
```

The Result of Example 1 would be: `Hello World`

Example 2:

```
printf("Hello World\n");
```

The Result of Example 2 would be: `Hello World` (with a new line)

Formatted Output with printf Function

Example 3:

```
int i = 2;
printf("The value of the integer is %d\n", i);
```

format tag

Variable whose value is used in format tag

String to print, with format tags

The Result of Example 3 would be: `The value of the integer is 2`

Example 4:

```
float x = 3.14159;
printf("The value of the float is %.2f\n", x);
```

format tag

String to print, with format tags

Variable whose value is used in format tag

The result of Example 4 would be: `The value of the float is 3.14`

Formatted Output with printf Function

Name	Type	Range of Values	Format Specifier
char	Character	ASCII characters	%c
int	Integer	-32,768 to 32,767 <or> -2,147,483,648 to 2,147,483,647	%d
float	Decimal (precision to 6 places)	1.2e-38 to 3.4e38	%f
double	Decimal (precision to 15 places)	2.3e-308 to 1.7e308	%f

There are many options to format output using the printf function. Feel free to Google :)

C Arrays

Data structure that holds a fixed number of data elements of a specific type


```
int A[10];     // declares an array of 10 integers
```

C Arrays

Data structure that holds a fixed number of data elements of a specific type

7	32	256	17	-20	22	1	0	59	-2
A[0]	A[1]	A[2]	A[3]	A[4]	A[5]	A[6]	A[7]	A[8]	A[9]

Each element is 4 bytes for int

```
int A[10];      // declares an array of 10 integers

A[0] = 7;       // assigns values to the array elements
A[1] = 32;
A[2] = 256;
A[3] = 17;
A[4] = -20;
A[5] = 22;
A[6] = 1;
A[7] = 0;
A[8] = 59;
A[9] = -2;
```

```
printf("The value of A[3] = %d\n", A[3]);
```

The result would be:

```
The value of A[3] = 17
```

Loops

- While Loop
- Do-While Loop
- For Loop

While Loops

```
while(expression){

   // Execute loop statements until expression evaluates to 0

}
```

`expression:` Evaluated before each iteration

03_loops/while_loop/while_loop.c

```c
#include <stdio.h>

int main(){

  float x   = 1000.0;

  while(x > 1.0){
    printf("x = %f\n", x);
    x = x / 2.0;
  }

  return 0;
}
```

```
$ cc -o while_loop.exe while_loop.c

$ aprun -n1 ./while_loop.exe
x = 1000.000000
x = 500.000000
x = 250.000000
x = 125.000000
x = 62.500000
x = 31.250000
x = 15.625000
x = 7.812500
x = 3.906250
x = 1.953125
```

Do-While Loops

```
do{
   // Execute loop statements until expression evaluates to 0
}while(expression)
```

`expression:` Evaluated after each iteration

For Loops

```
for(initialization; conditional_expression; iteration){

  // loop statements

}
```

`conditional_expression:`	**Evaluated before body of loop**
`iteration:`	**Evaluated after body of loop**

03_loops/for_loop/for_loop.c

```
#include <stdio.h>

int main(){

  int N   = 10;
  int sum = 0;

  for(int i=0; i<N; i++){

    sum = sum + i;
    printf("Iteration: %d, sum = %d\n", i, sum);

  }

  return 0;

}
```

i++ is same as i = i + 1

```
$ cc -o for_loop.exe for_loop.c

$ aprun -n1 ./for_loop.exe
Iteration: 0, sum = 0
Iteration: 1, sum = 1
Iteration: 2, sum = 3
Iteration: 3, sum = 6
Iteration: 4, sum = 10
Iteration: 5, sum = 15
Iteration: 6, sum = 21
Iteration: 7, sum = 28
Iteration: 8, sum = 36
Iteration: 9, sum = 45
```

Continue Statement

When a **continue** statement is encountered within a loop, the remaining statements in the loop body (after the continue) are skipped and the next iteration of the loop begins.

03_loops/continue/continue.c

