Practical C/C++ programming Part II

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Quick review of Part I

- Introduction to C and C++ language
- Basic syntax and grammar
- Data types, constants and variables:
  - Basic types (integer, float, void)
  - Derived types (arrays)
- Operators
  - Arithmetic
  - Logical
  - Relational
  - Misc (`sizeof`, `“,”`, `ternary`, etc)
- Control Flow
- Functions
- Input/Output control

Things to be covered today

- Pointers in C/C++
  - Use in functions
  - Use in arrays
  - Use in dynamic allocation
- User defined type
  - struct
- Introduction to C++
  - Changes from C to C++
  - C++ class and objects
- Introduction to common C++ libraries

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...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).
- Examples:

```
int a = 6;
int *p;
/* point p to a */
p = &a;
/* dereference pointer p */
*p = 10;
```

Part of symbol table:

var_name	var_address	var_value
a	0x22aac4	6
p	0x22aac0	0x22aac4

Pointer to variables and dereference pointer

```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 (1)

- As we have learned from Part 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 (2)

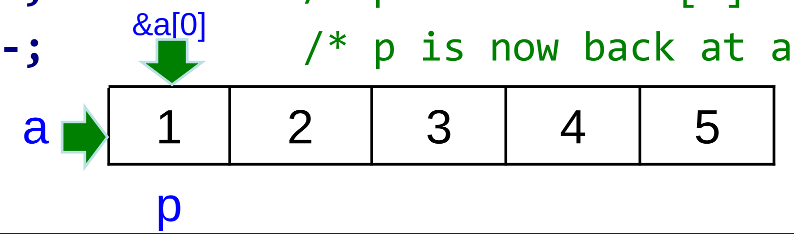
- The values of a and b do not change after calling swap(a,b)
- ***Pass by value means the called functions' parameter will be a copy of the callers' passed argument.*** The value of the caller and called functions will be the same, but the identity (the variable) is different - caller and called function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

```c
/* pass by pointer */
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 );
```

Pointers and Arrays (1)

- 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)***

```
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] */
```



Pointers and Arrays (2)

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

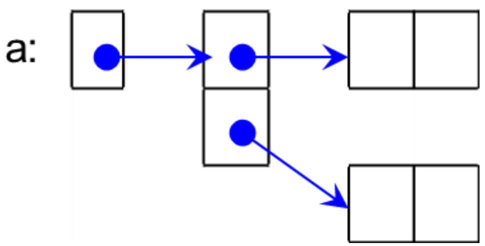
```
int a[2][2]={{1,2},{3,4}};
```

- 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]

	col 0	col 1
row 0	a[0][0]=1	a[0][1]=2
row 1	a[1][0]=3	a[1][1]=4

array a[0]	a[0][0]=1	a[0][1]=2
array a[1]	a[1][0]=3	a[1][1]=4

array a:	a⬄&a[0]
array a[0]:	a[0]⬄&a[0][0]
array a[1]:	a[1]⬄&a[1][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);
```

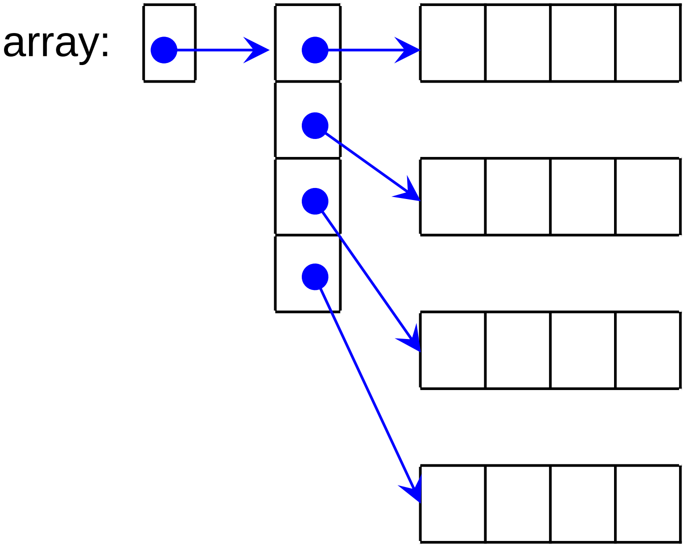
Example of 1D dynamic array

```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;
}
```

How to make dynamic 2D array?

