COMSW 1003-1

Introduction to Computer Programming in C

Lecture 25

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Review

Variables and Types

Variables and types

- **Variables** are placeholders for values
- They can have any name we choose
- In C, variables are divided into **types**, according to how they are **represented in memory** (always represented in binary)

int	**4 bytes**
float	**4 bytes**
double	**8 bytes**
char	**1 byte**

Integer division
vs
Floating point division

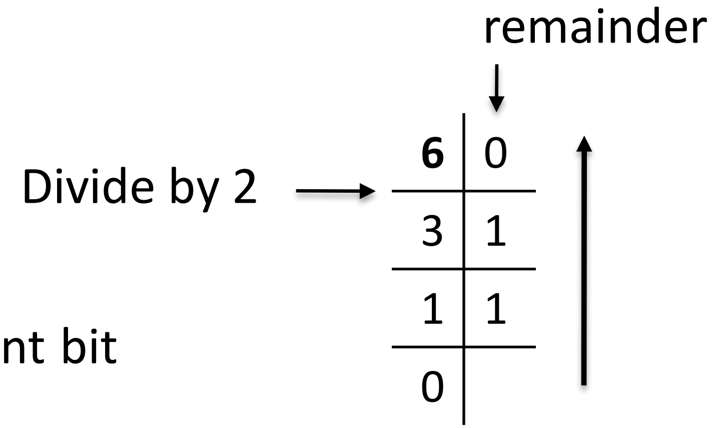
```
int i = 3, j;
float x = 3, y;


j = i/2;      // j = 1
i = x/2;      // j = 1
y = x/2;      // y = 1.5
y = i/2;      // y = 1
```

Implicit cast!

Binary Logic

- 1 = true, 0 = false

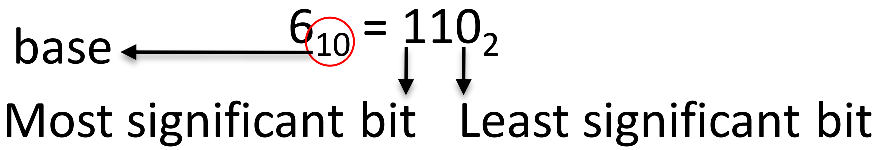
- Decimal to binary conversion



remainder

Divide by 2

6	0
3	1
1	1
0	



$6_{10} = 110_2$

base

Most significant bit

Least significant bit

- Binary to decimal conversion

$11001_2 = 1x2^0 + 0x2^1 + 0x2^2 + 1x2^3 + 1x2^4 = 25$

- AND
  v = x & y

x	y	v
0	0	0
0	1	0
1	0	0
1	1	1

- OR
  v = x | y

x	y	v
0	0	0
0	1	1
1	0	1
1	1	1

- NOT
  v = !x

x	v
0	1
1	0

- EXOR
  v = x ^ y

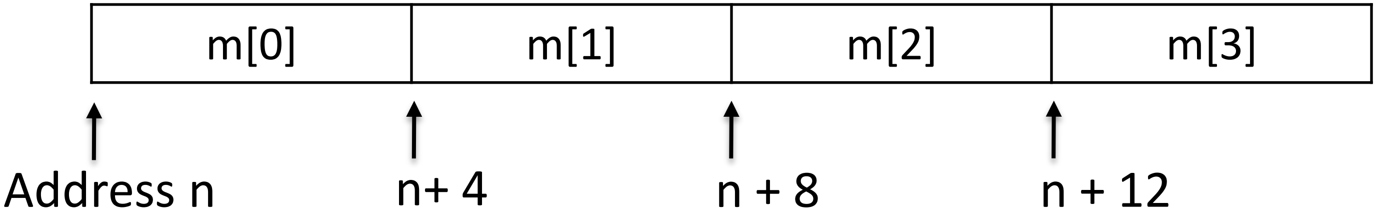
x	y	v
0	0	0
0	1	1
1	0	1
1	1	0

Arrays and Strings

Arrays

- “A set of **consecutive** memory locations used to store data” [PCP, Ch 5]

```
int m[4];  // a vector containing 4 integers
```



m[0]	m[1]	m[2]	m[3]

Address n

n+ 4

n + 8

n + 12

- Indexing starts at 0 !

```
m[0] = 3;
m[2] = 7;
```

- Be careful not to access uninitialized elements!

```
int x = m[7];
```

gcc will not complain about this, but the value of x is going to be random!

Arrays

- Multidimensional arrays

```
int p[4][3];  // a matrix containing 4x3 = 12 integers
```

p[0][0]	p[0][1]	p[0][2]
p[1][0]	p[1][1]	p[1][2]
p[2][0]	p[2][1]	p[2][2]
p[3][0]	p[3][1]	p[3][2]

- Indexing starts at 0 !

```
p[0][0] = 1;
p[3][1] = 7;
```

- Initialize arrays

```
int a[4] = { 3, 6, 7, 89};
int b[2][4] = { {19, 2, 6, 99}, {55, 5, 555, 0} };
int c[] = { 3, 6, 77};
```

This automatically allocates memory for an array of 3 integers

Strings

- Strings are arrays of `char`
- ‘\0’ is a special character that indicates the end of a string

```
char s[6] = {‘H’, ’e’, ‘l’, ‘l’, ‘o’, ‘\0’};
```

