Module 01: Programming in C++

Recap of C

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Module Objectives

- Revisit the concepts of C language
- Revisit C Standard Library components
- Revisit the Organization and Build Process for C programs
- Create the foundation for the concepts of C++ with backward compatibility to C

Module Outline

- Recap of C features
  - Data types
  - Variables
  - Literals
  - Operators
  - Expressions
  - Statements
  - Control Constructs – Conditional Flow & Loops
  - Arrays
  - Structures & Unions
  - Pointers
  - Functions
  - Input / Output
- C Standard Library
- Source Organization for a C program
- Build Process

Module 01: Lecture 01

- Recap of C features
  - Data types
  - Variables
  - Literals
  - Operators
  - Expressions
  - Statements
  - Control Constructs – Conditional Flow & Loops

First C program

- Print "Hello World"

Source Program

```
#include <stdio.h>

int main() {

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

    return 0;
}
```

- `stdio.h` header included for input / output
- `main` function is used to start execution
- `printf` function is used to print the string "Hello World"

Data Types

Data types in C are used for declaring variables and deciding on storage and computations:

- **Built-in** / **Basic** data types are used to define raw data
  - `char`
  - `int`
  - `float`
  - `double`

  Additionally, C99 defines:
  - `bool`

  All data items of a given type has the same size (in bytes). The size is implementation-defined.
- **Enumerated Type** data are internally of `int` type and operates on a select subset.

Data Types

Data types in C further include:

- **void**: The type specifier `void` indicates no type.
- **Derived** data types include:
  - Array
  - Structure – `struct` & `union`
  - Pointer
  - Function
  - String – C-Strings are really not a type; but can be made to behave as such using functions from `<string.h>` in standard library
- **Type modifiers** include:
  - `short`
  - `long`
  - `signed`
  - `unsigned`

Variables

- A variable is a name given to a storage area
- Declaration of Variables:
  - Each variable in C has a specific type, which determines the size and layout of the storage (memory) for the variable
  - The name of a variable can be composed of letters, digits, and the underscore character. It must begin with either a letter or an underscore

```
int    i, j, noOfData;
char   c, endOfSession;
float  f, velocity;
double d, dist_in_light_years;
```

Variables

- Initialization of Variables:
  - Initialization is setting an initial value to a variable at its definition

```
int    i = 10, j = 20, numberOfWorkDays = 22;
char   c = 'x';
float  weight = 4.5;
double density = 0.0;
```

Literals

- Literals refer to fixed values of a built-in type
- Literals can be of any of the basic data types

```
212     // (int) Decimal literal
0173    // (int) Octal literal
0b1010  // (int) Binary literal
0xF2    // (int) Hexadecimal literal
3.14    // (double) Floating-point literal
'x'     // (char) Character literal
"Hello" // (char *) String literal
```

- In C99, literals are constant values having `const` types as:

```
212     // (const int) Decimal literal
0173    // (const int) Octal literal
0b1010  // (const int) Binary literal
0xF2    // (const int) Hexadecimal literal
3.14    // (const double) Floating-point literal
'x'     // (const char) Character literal
"Hello" // (const char *) String literal
```

Operators

- An operator denotes a specific operation. C has the following types of operators:
  - Arithmetic Operators: + − * / % ++ −−
  - Relational Operators: == != > < >= <=
  - Logical Operators: && || !
  - Bit-wise Operators: & | ~ << >>
  - Assignment Operators: = += −= *= /= ···
  - Miscellaneous Operators: . , `sizeof` & * ?:
- **Arity of Operators:** Number of operand(s) for an operator
  - +, −, *, & operators can be *unary* (1 operand) or *binary* (2 operands)
  - ==, !=, >, <, >=, <=, &&, ||, +=, −=, *=, =, /=, &, |, <<, >> can work only as *b*inary (2 operands) operators
  - `sizeof` ! ~ ++ −− can work only as *unary* (1 operand) operators
  - ?: works as *t*ernary (3 operands) operator. The condition is the first operand and the `if` true logic and `if` false logic corresponds to the other two operands.