```
#include <stdio.h>

int main(){

  for(int i=0; i<10; i++){

    if(i == 7){
      continue;
    }

    printf("Loop iteration: %d\n", i);
  }

  return 0;
}
```

```
$ cc -o continue.exe continue.c

$ aprun -n1 ./continue.exe
Loop iteration: 0
Loop iteration: 1
Loop iteration: 2
Loop iteration: 3
Loop iteration: 4
Loop iteration: 5
Loop iteration: 6
Loop iteration: 8
Loop iteration: 9
```

Break Statement

When a **break** statement is encountered within a loop, the loop is terminated.

03_loops/break/break.c

```c
#include <stdio.h>

int main(){

  for(int i=0; i<10; i++){

    if(i == 7){
      break;
    }

    printf("Loop iteration: %d\n", i);
  }

  return 0;
}
```

```
$ cc -o break.exe break.c

$ aprun -n1 ./break.exe
Loop iteration: 0
Loop iteration: 1
Loop iteration: 2
Loop iteration: 3
Loop iteration: 4
Loop iteration: 5
Loop iteration: 6
```

Operators

Although we've been using them already, let's take a closer look at operators…

Arithmetic Operators

```
int A = 10;
int B = 2;
```

A *op* B

`+` Add	`A + B; // would give 12`
`-` Subtract	`A - B; // would give 8`
`*` Multiply	`A * B; // would give 20`
`/` Divide	`A / B; // would give 5`
`%` Modulus	`A % B; // would give 0` Remainder after division of B into A

`A++` Increment (same as `A = A + 1`) `// would give 11`

`B--` Decrement (same as `B = B - 1`) `// would give 1`

Relational Operators

Tests relationship between two operands

- If true, returns 1
- If false, returns 0

```
int A = 10;
int B = 2;
```

A *op* B

`==`	Equal to	`A == B; // would give 0 (false)`
`!=`	Not equal to	`A != B; // would give 1 (true)`
`>`	Greater than	`A > B;  // would give 1 (true)`
`<`	Less than	`A < B;  // would give 0 (false)`
`>=`	Greater than or equal to	`A >= B; // would give 1 (true)`
`<=`	Less than or equal to	`A <= B; // would give 0 (false)`

Assignment Operators

```
int A = 10;
int B = 2;
```

`=`	`A = B;   // would assign a value of 2 to A`	
`+=`	`A += B; // would assign a value of 12 to A`	(Same as `A = A + B`)
`-=`	`A -= B; // would assign a value of 8 to A`	(Same as `A = A - B`)
`*=`	`A *= B; // would assign a value of 20 to A`	(Same as `A = A * B`)
`/=`	`A /= B; // would assign a value of 5 to A`	(Same as `A = A / B`)
`%=`	`A %= B; // would assign a value of 10 to A`	(Same as `A = A % B`)

Logical Operators

Used in conjunction with relational operations for decision making

```
int A = 10;
int B = 2;
int C = 5;
```

`&&`	And (true if both true)	`((A > B) && (B == C)); // would give 0 (false)`
`||`	Or (true if at least 1 is true)	`((A > B) || (B == C)); // would give 1 (true)`
`!`	Not (returns the opposite)	`!(B == C);               // would give 1 (true)`

If statements

Let’s take a look at if statements …

If Statements

```
if(condition_1){
  // Execute these statements if condition_1 is met
}
else if(condition_2){
  // Execute these statements if condition_2 is met
}
else{
  // Execute these statements if other conditions are not met
}
```

Once a condition is met, the statements associated with that section are executed and all other sections are ignored.

04_if_statements/if_statement/if_statements.c

```c
#include <stdio.h>

int main(){

  int i = 1;


  if(i < 1){
    printf("i = %d (i < 1)\n", i);
  }
  else if(i == 1){
    printf("i is equal to 1\n");
  }
  else{
    printf("i = %d (i > 1)\n", i);
  }


  return 0;
}
```

```
$ cc -o if_statement.exe if_statement.c

$ aprun -n1 ./if_statement.exe
i is equal to 1
```

Functions

A reusable block of code that performs a specific task

- Standard Library Functions
- User-Defined Functions

Standard Library Functions

C built-in functions that can be accessed with appropriate `#include` statements

We have already encountered the `printf` function, which is can be used by including the `stdio.h` header file

There are many other C standard library functions defined in other header files

- `math.h`, `stdlib.h`, `string.h`, etc.

These functions should be used whenever possible in order to save time (why re-invent the wheel) and because they are well-tested and portable.

User Defined Functions