We need 6 characters because there is ‘\0’

‘H’	‘e’	‘l’	‘l’	‘o’	‘\0’

```
char s[10] = “Hello”;
```

‘H’	‘e’	‘l’	‘l’	‘o’	‘\0’				

```
char s[6];
s[0] = ‘H’;
s[1] = ‘e’;
s[2] = ‘l’;
s[3] = ‘l’;
s[4] = ‘o’;
s[5] = ‘\0’;
```

- Difference between string and char

```
char c =  ‘a’ ;
char s[2] = “a” ;
```

‘a’

‘a’	‘\0’

Strings functions – recap (<string.h>)

```
char s1[] = “Hello”;char s2[] = “He”;
int x; char c;
```

- strcmp(s1, s2)

```
x = strcmp(s1, s2) // x != 0
```

- strcpy(s1, s2)

```
strcpy( s2, s1 ); // s2 = “Hello”
```

- strcat(s1, s2)

```
strcat( s2, s1 ); //s2 = “HelloHello”
```

- strlen(s)

```
x = strlen(s1);   // x  = 5;
```

- sizeof(s)

```
x = sizeof(s1);   // x = 6;
```

- fgets(s, sizeof(s1), stdin)

```
fgets( s1, sizeof(s1), stdin);
```

User enters “7R”

- sscanf(s, “%d”, &var)

```
sscanf( s1, “%d%c”, &x, &c);
// x = 7; c = ‘R’;
```

Pointers

Pointers vs. Arrays

	Arrays		Pointers
1D array of 5 int	`int x[5];`	↔	`int *xPtr;`
2D array of 6 int 2x3 matrix	`int y[2][3];`	↔	`int **yPtr;`
2D array of 4 int 2x2 matrix	`int* z[2]={{1,2},{2,1}};`	↔	`int **zPtr;`
1D array of 5 char string	`char c[] = “mike”;`	↔	`char *cPtr;`

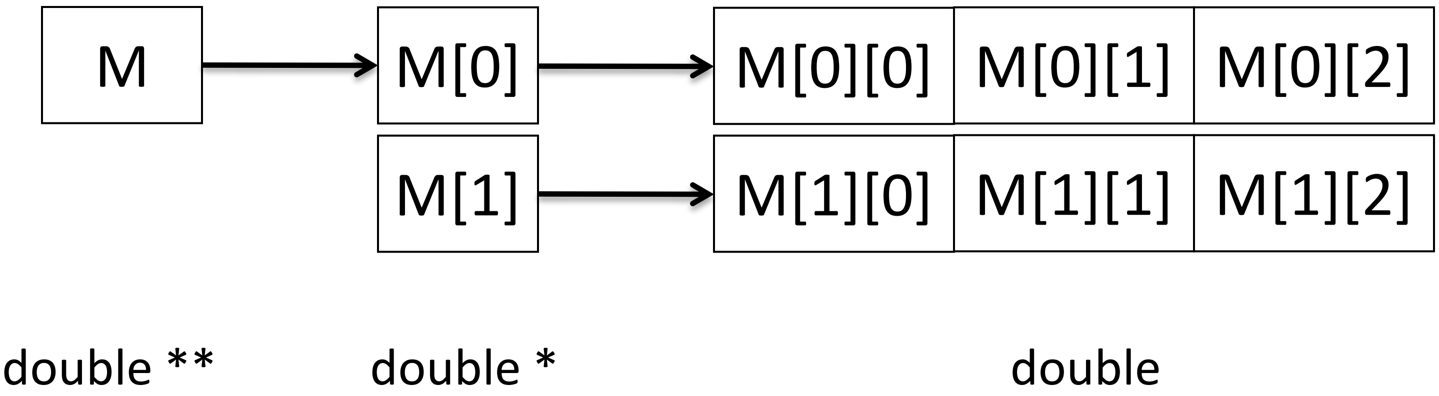
Space has been allocated in memory for the arrays

Space has been allocated in memory only for the pointers variables, **NOT** for the arrays they will point to.
The DIMENSIONS of the arrays are UNKNOWN

Multidimensional Arrays

2x3 matrix of double

```
double M0[2][3];
double *M1[2] = M0;
double **M = M0;
```



M

M[0]

M[1]

M[0][0] M[0][1] M[0][2]

M[1][0] M[1][1] M[1][2]

double **

double *

double

Dynamic Memory Allocation

Dynamic Memory Allocation

Example: create an array of 10 integers `int myArr[10];`

- Malloc()

  Example

  ```
  int *myArr = (int *) malloc( 10 * sizeof(int) );
  ```

- Calloc()

  Example

  ```
  int *myArr = (int *) calloc( 10 , sizeof(int) );
  ```

Dynamic Memory Allocation

Functions related to DMA are in the library **stdlib.h**

```
void *realloc(void *ptr, size_t size)
```

Changes the size of the allocated memory block pointed by *ptr* to *size*

Returns a pointer to the allocated memory on success, or NULL on failure

```
void free(void *ptr)
```

De-allocates (frees) the space in memory pointed by `ptr`

Advanced Types - Struct

We can initialize a struct variable at declaration time, just like with arrays

```
struct student {

    char name[100];
    int  age;
    double grade;
};
```