Operators

- **Operator Precedence:** Determines which operator will be performed first in a chain of different operators

  The precedence of all the operators mentioned above is in the following order: (left to right – Highest to lowest precedence)

  (), [], ++, –, + (unary), –(unary), !˜, *, &, sizeof, *, /, %, +, –, < <, > >, ==, !=, *=, =, /=, &, |, &&, | |, ?:, =, +=, –=, *=, =, /=, < <=, > >=

- **Operator Associativity:** Indicates in what order operators of equal precedence in an expression are applied

- Consider the expression a ˜ b ˜ c. If the operator ˜ has left associativity, this expression would be interpreted as (a ˜ b) ˜ c. If the operator has right associativity, the expression would be interpreted as a ˜ (b ˜ c).
  - Right-to-Left: ?:, =, +=, -=, *=, =, /=, <<=, >>=, –, +-, !˜, *, &, sizeof
  - Left-to-Right: *, /, %, +, -, <<, >>, ==, !=, *=, =, /=, &, |, &&, | |

Expressions

- Every expression has a value
  - A literal is an expression
  - A variable is an expression
  - One, two or three expression/s connected by an operator (of appropriate arity) is an expression
  - A function call is an expression
- Examples:
  - For

```
int i = 10, j = 20, k;
int f(int x, int y) { return x + y; }
```

  - Expression are:

```
2.5             // Value = 2.5
i               // Value 10
-i              // Value -10
i - j           // Value -10
k = 5           // Value 5
f(i, j)         // Value 30
i + j == i * 3 // Value true
(i == j)? 1: 2 // Value 2
```

Statement

- A statement is a command for a specific action. It has no value
  - A ; (semicolon) is a (null) statement
  - An expression terminated by a ; (semicolon) is a statement
  - A list of one or more statements enclosed within a pair of curly braces { and } or block is a compound statement
  - Control constructs like `if`, `if-else`, `switch`, `for`, `while`, `do-while`, `goto`, `continue`, `break`, `return` are statements
- Example: *Expression statements*

Expressions	Statements
`i + j`	`i + j;`
`k = i + j`	`k = i + j;`
`funct(i,j)`	`funct(i,j);`
`k = funct(i,j)`	`k = funct(i,j);`

- Example: *Compound statements*

```
{
    int i = 2, j = 3, t;

    t = i;
    i = j;
    j = t;
}
```

Control Constructs

- These statements control the flow based on conditions:
  - *Selection-statement*: `if`, `if-else`, `switch`
  - *Labeled-statement*: Statements labeled with identifier, `case`, or `default`
  - *Iteration-statement*: `for`, `while`, `do-while`
  - *Jump-statement*: `goto`, `continue`, `break`, `return`
- Examples:

```
if (a < b) {
    int t;

    t = a;
    a = b;
    b = t;
}
```

```
if (x < 5)
    x = x + 1;
else {
    x = x + 2;
    --y;
}
```

```
switch (i) {
    case 1: x = 5;
            break;
    case 3: x = 10;
    default: x = 15;
}
```

```
int sum = 0;
for(i = 0; i < 5; ++i) {
    int j = i * i;
    sum += j;
}
```

```
while (n) {
    sum += n;
    if (sum > 20)
        break;
    --n;
}
```

```
int f(int x, int y)
{
    return x + y;
}
```

Module 01: End of Lecture 01

- Recap of C features
  - Data types
  - Variables
  - Literals
  - Operators
  - Expressions
  - Statements
  - Control Constructs – Conditional Flow & Loops

Module 01: Lecture 02

- Recap of C features
  - Arrays
  - Structures
  - Unions
  - Pointers

Arrays

- An array is a collection of data items, all of the same type, accessed using a common name
  - Declare Arrays:

```
#define SIZE 10
int name[SIZE];     // SIZE must be an integer constant greater than zero
double balance[10];
```

  - Initialize Arrays:

```
int primes[5] = {2, 3, 5, 7, 11}; // Size = 5

int primes[]  = {2, 3, 5, 7, 11};
int sizeOfPrimes = sizeof(primes)/sizeof(int); // size is 5 by initialization

int primes[5] = {2, 3};           // Size = 5, last 3 elements set to 0
```

