

Initializing Class Objects: CONSTRUCTORS

- The class designer can guarantee the initialization of every object by providing a special member function called the **constructor**.
- The constructor is invoked **automatically** each time an object of that class is created (instantiated).
- These functions assign initial values to the data members, allocate memory for members, open files, establish a connection to a remote computer, etc.
- The constructor can accept parameters as needed, but it cannot return a value, so it cannot specify a return type (**even not void**).
- The constructor has the **same name** as the class itself.
- There are different types of constructors.
  For example, a constructor that defaults all of its arguments or requires no arguments, i.e., a constructor that can be invoked with no arguments, is called a *default constructor*.
- In this section, we will discuss different kinds of constructors.
- **Note:** If no initial value is specified for a member variable of a fundamental type (`double`, `int`, `bool` …) or pointer type (`int*, …`), it will contain a random garbage value.

Default Constructor:

A constructor that defaults all its arguments or requires no arguments, i.e., a constructor that can be invoked with no arguments.

```
class Point{                    // Declaration/Definition of the Point Class
 public:
   Point();                     // Declaration of the default constructor
   :
 private:
   int m_x, m_y;                // Attributes are not initialized
};

// Default Constructor
Point::Point()
{
   m_x = 0;                     // Assigns zeros to coordinates (just an example)
   m_y = 0;
}
// -------- Main Program -------------
int main()
{
  Point point1, point2{};     // Default constructor is called 2 times
  Point *pointPtr;            // pointPtr is not an object, the constructor is NOT called
  pointPtr = new Point;       // The object is created, the default constructor is called
```

Example e04_1.cpp

Default Constructor (cont'd):

- If you do not define any constructors for a class, then **the compiler generates** a *default constructor* for you.
- It is called a ***default default constructor*** because it is a default constructor that is generated by default.
- The purpose of a default default constructor is to allow an object to be created and all member variables to be set to their initial (default) values.
- Remember the examples about the `Point` class from the previous chapter, i.e., `e03_x.cpp`.

  We declared the `Point` class without a constructor and created objects from it.

  Actually, the compiler generated a default constructor with an empty body, and the variables got the initial values supplied by the *class creator*.

Example: A default constructor with an empty body.

It is not necessary to write such a default constructor; the compiler supplies it.

```
class Point{          // Declaration/Definition of the Point Class
 public:
   Point() {};        // Default constructor with an empty body (not necessary)
   :
 private:
   int m_x{}, m_y{};  // Attributes are initialized
};
```


Constructors with Parameters:

- There are two possible sources of initial values for objects:
  1. The class creator can provide the initial values in the class definition or in the default constructor.
  2. Users of a class (client programmers) may (and sometimes must) provide the initial values in a constructor with parameters.
- If the class creator defines a constructor with parameters, users of the class (client programmers) must supply the required arguments to create objects.

  Example:

```
class Point{          // Declaration/Definition Point Class
 public:
   Point(int, int);   // Constructor with two parameters
   :
 private:
   int m_x, m_y;      // Attributes are not initialized
};
```

- This declaration indicates that users of the `Point` class can supply two integer arguments when defining objects of that class.

  For example, `Point point1 {10, 20};` or `Point point1 (10, 20);`
- Constant objects can also be initialized: `const Point fixed_point {100, 200}; // cannot move`

Example (cont'd):

The `Point` class has a constructor with two parameters to initialize the coordinates.

```
// Constructor with two parameters to initialize x and y coordinates
Point::Point(int firstX, int firstY)
{
  if (firstX >= MIN_x) m_x = firstX;    // Accepts only valid values
  else m_x = MIN_x;
  if (firstY >= MIN_y) m_y = firstY;    // Accepts only valid values
  else m_y = MIN_y;
}
```

Example e04_2.cpp

- In our example `e04_2.cpp`, the class creator has already provided initial values for the attributes in the definition `int m_x{MIN_x}, m_y{MIN_y};`
- However, now, the client programmer can also provide other initial values under the control of the constructor function.
- When the class creator provides a constructor with parameters, the compiler does not provide a default default constructor.
- If a class contains only parameterized constructors, the client programmer cannot create objects without providing the necessary parameters. Example: `Point point1; // `***`Error! No default constructor`***
- Remember: The class creator sets the rules, and class users must follow them.

Multiple Constructors

- Constructors can also be overloaded following the rules of function overloading.
- So, a class may have multiple constructors with different signatures (the numbers or types of input parameters must be different).