```
return_type function_name(type1 arg1, type2 arg2, ...){
  // Function Body
}
```

Let’s see some examples …

05_functions/add_two_numbers/add_two_numbers.c

```c
#include <stdio.h>

// Function Definition
int add_numbers(int i, int j){

  int result;
  result = i + j;

  return result;
}

// Main Function
int main(){

  int num1 = 3;
  int num2 = 7;

  int sum = add_numbers(num1, num2);
  printf("The sum of num1 and num2 is %d\n", sum);

  return 0;
}
```

```
$ cc -o add_two_numbers.exe add_two_numbers.c

$ aprun -n1 ./add_two_numbers.exe
The sum of num1 and num2 is 10
```

05_functions/add_two_numbers/add_two_numbers.c

```c
#include <stdio.h>

// Function Definition
int add_numbers(int i, int j){

  int result;
  result = i + j;

  return result;
}

// Main Function
int main(){

  int num1 = 3;
  int num2 = 7;

  int sum = add_numbers(num1, num2);
  printf("The sum of num1 and num2 is %d\n", sum);

  return 0;
}
```

```
$ cc -o add_two_numbers.exe add_two_numbers.c

$ aprun -n1 ./add_two_numbers.exe
The sum of num1 and num2 is 10
```

Formal parameters/arguments

Actual parameters/arguments

05_functions/change_value/change_value.c

```
#include <stdio.h>

// Function Definition
void change_number(int i){
  i = 2;
  printf("Inside the function, the number's value is %d\n", i);
}

// Main Function
int main(){

  int number = 1;
  printf("\nBefore calling the function, number = %d\n", number);

  change_number(number);

  printf("After calling the function, number = %d\n\n", number);

  return 0;
}
```

```
$ cc -o change_value.exe change_value.c

$ aprun -n1 ./change_value.exe
Before calling the function, number = 1
Inside the function, the number's value is 2
After calling the function, number = 1
```

Wait.
What's going on here?

The values of the actual arguments are copied to the formal arguments.

- So changes to the formal arguments do not affect the actual arguments.
- This is called "call by value"

ASIDE: Variable Addresses and Pointers

Variable Addresses

The memory address of a variable can be referenced using the reference operator, &

```
#include <stdio.h>

int main(){

  int i = 1;

  printf("The value of i:   %d\n", i);
  printf("The address of i: %p\n", &i);

  return 0;
}
```

%p – format tag to print address

& (reference operator) – gives the address of the variable

```
$ cc -o variable_addresses.exe variable_addresses.c

$ aprun -n1 ./variable_addresses.exe
The value of i:   1
The address of i: 0x7fff3e720c2c
```
(this address will vary)

Pointer Variables

06_addresses_and_pointers/pointers_1/pointers_1.c

There are special variables in C to store memory addresses: pointers

```
#include <stdio.h>

int main(){

  float x = 2.713;
  float *p_x;

  p_x = &x;

  printf("The value of x:   %f\n", x);
  printf("The address of x: %p\n", &x);
  printf("The value of p_x: %p\n", p_x);
  printf("The value stored in the memory address stored in p_x: %f\n", *p_x);

  return 0;
}
```

* used to declare pointer (`float *p_x;`)

The pointer is assigned the value of the memory address of x (`p_x = &x;`)

* (dereference operator) – gives the value stored at a memory address (`*p_x`)

This is different use of * than above!

```
$ cc -o pointers_1.exe pointers_1.c

$ aprun -n1 ./pointers_1.exe
The value of x:   2.713000
The address of x: 0x7fff5ce8aa68
The value of p_x: 0x7fff5ce8aa68
The value stored in the memory address stored in p_x: 2.713000
```

Pointer Variables

06_addresses_and_pointers/pointers_2/pointers_2.c

```
$ cc -o pointers_2.exe pointers_2.c

$ aprun -n1 ./pointers_2.exe
The value of x:   2.713000
The address of x: 0x7fff5ce8aa68
The value of p_x: 0x7fff5ce8aa68
The value stored in the memory address stored in p_x: 2.713000