  - Access Array elements:

```
int primes[5] = {2, 3};
int EvenPrime = primes[0]; // Read 1st element
primes[2] = 5;             // Write 3rd element
```

  - Multidimensional Arrays:

```
int mat[3][4];

for(i = 0; i < 3; ++i)
    for(j = 0; j < 4; ++j)
        mat[i][j] = i + j;
```

Structures

- A structure is a collection of data items of different types. Data items are called *members*. The size of a structure is the sum of the size of its members.
  - Declare Structures:

```
struct Complex { // Complex Number
    double re;   // Real component
    double im;   // Imaginary component
} c;             // c is a variable of struct Complex type
printf("size = %d\n", sizeof(struct Complex)); // Prints: size = 16

typedef struct _Books {
    char  title[50];    // data member
    char  author[50];   // data member
    int   book_id;      // data member
} Books; // Books is an alias for struct _Books type
```

  - Initialize Structures:

```
struct Complex x = {2.0, 3.5}; // Both members
struct Complex y = {4.2};      // Only the first member
```

  - Access Structure members:

```
struct Complex x = {2.0, 3.5};
double norm = sqrt(x.re*x.re + x.im*x.im); // Using . (dot) operator

Books book;
book.book_id = 6495407;
strcpy(book.title, "C Programming");
```

Unions

- A union is a special structure that allocates memory only for the largest data member and holds only one member as a time
  - Declare Union:

```
typedef union _Packet { // Mixed Data Packet
    int    iData;       // integer data
    double dData;       // floating point data
    char   cData;       // character data
} Packet;
printf("size = %d\n", sizeof(Packet)); // Prints: size = 8
```

  - Initialize Union:

```
Packer p = {10}; // Initialize only with a value of the type of first member
printf("iData = %d\n", p.iData);   // Prints: iData = 10
```

  - Access Union members:

```
p.iData = 2;
printf("iData = %d\n", p.iData);   // Prints: iData = 2
p.dData = 2.2;
printf("dData = %lf\n", p.dData);  // Prints: dData = 2.200000
p.cData = 'a';
printf("cData = %c\n", p.cData);   // Prints: cData = a

p.iData = 97;
printf("iData = %d\n", p.iData);   // Prints: iData = 97
printf("dData = %lf\n", p.dData);  // Prints: dData = 2.199999
printf("cData = %c\n", p.cData);   // Prints: cData = a
```

Pointers

- A pointer is a variable whose value is a memory address
- The type of a pointer is determined by the type of its pointee

```
int    *ip;   // pointer to an integer
double *dp;   // pointer to a double
float  *fp;   // pointer to a float
char   *ch    // pointer to a character
```

- Using a pointer:

```
int main() {
    int  i = 20;   // variable declaration
    int  *ip;      // pointer declaration
    ip = &i;       // store address of i in pointer

    printf("Address of variable: %p\n", &i); // Prints: Address of variable : 00A8F73C

    printf("Value of pointer: %p\n", ip);    // Prints: Value of pointer : 00A8F73C

    printf("Value of pointee: %d\n", *ip);   // Prints: Value of pointee : 20

    return 0;
}
```

Pointers

• Pointer-Array Duality

```
int a[] = {1, 2, 3, 4, 5};
int *p;

p = a;
printf("a[0] = %d\n", *p);      // a[0] = 1
printf("a[1] = %d\n", *++p);    // a[1] = 2
printf("a[2] = %d\n", *(p+1)); // a[2] = 3

p = &a[2];
*p = -10;
printf("a[2] = %d\n", a[2]);    // a[2] = -10
```

• malloc-free

```
int *p = (int *)malloc(sizeof(int));

*p = 0x8F7E1A2B;
printf("%X\n", *p);    // 8F7E1A2B

unsigned char *q = p;
printf("%X\n", *q++); // 2B
printf("%X\n", *q++); // 1A
printf("%X\n", *q++); // 7E
printf("%X\n", *q++); // 8F

free(p);
```

• Pointer to a structure

```
struct Complex { // Complex Number
    double re;   // Real component
    double im;   // Imaginary component
} c = { 0.0, 0.0 };

struct Complex *p = &c;

(*p).re = 2.5;
p->im = 3.6;

printf("re = %lf\n", c.re); // re = 2.500000
printf("im = %lf\n", c.im); // im = 3.600000
```