The initialization fields must be consistent with the fields types !

char   int   double

```
struct student st1 = {“mike”, 22, 77.4};
```

Pointer to struct : -> operator to access struct fields

```
struct student *ptr = &st1;
ptr->age = 33;
```

Advanced types - Typedef

typedef is used to define a new type

```
struct student {
   char name[100];
   int  age;
   double grade;
};

struct student st1, st2;

st1.age = 3;
st2.age = st1.age - 10;
```

```
struct student {
    char name[100];
    int  age;
    double grade;
 };

 typedef struct student stud;
 stud st1, st2;

 st1.age = 3;
 st2.age = st1.age - 10;
```

Advanced Types - Union

- Similar to struct, but all fields share same memory
- Same location can be given many different field names

```
struct value{
    int   iVal;
    float fVal;
};
```

```
union value{
    int   iVal;
    float fVal;
};
```

We can use the fields of the union only one at a time!

Advanced Types - Enum

- Designed for variables containing only a limited set of values
- Defines a set of **named integer constants**, starting from 0

```
enum name{ item1, item2, … , itemN};
```

```
                0       1    2       3      4      5        6
enum dwarf { BASHFUL, DOC, DOPEY, GRUMPY, HAPPY, SLEEPY, SNEEZY};

enum dwarf myDwarf = SLEEPY;

myDwarf = 1 + HAPPY;   // myDwarf  = SLEEPY = 5;

int x = GRUMPY + 1;    // x = 4;

printf(”dwarf %d\n”,BASHFUL); // ‘dwarf 0’
```

Advanced Types- const

Regular variables

`const` defines a variable whose value cannot be changed

```
double r;
const double PI;

r++; V

PI++; ✗

r = PI; V
```

Pointers

When we declare a pointer to be a constant, it means that the value at the address in memory it points cannot be modified

This does NOT mean that the pointer is constant, it can be changed!

```
int x = 7, y = 3;
const int *ptr = &x;

*ptr = 11;   ✗

x = 8;   V

ptr = &y;    V

*ptr = 9;  ✗
```

Advanced Types- void

Regular variables

`void` defines emptiness. It could be used for a function that

Does not return anything

Does not take any input argument

```
void printArrow(void){

      printf(“--->\n”);

      return;
}

int main(){

   printArrow();

   return 0;

}
```

Pointers

`void *` means a pointer of ANY type

This allows the programmer to specify the type of pointer to use at **invocation time**

```
void *pointElement(void *A, int i){
    return( A+i );
}

int main(){

  int M[3] = {1 , 2, 3};

  int *M2 = (int *) pointElement(
        (int *) M , sizeof(int) * 2);

  return(0);
}
```

Functions

Functions

Function declaration

Specifies:

- return type
- number and type of the arguments

After declaration, function can be invoked in code

```
int mean(float, float);
```

Function Definition

Actual implementation

Declaration can be embedded in definition

```
int mean(float n1, float n2){

    return( (n1+n2)/2 );
}
```

Functions
Passing arguments by value/reference

- Pass by value : the value of the variable used at invocation time is copied into a local variable inside the function

- Pass by reference : a pointer to the variable used at invocation time is passed to the function. We can modify the variable's value inside the function

Functions - Recursion

- What if a function calls itself? Recursion

```
/* Fibonacci value of a number */
int fib ( int num ) {

  switch(num) {
   case 0:
        return(0);

   case 1:
        return(1);

   default: /* Including recursive calls */
        return(fib(num - 1) + fib(num - 2));

  }
}
```

Why are there no `breaks` ?

Pointers to functions

```
int (*f_ptr)(); // pointer to function that returns an int
```

Parentheses are important! Without parentheses, **f_ptr looks like it returns a** pointer to an int.

```
int (*f_ptr)(int, int);

int greater_than(int a, int b);

f_ptr = greater_than;
```

```
int *ptr;

int x[2];

ptr = x;
```

Input / Output

Reading strings

Use functions from library stdio.h

- fgets() : get string from standard input (command line)

```
fgets( name , sizeof(name), stdin);
```

Reads a maximum of sizeof(*name*) characters of a string from stdin and saves them into string *name*

```
char s1[100];
fgets( s1, sizeof(s1), stdin);
```

NOTE: fgets() reads the newline character ‘\n’, so we should substitute it with ‘\0’;

```
name[strlen(name)-1] = ‘\0’;
```

‘H’	‘e’	‘l’	‘l’	‘o’	‘\n’

‘H’	‘e’	‘l’	‘l’	‘o’	‘\0’

- sizeof() : returns the size (number of bytes occupied in memory) of a variable (for strings it counts the number of elements, including ‘\0’)

Reading numbers

- First, read a string
- Then, convert string to number
- sscanf() : get string from standard input (command line)

```
sscanf( string, “format”, &var1, …, &varN);
```