- Use dynamic 2D array in Exercise 3 (refer to `/*dynamic_2d_array.c*/`)
  - Hint:

```
/* First malloc a 1D array of pointer to pointers, then for each address,
malloc a 1D array for value storage: */
int** array;
array=(int**)malloc(nrows*sizeof(int*));
for (i=0; i<nrows; i++)
    array[i]=(int*)malloc(ncols*sizeof(int));
/* DO NOT forget to free your memory space */
for (i=0; i<nrows; i++)
      free((void*)array[i]);
free((void*)array);
```



  - Question:
    - What is the difference between the dynamic 2D array generated using the above method and the static 2D one defined using the method in Part 1 slide (page 45)? (Hint: check whether the memory for the dynamic 2D array is contiguous by print the address of the pointer array)
    - Any solutions to the above method? (This method will be important when being used in MPI (Message Passing Interface) function calls)

Structures

- User-defined type in C: ***struct***, union and enum
- A C ***struct*** is an aggregate of elements of (nearly) arbitrary types.
- Structures are the basic foundation for objects and classes in C++.
- Structures are used for:
  - Passing multiple arguments in and out of functions through a single parameter
  - Data structures such as linked lists, binary trees, graph, and more
- Syntax for defining structure:

```
/* syntax for defining structure */
struct [structure tag] /* tag is optional */
{
   member definition;
   member definition;
   ...
   member definition;
} [one or more structure variables];
```

How to use struct

- Example of defining a “Point” struct

```
/* define a structure “Point” */
struct Point {
    int index;
    char tag;
    double x;
    double y;
};
```

- Define the struct Point type variables:

```
/* define two struct Point variables */
struct Point p1, p2, p3;
```

- Here is how we access the struct Point type variables, using the “.”:

```
p1.index=0; /* access members of p1 with dot “.” operator */
p1.tag = 'a';
p1.x = 0.0;
p1.y = 0.0;
p3 = p1; /* assign struct variable p1 to variable p3 */
```

Using typedef to define new variables

- C provides a keyword called ***typedef*** to name a new variable type (note that typedef does not create new types).

```
typedef existing_type new_type_name;
```

- Use ***typedef*** with struct in the previous example:

```
typedef struct Point point;
typedef struct Point {/* alternative way to define Point*/
    int index;
    char tag;
    double x;
    double y;
} Point;
```

- ***typedef*** can also used to give alias to existing variable types:

```
typedef double real; /* typedef float real; easy switch between precisions*/
```

- Use the newly defined type to define your variables, e.g.:

```
real x; /* x is actually double defined above */
Point p1, p2, p3; /* p1, p2 and p3 are struct Point */
```

Pointer to struct

- Define pointers to structures in the same way as pointer to any other basic variables:

```
Point *ptr_p; /* define a pointer to Point */
```

- Use the pointer to point to the actual struct variable by: store the address of a structure variable in the above defined pointer variable with the address "&" operator:

```
ptr_p = &p3;  /* point prt_p to struct p3  */
```

- To access struct members with pointer, use the "->" operator

```
printf("tag=%c\n", ptr_p->tag); /* access the struct member through pointer */
```

- Alternatively, use the dereference operator "*" and the "." operator

```
printf("tag=%c\n", (*ptr_p).tag); /* access the struct member through dereference operator */
```

❖ The "->" operator will be largely used in the class and object operations in C++

struct Example - Point struct (1)

```c
/* struct_example.c */
#include <stdio.h>

typedef double real;
/* typedef float real; easy switch between single and double precisions */

typedef struct Point {
    int index;
    char tag;
    real x;
    real y;
} Point;

void print_point(struct Point point);

int main() {
  /* define two struct Point variables */
  /* struct Point p1, p2; */
  Point p1, p2, p3;
  /* assign values to struct members of p1 */
  p1.index=0;
  p1.tag = 'a';
  p1.x = 0.0;
  p1.y = 0.0;
```

struct Example - Point struct (2)

```
  /* assign values to struct members of p2 */
  p2.index=1, p2.tag = 'b', p2.x = 1.0, p2.y = 1.0;
  p3 = p1; /* assign struct var p1 to var p3 */
  /* output p1 and p2 */
  print_point(p1);
  print_point(p2);
  print_point(p3);
}

void print_point(struct Point point)
{
   printf( "\npoint %c:\n", point.tag);
   printf( "\tindex : %d\n", point.index);
   printf( "\tx = %7.2lf\n", point.x);
   printf( "\ty = %7.2lf\n", point.y);
   printf( "\n" );
}
```