• Dynamically allocated arrays

```
int *p = (int *)malloc(sizeof(int)*3);

p[0] = 1; p[1] = 2; p[2] = 3;

printf("p[1] = %d\n", *(p+1)); // p[1] = 2
free(p);
```

Module 01: End of Lecture 02

- Recap of C features
  - Arrays
  - Structures
  - Unions
  - Pointers

Module 01: Lecture 03

- Recap of C features
  - Functions
  - Input / Output
- C Standard Library
- Source Organization for a C program
- Build Process

Functions

- A function performs a specific task or computation
  - Has 0, 1, or more parameters / arguments. Every argument has a type (`void` for no argument)
  - May or may not return a result. Return value has a type (`void` for no result)
  - Function declaration:

```
// Function Prototype / Header / Signature
// Name of the function: funct
// Parameters: x and y. Types of parameters: int
// Return type: int

int funct(int x, int y);
```

  - Function definition:

```
// Function Implementation
int funct(int x, int y)

// Function Body
{
    return (x + y);
}
```

Functions

- **Call-by-value** mechanism for passing arguments. The value of an actual parameter copied to the formal parameter
- **Return-by-value** mechanism to return the value, if any.

```
int funct(int x, int y) {
    ++x; ++y;                // Formal parameters changed
    return (x + y);
}

int main() {
    int a = 5, b = 10, z;

    printf("a = %d, b = %d\n", a, b); // prints: a = 5, b = 10

    z = funct(a, b); // function call by value
                     // a copied to x. x becomes 5
                     // b copied to y. y becomes 10
                     // x in funct changes to 6  (++x)
                     // y in funct changes to 11 (++y)
                     // return value (x + y) copied to z

    printf("funct = %d\n", z); // prints: funct = 17

    // Actual parameters do not change on return (call-by-value)
    printf("a = %d, b = %d\n", a, b); // prints: a = 5, b = 10

    return 0;
}
```

Functions

- A function may be recursive (call itself)
  - Has recursive step/s
  - Has exit condition/s
- Example:

```
// Factorial of n
unsigned int factorial(unsigned int n) {
    if (n > 0)
        return n * factorial(n - 1); // Recursive step
    else
        return 1;                    // Exit condition
}

// Number of 1's in the binary representation of n
unsigned int nOnes(unsigned int n) {
    if (n == 0)
        return 0; // Exit condition
    else // Recursive steps
        if (n % 2 == 0)
            return nOnes(n / 2);
        else
            return nOnes(n / 2) + 1;
}
```

Function pointers


```
#include <stdio.h>
struct GeoObject {
    enum { CIR = 0, REC, TRG } gCode;
    union {
        struct Cir { double x, y, r; } c;
        struct Rec { double x, y, w, h; } r;
        struct Trg { double x, y, b, h; } t;
    };
};

typedef void(*DrawFunc) (struct GeoObject);

void drawCir(struct GeoObject go) {
    printf("Circle: (%lf, %lf, %lf)\n",
        go.c.x, go.c.y, go.c.r); }

void drawRec(struct GeoObject go) {
    printf("Rect: (%lf, %lf, %lf, %lf)\n",
        go.r.x, go.r.y, go.r.w, go.r.h); }

void drawTrg(struct GeoObject go) {
    printf("Triag: (%lf, %lf, %lf, %lf)\n",
        go.t.x, go.t.y, go.t.b, go.t.h); }
```

```
DrawFunc DrawArr[] = { // Array of func. ptrs
    drawCir, drawRec, drawTrg };

int main() {
    struct GeoObject go;

    go.gCode = CIR;
    go.c.x = 2.3; go.c.y = 3.6;
    go.c.r = 1.2;
    DrawArr[go.gCode](go); // Call by ptr

    go.gCode = REC;
    go.r.x = 4.5; go.r.y = 1.9;
    go.r.w = 4.2; go.r.h = 3.8;
    DrawArr[go.gCode](go); // Call by ptr

    go.gCode = TRG;
    go.t.x = 3.1; go.t.y = 2.8;
    go.t.b = 4.4; go.t.h = 2.7;
    DrawArr[go.gCode](go); // Call by ptr

    return 0;
}
```

```
Circle: (2.300000, 3.600000, 1.200000)
Rect: (4.500000, 1.900000, 4.200000, 3.800000)
Triag: (3.100000, 2.800000, 4.400000, 2.700000)
```