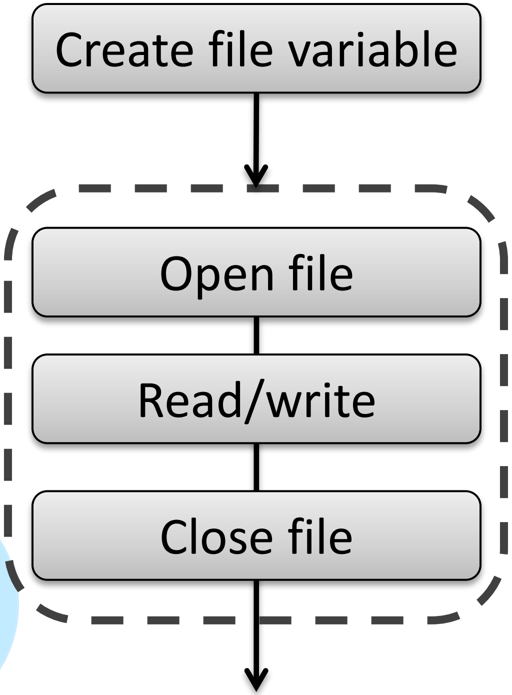
```
char s1[100];
int x, y;
printf(“Please enter two numbers separated by a space\n”)
fgets( s1, sizeof(s1), stdin);
```

User enters: 3 18

```
sscanf( s1, “%d %d”, &x, &y );

// x = 3; y = 18;
```

Files I/O

- Files have a special type of variable associated with them: `FILE *`
- In order to read/write to a file, we must first OPEN it
- After we are done, we must CLOSE the file



Create file variable

Open file

Read/write

Close file

```
FILE *fVar;

fVar = fopen( fileName, mode);

/* read, write or append */

fclose(fVar);
```

Summary of Functions

Name	Input	Output
fprintf()	formatted text + args	file
printf()	formatted text + args	stdout
sprintf()	formatted text + args	string
fputc(), fputs()	char,string	file
fscanf()	file	formatted text + args
scanf()	stdin	formatted text + args
sscanf()	string	formatted text + args
fgetc(), fgets()	file	(char) int, string

Preprocessor

C Preprocessor

Preprocessor is a facility to handle :

- Header files

```
#include <nameOfHeader.h>
#include “nameOfHeader.h”
```

→ For standard C libraries

→ For user defined headers

- Macros
  - Object like macros `#define SIZE 10`
  - Function like macros `#define SQR(x) ((x) * (x))`
- Conditional compilation

```
#ifdef var      #else
#ifndef var     #endif
                #undef var
```

Compiling

gcc

```
gcc -option -o executable source1 source2…
```

Options:

`-Wall` : show warnings

`-E` : print source code after preprocessor

`-g` : compile with debugging information

`-c` : compile sources without main() function.
Used to compile modules

`-lm` : link `<math.h>` library

Main Function Arguments

Makefile – Multiple Modules

```
#---------------------------------------------------------#
#     Makefile for UNIX system                            #
#     using a GNU C compiler (gcc)                        #
#---------------------------------------------------------#

CC=gcc
CFLAGS=-Wall

mainProgram : mainProgram.c  calculator.o
    $(CC) $(CFLAGS) -o mainProgram mainProgram.c calculator.o

calculator.o : calculator.c calculator.h


clean:
      rm -f calculator.o mainProgram
```

Clarguments.c

Command Line Arguments

- Input parameters of the function main()
- `argc, argv`

```
int main( int argc, char* argv[] )
```

`argc`

- Integer
- Specifies the **number** of arguments on the command line (including the program name)

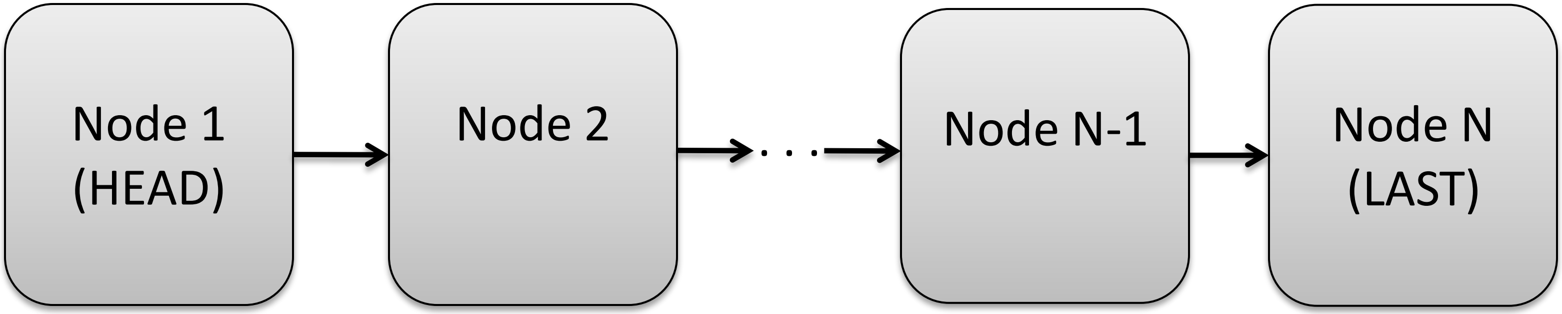
`argv`

- **Array of strings**
- **Contains the actual arguments on the command line**
- **First element is the name of the program**

Data Structures

Linked Lists

- A chain of elements
- First element is called HEAD
- Each element (called NODE) points to the next
- The last node does not point to anything
- Like a treasure hunt with clues leading one to another