From C to C++

- C++ can be considered as a superset of C
- Some minor C++ features over C
  - You can use "//" to type a comments
  - To use standard C libraries: `using namespace std;`
  - Input from the keyboard and output to the screen can be performed through cout `<<` (insertion operator) and cin `>>` (extraction operator)
  - Variables can be declared anywhere inside the code (e.g. C++ allows you to declare a variable to be local to a loop)
  - Can use reference for a variable instead of pointer
  - Memory manipulation: `new` and `delete`
- Major difference: C is function-driven while C++ is object-driven. ⬄ C is procedure oriented while C++ is ***object oriented***.
- Will touch these features in the next section.
- To compile a C++ program, change the compiler name to g++ using the GNU compiler:

```
$ g++ cpp_features.cpp
```

Minor C++ features over C

```
#include <iostream>
// use standard libraries
using namespace std;
// we are using C++ style comments
int main() {
    int n = 2*3; // Simple declaration of n
    int *a = new int[n]; //use "new" to manage storage
    // C++ style output
    cout << "Hello world with C++" << endl;
    for (int i = 0; i < n ; i++) {  // Local declaration of i
        a[i]=i;
        // we are using C++ cout for output
        cout << "a[" << i << "] = " << a[i] << endl;
    }
    delete[] a; // free the memory space we used
    return 0;
}
```

References in C++

- C++ references allow you to create an ***alias*** for the variable which allows you to treat the reference exactly as though it were the original variable.
- Declaring a variable as a reference by appending an ampersand "&" to the type name, reference must be initialized at declaration:

```
int& rx = x;// declare a reference for x
```

- Example using C++ reference as function parameters (see ***ref.cpp***):

```
int main() {
    int x,y=4;
    int& rx = x;// declare a reference for x
    rx = 3;// rx is now a reference to x so this sets x to 33
    cout << "before: x=" << x << " y=" << y << endl;
    swap(x,y);
    cout << "after: x=" << x << " y=" << y << endl;
}
void swap (int& a, int& b) {// using reference instead of pointers
    int t;
    t=a,a=b,b=t;
}
```

Major migration – Class and Object in C++

- Definition of class
  - ***A class is a user-defined type.*** It is an expanded concept of user-defined type struct.
- Definition of object
  - ***An object is an instance of a class.***
- In terms of variables, a class would be the variable type, and an object would be the variable.
- In C++, Classes are defined using either keyword **`class`** or keyword **`struct`**, with the following syntax:

```
// syntax for defining a class
class class_name {
  access_specifier_1: // private, public or protected
    member1;          // list of class members
  access_specifier_2:
    member2;
  ...
} [object_names]; // object_names is an optional list of this class
```

More on C++ class definition

- class_name is a valid identifier for the class
- object_names is an optional list of names for objects of this class.
- The body of the declaration can contain members, which can either be data or function declarations, and optionally access specifiers.
- An access specifier is one of the following three keywords:

```
private: // accessible only from within class or their "friends"
public:  // The members declared as public are accessible from outside the class through an object of the class
protected: // accessible from outside the class BUT only in a class derived (derived class) from it.
```

- By default, all members of a class is `private` unless access specifier is used.
- The definition is very similar to plain data struct except that they can also include ***functions (methods) with access specifier***.

Class example: Point class

- Below is an example rewrite the Point struct to class:

```
class Point {  //define a class Point
private:       //list of private members
    int index; // index of the point
    char tag;  // name of the point
    real x;    // x coordinate, real: typedef double real;
    real y;    // y coordinate
public:
    // use this function to set the private members
    void set_values(int,char,real,real);
    // use this function to output the private members
    void print_values();
};

// define the "set_values" method
void Point::set_values(int idx,char tg,real xc,real yc) {
    index=idx, tag=tg, x=xc, y=yc;
}

// define the "print_values" method
void Point::print_values() {
   cout << "point " << tag << ": index = " << index
        << ", x = " << x << ", y = " << y << endl;
}
```