Input / Output

- `int printf(const char *format, ...)` writes to `stdout` by the format and returns the number of characters written
- `int scanf(const char *format, ...)` reads from `stdin` by the format and returns the number of characters read
- Use %s, %d, %c, %lf, to print/scan string, `int`, `char`, `double`

```
#include <stdio.h>

int main() {

    char str[100];
    int i;

    printf("Enter a value :");              // prints a constant string

    scanf("%s %d", str, &i);                // scans a string value and an integer value

    printf("You entered: %s %d ", str, i); // prints string and integer

    return 0;
}
```

Input / Output

- To write to or read from file:

```
#include <stdio.h>

int main() {

    FILE *fp = NULL;
    int i;

    fp = fopen("Input.dat", "r");
    fscanf(fp, "%d", &i);           // scan from Input.dat
    fclose(fp);

    fp = fopen("Output.dat", "w");
    fprintf("%d^2 = %d\n", i, i*i); // prints to Output.dat
    fclose(fp);

    return 0;
}
```

C Standard Library

- Common Library Components:

Component	Data Types, Manifest Constants, Macros, Functions, ...
`stdio.h`	Formatted and un-formatted file input and output including functions • `printf`, `scanf`, `fprintf`, `fscanf`, `sprintf`, `sscanf`, `feof`, etc.
`stdlib.h`	Memory allocation, process control, conversions, pseudo-random numbers, searching, sorting • `malloc`, `free`, `exit`, `abort`, `atoi`, `strtold`, `rand`, `bsearch`, `qsort`, etc.
`string.h`	Manipulation of C strings and arrays • `strcat`, `strcpy`, `strcmp`, `strlen`, `strtok`, `memcpy`, `memmove`, etc.
`math.h`	Common mathematical operations and transformations • `cos`, `sin`, `tan`, `acos`, `asin`, `atan`, `exp`, `log`, `pow`, `sqrt`, etc.
`errno.h`	Macros for reporting and retrieving error conditions through error codes stored in a static memory location called `errno` • `EDOM` (parameter outside a function's domain – sqrt(-1)), • `ERANGE` (result outside a function's range), or • `EILSEQ` (an illegal byte sequence), etc.