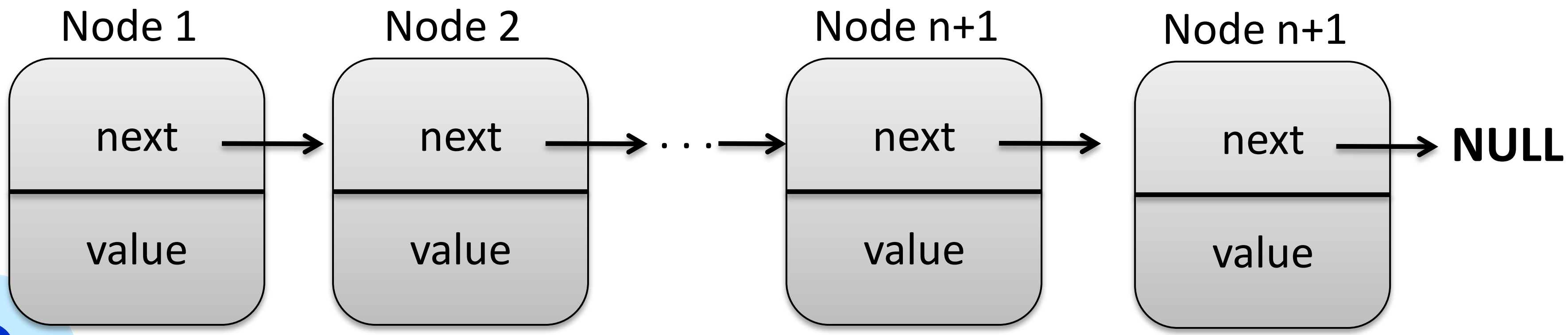


Linked Lists

linkedList.c

- Structure declaration for a node of a linked list

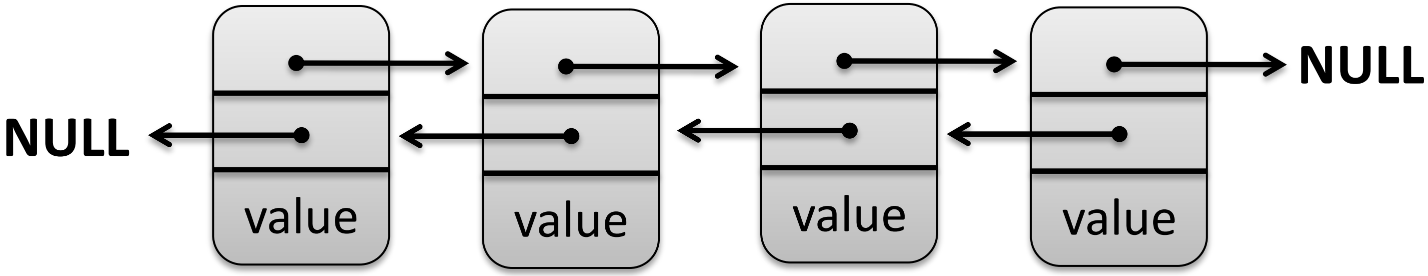
```
struct ll_node {
        int value;
        struct ll_node *next;
};
typedef struct ll_node node;
```