Some explanation of the Point class

- `private` members of Point: **`index, tag, x, y`** cannot be accessed from outside the Point class:
  - they have private access
  - they can only be accessed from within other members of that same class.
- `public` members of Point can be accessed as normal functions via the dot operator "`.`" between object name and member name.
- The implementation of the member functions can be either inside or outside the class definition. In the previous slide, the member function is defined outside the class definition.
- The scope operator "`::`", for the function definition is used to specify that the function being defined is a member of the class Point and not a regular (non-member) function:

```
// define the "set_values" method using scope operator "::"
void Point::set_values(int idx,char tg,real xc,real yc) {
    index=idx, tag=tg, x=xc, y=yc; // overuse of comma operator :-)
}
```

Use class to define objects

- To declare objects of a class, use exactly the same type of declaration as declaring variables of basic types.
- Following statements declare two objects of class Point, just the same as we define basic type variables:

```
Point p1, p2; // define two object of Point
```

- Then the objects p1 and p2 access their member functions:

```
p1.set_values(0,'a',0,0); // object p1 use set_values method
p2.set_values(1,'b',1,1); // object p2 use set_values method
p1.print_values();        // object p1 use print_values method
p2.print_values();        // object p2 use print_values method
```

- We cannot directly access the private members of p1 and p2:

```
double x1= p1.x;          // compilation error!
```

- So far, we have got very basic idea about C++ classes and objects.

Constructor (1)

- In C++ class, a special function, which is automatically called whenever a new object of this class is created, allowing the object to initialize member variables or allocate storage is called ***constructor***.
- Constructor function is declared just like a regular member function with the class name, but without any return type (**not even void**).
- Modify the Point class to use constructor, add the following lines in the class declaration:

```
class Point { //define a class Point
private:
    //list of private members ...
public:
    // define a constructor to initialize members
    Point();
    // list of other member functions
};
```

Constructor (2)

- Definition of the Point class constructor:

```
// define a constructor to initialize members
// Note that no return type is used
Point::Point() {
    index=0, tag=0, x=0, y=0; //initialize the private members
}
```

- After defining the constructor, when we define an object variable of Point, its private members are initialized using the constructor.

```
Point p3;  // what is index, tag, x, y of p3 at this point?
```

- How do we initialize private members using different values at time of definition?

```
// declare another constructor with parameters
Point(int,char,real,real);
// define another constructor with parameters
Point::Point(int idx,char tg,real xc,real yc) {
    index=idx, tag=tg, x=xc, y=yc; //initialize with parameters
}
```

Overloaded constructors

- We have seen the Point class can have two constructors:

```
Point();
Point(int,char,real,real);
```

- One class can have two functions with the same name, and the objects of Point can be initialized in either of the two ways.

```
Point p1, p2; // calling the Point() default constructor
Point p3(0,'c',0,1); // calling the Point(...) constructor
```

- The compiler will analyze the types of arguments and matching them to the types of parameters of different function definitions.
- The above example also introduces a special kind constructor: the ***default*** constructor.
  - The default constructor is the constructor that takes no parameters.
  - The default constructor is called when an object is declared but is not initialized with any arguments.

Destructor

- Destructors are usually used to de-allocate memory and do other cleanup for a class object and its class members when the object is destroyed. Destructor is considered the inverse of constructor function.
- A destructor will have the same name as the class prefixed with a tilde (~) and it can neither return a value nor can it take any parameters.
- There is only **one** destructor per class in C++.
- A destructor is called for a class object when that object passes out of scope or is explicitly deleted. An example of destructor definition in Point class:

```
// declare a destructor in class declaration
~Point();
// define the destructor
Point::~Point() {
    cout << "Destructor called." << endl;
}
```

new and delete in C++

- In C++, the dynamic memory functions are: **new** and **delete**
- The major difference between malloc and free: **new** and **delete** will call the constructor and destructor.
- Using the following constructor and destructor in the Point class:

```
// define another constructor with parameters
Point::Point() {
    cout << "Constructor called." << endl;
}
Point::~Point() {// define the destructor
    cout << "Destructor called." << endl;
}
```

- What will be the output in the main() function call? (***point_class_new_delete.cpp***)

```
void main(void) {
    Point *ptr_p = new Point[2];
    delete[] ptr_p;
    ptr_p =(Point*)malloc(2*sizeof(Point));
    free(ptr_p);
}
```