Source Organization for a C program

Header Files

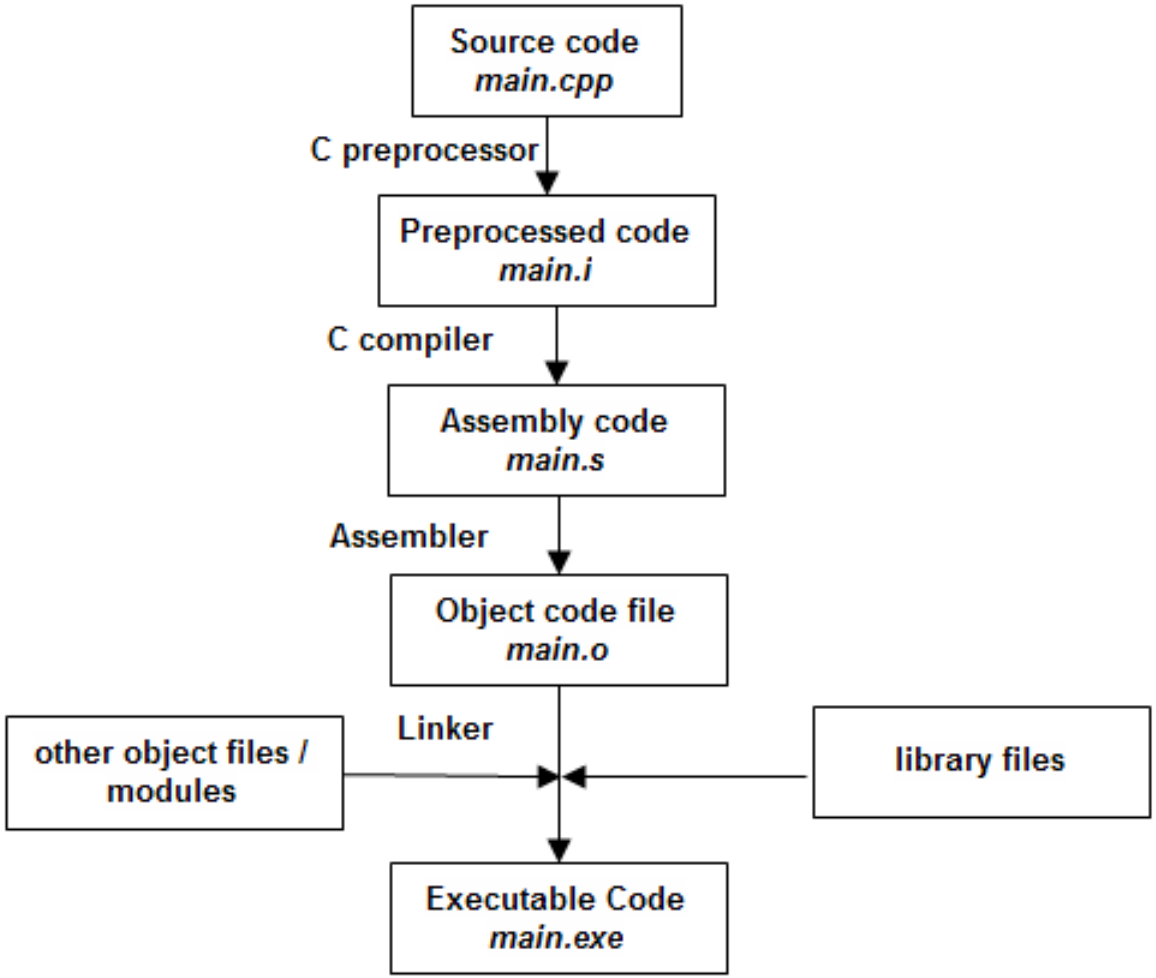
- A header file has extension `.h` and contains C function declarations and macro definitions to be shared between several source files
- There are two types of header files:
  - Files that the programmer writes
  - Files from standard library
- Header files are included using the `#include` pre-processing directive
  - `#include <file>` for system header files
  - `#include "file"` for header files of your own program

Source Organization for a C program

- Example:

```
// Solver.h --  Header files
int quadraticEquationSolver(double, double, double, double*, double*);

// Solver.c -- Implementation files
#include "Solver.h"

int quadraticEquationSolver(double a, double b, doublec , double* r1, double* r2) {
    // ...
    // ...
    // ...
    return 0;
}

// main.c  -- Application files
#include "Solver.h"

int main() {
    double a, b, c;
    double r1, r2;

    int status = quadraticEquationSolver(a, b, c, &r1, &r2);

    return 0;
}
```

Build Flow



Build Process

- C Pre-processor (CPP) substitutes and includes functions, headers and macros before compilation

```
int sum(int, int);
int main() {
    int a = sum(1,2);
    return a;
}
```

- The compiler translates the pre-processed C code into assembly language, which is a machine level code that contains instructions that manipulate the memory and processor directly
- The linker links our program with the pre-compiled libraries for using their functions
- In the running example, `function.c` and `main.c` are first compiled and then linked

```
int sum(int a,int b) { return a+b; }

int main() {
    int a = sum(1,2);  // as files are linked, uses functions directly
    return a;
}
```

Tools

- Development IDE: Code::Blocks 16.01
- Compiler: -std=c++98 and -std=c99

References

- Kernighan, Brian W., and Dennis M. Richie. The C Programming Language. Vol. 2. Englewood Cliffs: Prentice-Hall, 1988.
- King, Kim N., and Kim King. C programming: A Modern Approach. Norton, 1996.

Module Summary

- Revised the concept of variables and literals in C
- Revised the various data types and operators of C
- Re-iterated through the control constructs of C
- Re-iterated through the concepts of functions and pointers of C
- Re-iterated through the program organization of C and the build process.

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