Doubly linked lists

- Pointer to next AND previous node
- Faster backtracking

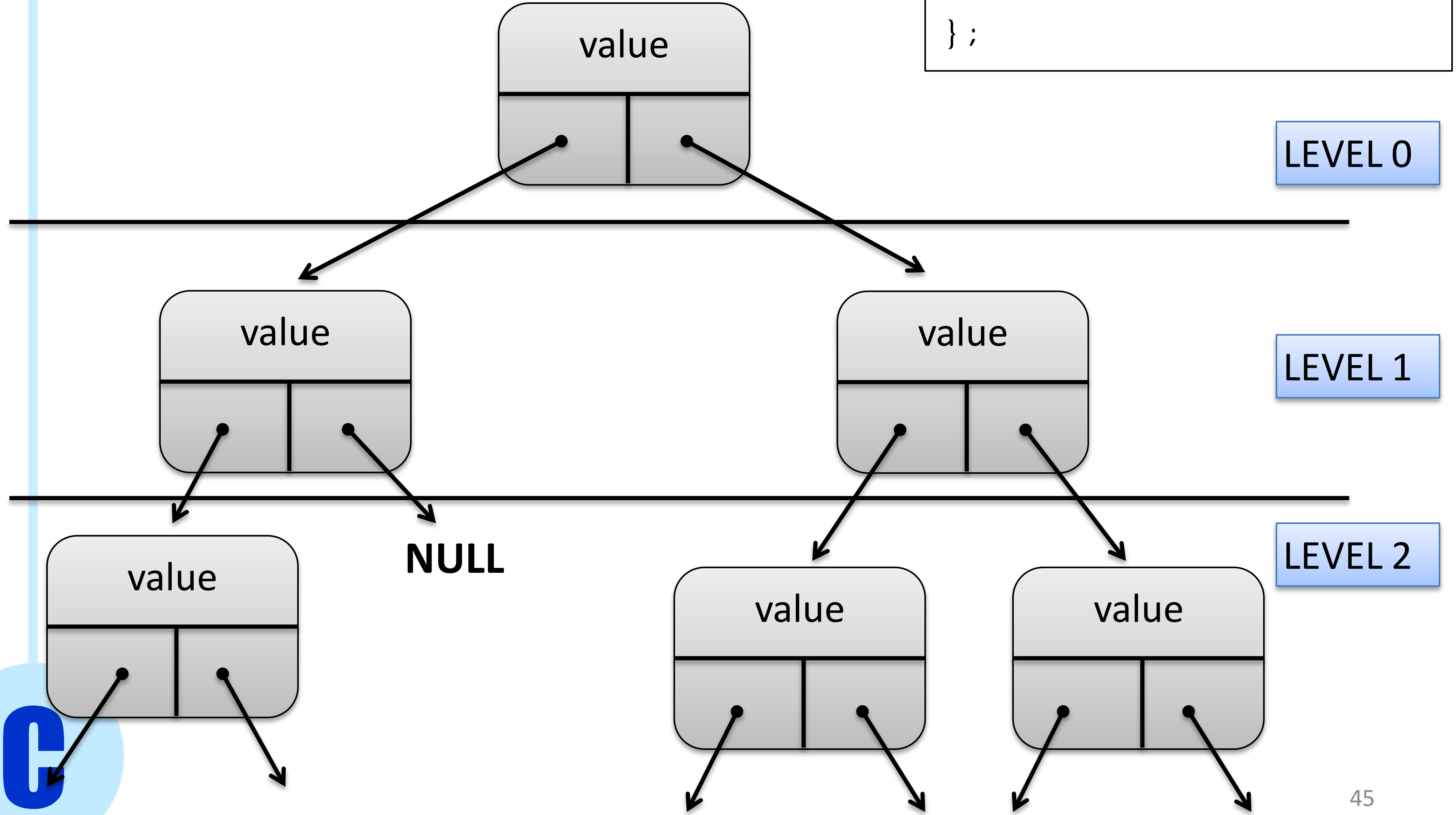
```
struct dll_node {
    int value;
    struct dll_node *prev;
    struct dll_node *next;
};
```



Binary Trees

- Left has a value < current node
- Right has a value > current node

```
struct t_node {
   int value;
   struct t_node *left;
   struct t_node *right;
};
```



value

LEVEL 0

value

value

LEVEL 1

value

NULL

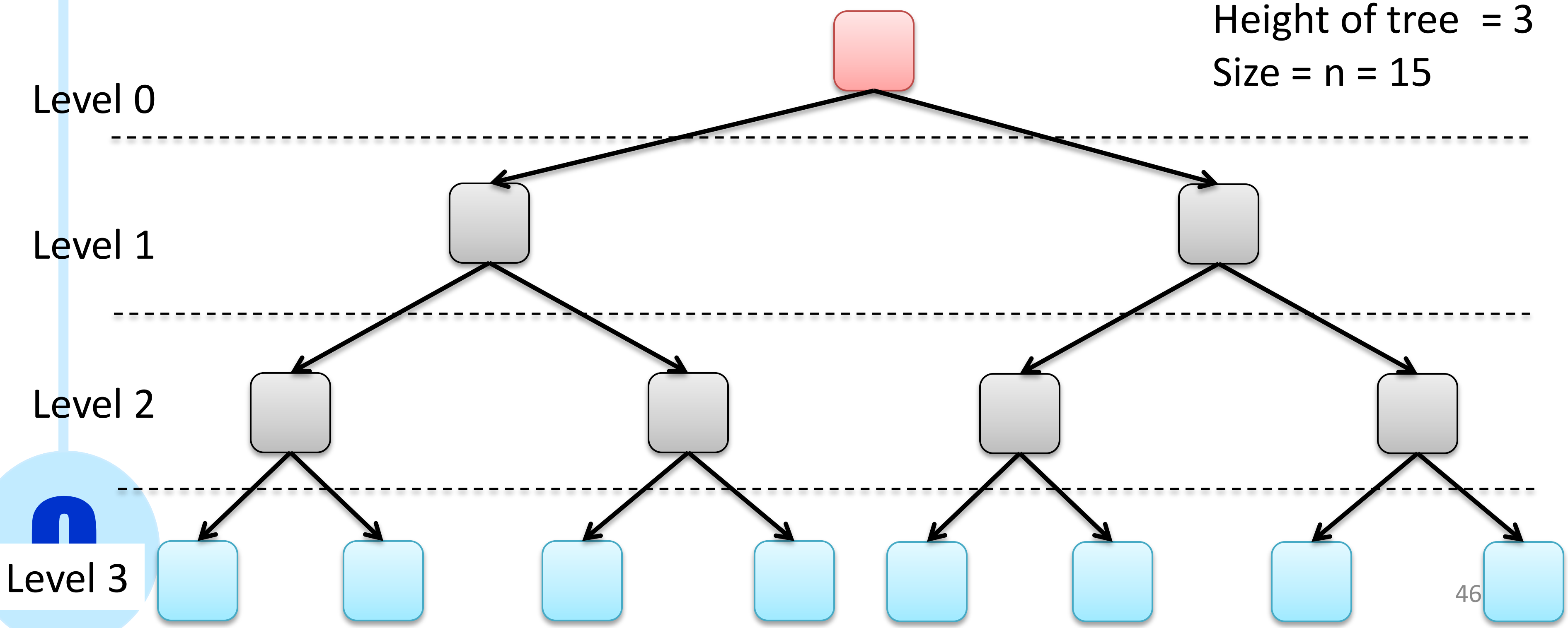
value

value

LEVEL 2

Trees Definitions

- Root : node with no parents. Leaf : node with no children
- Depth (of a node) : path from root to node
- Level: set of nodes with same depth
- Height or depth (of a tree) : maximum depth
- Size (of a tree) : total number of nodes
- Balanced binary tree : depth of all the leaves differs by at most 1.