Overloading functions

- In C++, two different functions can have the same name either:
  - because they have a different number of parameters,
  - because any of their parameters are of a different type.
- See we overload the set_values function for the Point class

```
// define the "set_values" method using 4 values
void Point::set_values(int idx,char tg,real xc,real yc) {
    index=idx, tag=tg, x=xc, y=yc;
}
// define the "set_values" method using another object
void Point::set_values(Point p) {
    index=p.index, tag=p.tag, x=p.x, y=p.y;
}
```

- Overloading is simply defined as the ability of one function to perform different tasks.
- In C++, operators (e.g. **`+, -, *, /, <<, etc.`**) can also be overloaded. See training folder for examples (Not covered in this training).

Pointer to class

- Use the same way as pointer to a struct and to access members of a pointer to a class with the member access operator "->"
- As with all pointers, pointers must be initialized before using:

```
Point p1, p2; // calling the Point() constructor
Point *ptr_p; //define pointer to class
ptr_p = &p2;  // point prt_p to p2 object
p1.set_values(0,'a',0,0); // object p1 use set_values method
p2.set_values(1,'b',1,1); // object p2 use set_values method
//access the member funtion using pointer ptr_p
ptr_p->set_values(2,'d',1,0);
ptr_p->print_values();
p2.print_values();
```

- What will be the output? (hint: we used the address of p2)

Derived Class - Inheritance

- Inheritance is one of the most important concepts in object-oriented programming.
- In C++ new class can inherit the members of an existing class. The existing class is called the ***base class***, and the new class is called the ***derived class***.
- A derived class can be derived from multiple base classes.

```
// syntax for declaring a derived class
class derived_class: access_specifier base_class_list
```

  - Access_specifier: `public, protected, private`
  - base-class is the name list of previously defined classes
  - If the access-specifier is not used, it is private by default.
- An example of derived class Particle based on Pointe:

```
class Particle: public Point {
};
```

- In order for class Particle to access the members in Point: index, tag, x, y, the access specifier needs to be changed to `protected`

Access Control and Inheritance

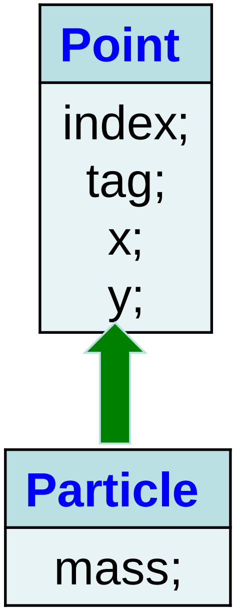
- Base class members in derived class:
  - `public` Inheritance: public members of the base class become public members of the derived class and protected members of the base class become protected members of the derived class. A base class's private members are not accessible.
  - `protected` Inheritance: public and protected members of the base class become protected.
  - `private` Inheritance: public and protected members of the base class become private.
  - Protected or private inheritance is ***rarely*** used. Most inheritance is **`public`**.

Access	**public**	**protected**	**private**
Within Same class	yes	yes	yes
Derived classes	yes	yes	no
Outside classes	yes	no	no

Implementation of Particle class

- In this example, we attempt to create a Particle class based on Point, we will add another attribute: mass of the particle.

```
// declare a derived class Particle based on Point
class Particle: public Point {
    protected:
        real mass;
    public:
        Particle(){ mass=0.0; };
        void set_mass(real);
        real get_mass();
};
// define the set_mass method
void Particle::set_mass(real m){
    mass = m;
}
// define the get_mass method
real Particle::get_mass(){
    return mass;
}
```



Example using the derived class

- Define an object of Particle class and access its methods:

```
int main(void) {
    Particle p; // which constructor is called?
    // calls the base class method (function)
    p.set_values(1,'a',0.5,1.0);
    p.print_values();
    // calls the derived class method (function)
    p.set_mass(1.3);
    // read how to control the format using cout
    // http://www.cplusplus.com/reference/ios/ios_base/precision/
    cout << "mass of p = " << fixed << setprecision(3)
         << p.get_mass() << endl;
    return 0;
}
```

- The output of the above code on a terminal:

```
$ ./a.out
point a: index = 1, x = 0.5, y = 1
mass of p = 1.300
```