The value of x:   3.141000
```

```
#include <stdio.h>

int main(){

  float x = 2.713;
  float *p_x;

  p_x = &x;

  printf("The value of x:   %f\n", x);
  printf("The address of x: %p\n", &x);
  printf("The value of p_x: %p\n", p_x);
  printf("The value stored in the memory address stored in p_x: %f\n", *p_x);

  *p_x = 3.141;

  printf("\nThe value of x:   %f\n", x);

  return 0;
}
```

* (dereference operator) – gives the value stored at a memory address

* (dereference operator) – also allows you to change the value stored at that memory address

Ok, back to functions …

05_functions/change_value/change_value.c

```
$ cc -o change_value.exe change_value.c

$ aprun -n1 ./change_value.exe
Before calling the function, number = 1
Inside the function, the number's value is 2
After calling the function, number = 1
```

```c
#include <stdio.h>

// Function Definition
void change_number(int i){
  i = 2;
  printf("Inside the function, the number's value is %d\n", i);
}

// Main Function
int main(){

  int number = 1;
  printf("\nBefore calling the function, number = %d\n", number);


  change_number(number);


  printf("After calling the function, number = %d\n\n", number);


  return 0;
}
```

In order to change the value of an actual argument, we must pass its memory address, not just its value.

(call by reference)

05_functions/change_value_correct/change_value_correct.c

```
$ cc -o change_value_correct.exe change_value_correct.c

$ aprun -n1 ./change_value_correct.exe
Before calling the function, number = 1
Inside the function, the number's value is 2
After calling the function, number = 2
```

```
#include <stdio.h>

// Function Definition
void change_number(int *i){
  *i = 2;
  printf("Inside the function, the number's value is %d\n", *i);
}

// Main Function
int main(){

  int number = 1;
  printf("\nBefore calling the function, number = %d\n", number);


  change_number(&number);


  printf("After calling the function, number = %d\n\n", number);


  return 0;
}
```

Remember, the * used declare the pointer variable, i, in the function argument is different than the * used within the body of the function. To be clear,

`int *i`

- The * here is simply because this is how you declare a pointer to an integer.

`*i = 2`
`printf(" … %d\n", *i)`

- The * in these statements is the dereference operator, which allows you to access the value of the variable associated with the memory address.

"Call by reference"

Memory Allocation

- Stack
  - Region of computer memory that stores temporary variables
    - When a new function is called the variables are created on stack
    - When the function returns, the memory is returned to the stack (LIFO)
  - Memory managed for you
  - Variables can only be accessed locally
  - Variable size must be known at compile time

- Heap
  - Region of compute memory for dynamic allocation
    - No pattern to allocation/deallocation (user can do this any time)
  - Memory managed by user
    - E.g. using malloc(), free(), etc.
  - Variables can be accessed globally
  - Variable size can be determined at run time

07_memory_allocation/static.c

```c
#include <stdio.h>

int main(){

// Statically-allocated array of floats
  int N = 5;
  float f_array[N];

  for(int i=0; i<N; i++){
    f_array[i] = 0.25*i;
  }

  for(int i=0; i<N; i++){
    printf("f_array[%d] = %f\n", i, f_array[i]);
  }

  return 0;
}
```

```
$ cc -o static.exe static.c

$ aprun -n1 ./static.exe
f_array[0] = 0.000000
f_array[1] = 0.250000
f_array[2] = 0.500000
f_array[3] = 0.750000
f_array[4] = 1.000000
```

07_memory_allocation/dynamic.c

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

int main(){

// Dynamically-allocated array of floats
  int N = 5;
  float *f_array_dyn = malloc(N*sizeof(float));

  for(int i=0; i<N; i++){
    f_array_dyn[i] = 0.25*i;
  }

  for(int i=0; i<N; i++){
    printf("f_array_dyn[%d] = %f\n", i, f_array_dyn[i]);
  }

  free(f_array_dyn);

  return 0;
}
```

```
$ cc -o dynamic.exe dynamic.c

$ aprun -n1 ./dynamic.exe
f_array_dyn[0] = 0.000000
f_array_dyn[1] = 0.250000
f_array_dyn[2] = 0.500000
f_array_dyn[3] = 0.750000
f_array_dyn[4] = 1.000000
```