Complexity analysis and big-O notation

Measuring Algorithms

- In Computer Science, we are interested in finding a function that defines the quantity of some resource consumed by a particular algorithm
- This function is often referred to as a **complexity** of the algorithm
- The resources we usually investigate are
  - running time
  - memory requirements

Big–O : Relationship among common cases

$O(1) < O(\log n) < O(n) < O(n \log n) < O(n^2) < O(n^3) < O(a^n)$

Example : big-O when a function is the *sum of several statements*

```
int i=0;
for(i=0 ; i < n; i++){
   for(j=0 ; j < n; j++){
        if( (i!=j) && arr[i] == arr[j])
             dup[i][j] = 1;
   }
}
```

$RT = O(4n^2+n) = O(n^2)$

↓

increment `i`

increment `j`

check `i!=j`

check `arr[i]==arr[j]`

`dup[i][j] = 1`

Longest operation dominates (worst case)

Sorting

Sorting

- Given a set of N elements, put them in order according to some criteria

- Compare pairs of elements

- Many algorithms, some of the most famous are:

– Bubble sort	**Complexity = $O(n^2)$**
– Selection sort	**Complexity = $O(n^2)$**
– Merge sort	**Complexity = $O(n \log(n))$**
– Counting sort	**Complexity = $O(k+n)$**

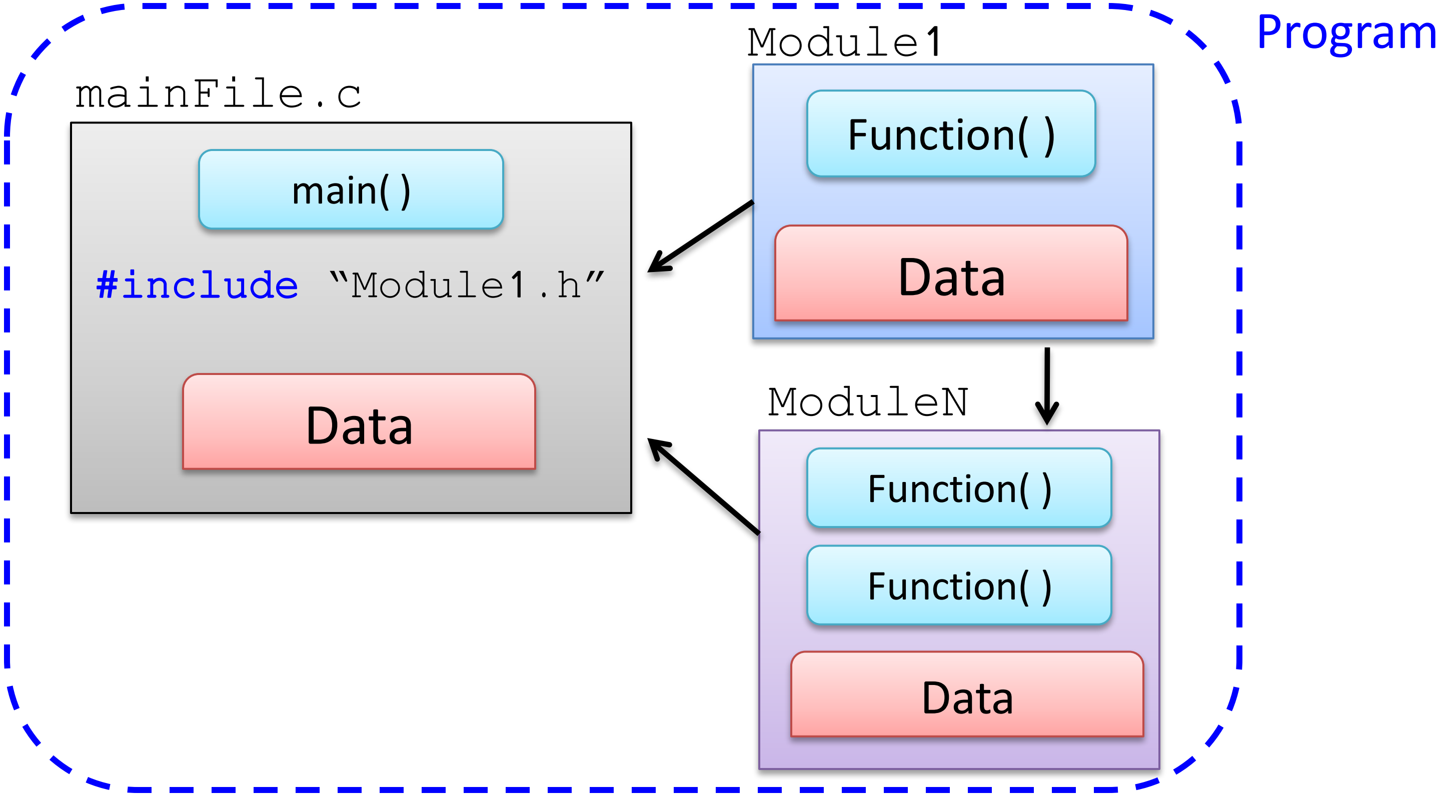
C++

C++

- Main factors differentiating C++ from C:
  - Slightly different syntax, contains type `bool`
  - Functions overloading
  - Object oriented