Template and Generic Programming

- Template is a feature of the C++ that allow functions and classes to operate with generic types. There are two kinds of templates: function template and class template
- Declare a function template:

```
// Both expressions have exactly the same meaning behavior.
template <class    identifier> function_declaration;
template <typename identifier> function_declaration;
```

- Example of defining a template function:

```
// T is a generic "Type"
template<typename T>
T add(T a, T b) {
    return a+b;
}
```

- C++ provides unique abilities for ***Generic Programming*** through templates.
- Generic Programming achieved its first major success in C++ with the ***Standard Template Library***

Introduction to STL (Standard Template Library)

- The Standard Template Library, or STL, is a C++ library of ***container classes, algorithms, and iterators***.
- It provides many of the basic algorithms and data structures of computer science.
- STL is a generic library, meaning that its components are heavily parameterized: almost every component in the STL is a template.
- The STL can be categorized into two parts:
  - The Standard Function Library: consists of general-purpose, template based generic functions.
  - The Object Oriented Class Library: a collection of class templates and associated functions.
- STL is now part of the ANSI/ISO C++ Standard.
- We will touch std::vector and std::list in the training.
- Fortunately, we can use STL without knowing much about how to write them.

std::vector and std::list

- A std::vector is a collection of objects, all of which have the same type.
- Similar to arrays, vectors use contiguous storage locations for their elements, e.g. elements can also be accessed using offsets on regular pointers to its elements efficiently.
- Unlike arrays, vector can change size dynamically, with their storage being handled automatically by the container.
- Use of std::vector:

```
// include the appropriate header with "using" declaration
#include<vector>
using std::vector;
// define the std::vector objects (variables)
vector<int> index_vec;     // index_vec holds objects of type int
vector<double> value_vec; // value_vec holds objects of type double
vector<Point> point_vec;  // point_vec holds objects of class Point
```

An example using std::vector

- Below is an example using std::vector to: (1) find a value in an array (2) sort the array

```
#include <vector>
#include <algorithm>
#include <iostream>
using namespace std;
// using STL to: (1) find a value in an array (2) sort the array
int main() {
    int arr[]={2,3,1,5,4,6,8,7,9,0};
    int *p = find(arr,arr+10,5); // find number "5" using std::find
    p++;
    cout << "The number after 5 is " << *p << endl;
    vector<int> vec (arr,arr+10); // assign the array values to std::vector
    // now sort the array
    sort(vec.begin(),vec.end());
    for(int i=0; i<vec.size(); i++)
        cout << vec[i]<< " ";
    cout << endl;
    return 0;
}
```

Other important C++ concepts

- C++ Polymorphism
  - A call to a member function will cause a different function to be executed depending on the type of object that invokes the function (static polymorphism, dynamic polymorphism)
- C++ Encapsulation
  - Mechanism of exposing only the interfaces and hiding the implementation details from the user. (data hiding)
- C++ Abstraction, etc.

- Refer to C++ text books for further details, e.g.:
  - *C++ Primer (Stanley B. Lippman, Josée Lajoie, Barbara E. Moo)*
  - *Thinking in C++ (Chuck Allison and Bruce Eckel)*
  - *The C++ Programming Language (Bjarne Stroustrup)*

Selected C++ Libraries

- Use existing libraries for your work instead of starting from scratch!
- Generic:
  - Boost
- 3D Graphics:
  - Ogre3D
  - OpenGL
- Math:
  - BLAS and LAPACK
  - UMFPACK
  - Eigen
- Computational geometry
  - CGAL
- Finite Element Method, Finite Volume Method
  - deal.II
  - OpenFOAM, Overture

Exercise 2

- Calculate the result of a constant times a vector plus a vector: where $\boldsymbol{a}$ is a constant, $\vec{x}$ and $\vec{y}$ are one dimensional vectors.

$$\vec{y} \Leftarrow a\vec{x} + \vec{y}$$

1. Complete the code for the vector addition;
2. Change *x* and y to dynamic arrays

Exercise 3

- Complete the C code for matrix multiplication

$$A \cdot B = C$$

where:

$$a_{i,j} = i + j$$

$$b_{i,j} = i \cdot j$$

$$c_{i,j} = \sum_k a_{i,k} \cdot b_{k,j}$$

Also complete the following functions for 2d dynamic array:

- allocate_dynamic_2d_array
- free_dynamic_2d_array