Allocates `N*sizeof(float)` bytes of memory and returns pointer to the block of memory

Releases block of memory associated with f_array_dyn

Additional Resources

- Exercises that go with these slides (as well as some examples to work through)
  - https://github.com/olcf/intro_to_C
- Other sites
  - https://en.cppreference.com/w/c/language
  - https://en.wikibooks.org/wiki/C_Programming
  - https://stackoverflow.com/questions/tagged/c
  - Many other tutorials can be found by googling “c programming language”
- Website with many practice problems
  - https://projecteuler.net/

Examples Used in These Slides

The examples used in these slides can be obtained from OLCF's GitHub:

```
$ cd $MEMBERWORK/trn001
```

← Since jobs must be launched from Lustre

```
$ git clone https://github.com/olcf/intro_to_C.git
```

Grab a node in an interactive job:

```
$ qsub -I -A TRN001 -l nodes=1,walltime=2:00:00
qsub: waiting for job 4109771 to start
qsub: job 4109771 ready

$ cd $MEMBERWORK/trn001
```

← This is where we cloned the intro_to_C repository.

Launch executables with `aprun` command:

```
$ aprun -n1 ./a.out
```


Thank You.

Bonus Slides

Compiled vs Interpreted Language

In both cases, a high-level language must be converted into lower-level instructions that the processor can understand

- Interpreted Language (e.g. Python)
  - Parse commands in high-level language, translate each command into machine code, then execute each command
  - Typically slower due to
    - Translation occurring while code is being run
    - Redundant translations (e.g. loops)
    - No global optimization (e.g. pipelining work)
  - Easier interactive code development (simply edit code and run)

- Compiled Language (e.g. C, Fortran)
  - Compiler parses "source code" files in high-level language and translate into an executable (machine code).
  - Typically faster due to
    - Executable can be run without need for "in-line" translation
    - Reduce redundant translations
    - Allows global optimizations (e.g. compiler can determine which instructions come next, so can "pre-fetch" data for that command)

02_data_types/data_types/data_types.c

```
$ cc -o data_types.exe data_types.c

$ aprun -n1 ./data_types.exe

The value of character a:              X (size 1 byte)
The value of integer i:                22 (size 4 bytes)
The value of float x:                  3.1415927410125732 (size 4 bytes)
The value of double y:                 3.1415926535897931 (size 8 bytes)
The value of pi to 29 decimal places: 3.14159265358979323846264338327
```

```c
#include <stdio.h>

int main(){

  char a = 'X';
  int i = 22;
  float x = 3.14159265358979323846264338327;
  double y = 3.14159265358979323846264338327;

  // Strings in C are arrays of char
  char pi[31] = "3.14159265358979323846264338327";

  printf("\n");
  printf("The value of character a:              %c (size %d byte)\n", a, sizeof(char));
  printf("The value of integer i:                %d (size %d bytes)\n", i, sizeof(int));
  printf("The value of float x:                  %.16f (size %d bytes)\n", x, sizeof(float));
  printf("The value of double y:                 %.16f (size %d bytes)\n", y, sizeof(double));
  printf("The value of pi to 29 decimal places: %s\n", pi);
  printf("\n");

  return 0;

}
```

03_loops/do_while_loop/do_while_loop.c

```c
#include <stdio.h>

int main(){

  int j   = 10; // Declare j and set value to 10

 /* ---------------------------------------
  while loop
    -> Executes statements ONLY if
       condition is met
  ---------------------------------------*/
  while(j > 10 && j < 20){
    printf("while: j = %d\n", j);
    j = j + 1;
  }

  j = 10; // Reset value of j to 10

  /* ---------------------------------------
  do while loop
    -> Executes statements at least 1 time,
       even if condition is not met
  ---------------------------------------*/
  do{
    printf("do-while: j = %d\n", j);
    j = j + 1;
  }while(j > 10 && j < 20);

  return 0;

}
```

```
$ cc -o do_while_loop.exe do_while_loop.c

$ aprun -n1 ./while_loop.exe
do-while: j = 10
do-while: j = 11
do-while: j = 12
do-while: j = 13
do-while: j = 14
do-while: j = 15
do-while: j = 16
do-while: j = 17
do-while: j = 18
do-while: j = 19
```