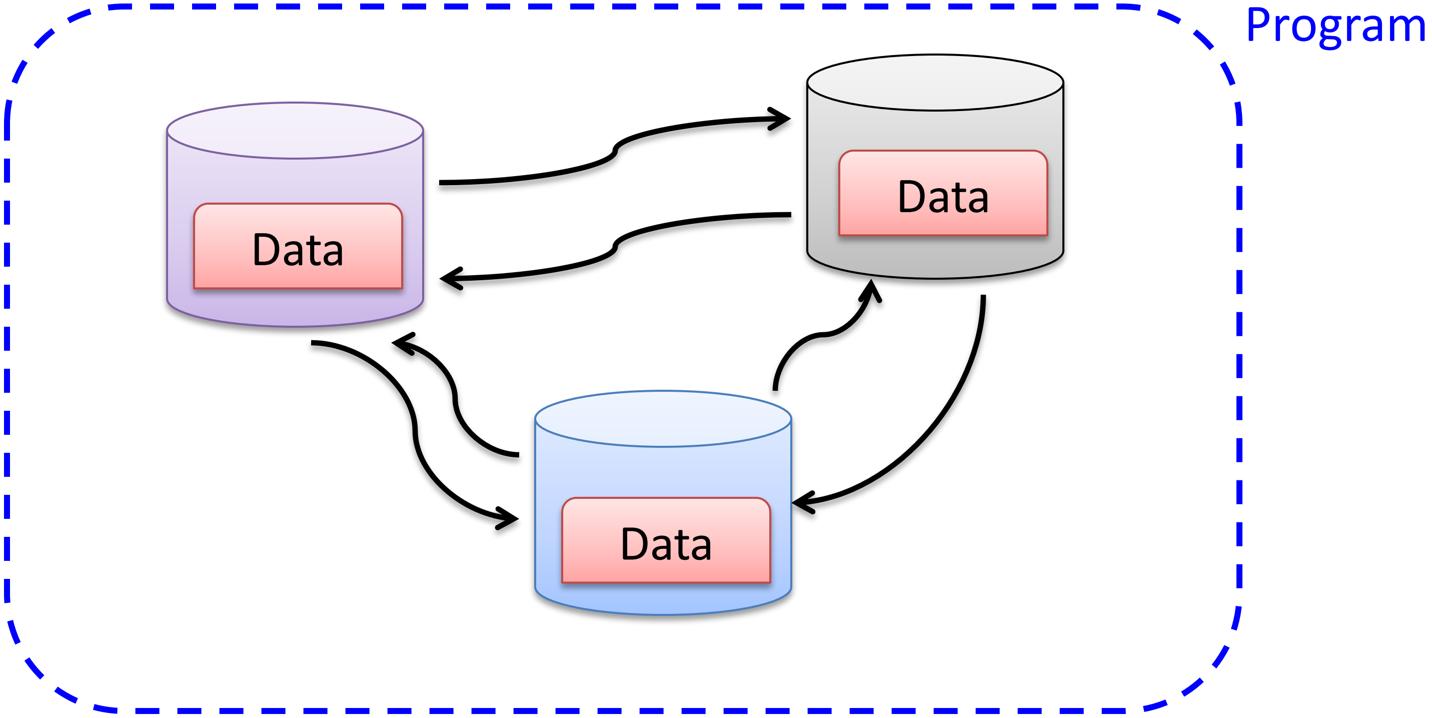
Modular Programming

- Multiple files
- Functions of similar logical goal grouped into ***modules***
- Different data manipulated inside functions in modules



Object Oriented Programming

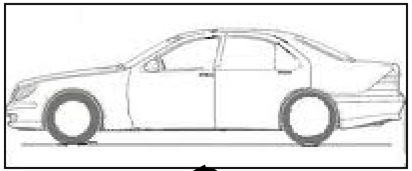
- Based on ***objects*** interacting with each other
- Objects exchange **messages**, but maintain their state and data
- Usually associated also with modular programming



Object oriented programming

- Classes
- Objects
- Inheritance
- Polymorphism

car



- Make
- Model
- Year
- Color

- printAttributes()
- getYear()

Race car

- Make
- Model
- Year
- Color
- **Pilot**

- printAttributes()
- getYear()
- **numRaces()**

SUV

- Make
- Model
- Year
- Color
- **Shaded windows**

- printAttributes()
- getYear()

City car

- Make
- Model
- Year
- Color

- printAttributes()
- getYear()
- **isParked()**