Example:

```
class Point{                    // Declaration/Definition Point Class
 public:
   Point();                     // Default constructor
   Point(int, int);             // Constructor with two parameters
   :
 private:
   int m_x, m_y;                // Attributes are not initialized
};
```

- Now, the client programmer can define objects in different ways:

```
Point point1;                   // Default constructor is called
Point point2 { 10, 20 };        // Constructor with two parameters is called
```

- The following statement causes a compiler error because the class does not include a constructor with only one parameter.

```
Point point3 {30};             //ERROR! There is no constructor with a single parameter
```

Defining a default constructor using the `default` keyword

- Remember: If the class creator adds a constructor, the compiler no longer implicitly defines a default default constructor.
- If you still want it to be possible to create objects without providing any parameters (as in "`Point point1;`"), you should add a default constructor to the class.
- If the class definition already provides initial values of member variables, the body of the default constructor may be empty.
- Instead of defining a default constructor with an empty function body, you can use the `default` keyword to increase the readability of your code.

```
class Point{
 public:
   Point() = default;   // Default constructor with an empty body
   Point(int, int);     // Constructor with two parameters
     :
 private:
   int m_x{}, m_y{};    // Attributes are already initialized to zero
};
...
Point point1 {10, 20};   // m_x = 10, m_y = 20
Point point2;            // m_x = 0, m_y = 0, (initial values)
```


Default Arguments for Constructor Parameters

- Like all functions, a constructor can have default values for its parameters.

```
class Point{
  public:
   Point (int = 0, int = 0);            // Default values must be in the declaration
     :
};

// Definition (body) of the constructor (default values are in the declaration)
Point::Point(int firstX, int firstY)
{
   if (firstX >= MIN_x) m_x = firstX;    // Accepts only valid values
    ...
}
```

- Now, a client of the class can create objects as follows:

```
Point point1 {15, 75};  // m_x = 15, m_y = 75
Point point2 {100};     // m_x = 100, m_y = 0
```

- Since both parameters have default values (`m_x = 0`, `m_y = 0`), this constructor also counts as a ***default constructor***.

```
Point point3;           // m_x = 0, m_y = 0
```

Member Initializer List

- Data members of an object can be initialized using a member initializer list instead of assignment statements within the constructor's body.

Example:

```
// Definition of the default constructor
Point::Point() : m_x {}, m_y {}          // m_x = 0, m_y = 0
{

  ... // The body can be empty
}
```

Member initializer lists starts with ":"
It is places befor the body of the constructor.

```
// Definition of the constructor with two parameters
Point::Point(int firstX, int firstY) : m_x {firstX}, m_y {firstY}
{
  ... // The body can be empty
}
```

Member initializer list

- The member initializer list is especially essential when a class contains objects of other classes (Chapter 6) or when a class inherits from a base class (Chapter 7).

Member Initializer List (cont'd)

Initializing constant data members:

- The *member initializer list* is the **<u>only way</u>** to assign initial values to **constant** members.

Example: Constant data members of the Point class are initialized by the objects (class users)

- In our Point class, we have two constant data members, i.e.,

```
const int MIN_x {};   // intialized to zero
const int MIN_y {};
```

- Assume that the class creator wants to allow the client programmers (objects) to initialize these constant values by calling a constructor.
- However, you cannot assign a value to a constant in the constructor's body.

```
// Constructor to initialize all members of a Point object
Point::Point(int firstMINX, int firstMINY, int firstX, int firstY)
{
    MIN_x = firstMINX;     // ERROR! MIN_x is not modifiable
    MIN_y = firstMINY;     // ERROR! MIN_y is not modifiable
    :
}
```

Member Initializer List (cont'd)

Example: Constant data members of the Point class are initialized by the objects (cont'd)

- The constructor uses a *member initializer list* to initialize **constant data** members.

```
// Constructor to initialize all members of a Point object
Point::Point(int firstMINX, int firstMINY, int firstX, int firstY)
                        : MIN_x {firstMINX}, MIN_y {firstMINY}   Member initializer list
{
  ... // Code to initialize x and y coordinates according to given minimum values
}
```

- After the initialization in the constructor, the constant members cannot be modified later.

```
Point point1 {50, 60, 100, 200};    // MIN_x = 50, MIN_y = 60
                                    // m_x = 100, m_y = 200

Point point2 {-10, 0, -15, 20};     // MIN_x = -10, MIN_y = 0
                                    // m_x = -10, m_y = 20
                                    // The given firstX (-15) is not accepted
```

Example e04_3.cpp

In this example, we have two Point objects with different constant minimum values.

Member Initializer List (cont'd)

- If you use the member initializer list to initialize coordinates of the point objects, you cannot compare their values to limits.

Example: A member initializer list is used to initialize all members of a Point object

```
// Constructor to initialize all members of a Point object
Point::Point(int firstMINX, int firstMINY, int firstX, int firstY)
                    : MIN_x{firstMINX}, MIN_y{firstMINY}, m_x{firstX}, m_y{firstY}
{
  ...     // You may check and modify x and y coordinates
}
```

Initializing using an assignment statement vs. using an initializer list:

- When you initialize a member variable **using an assignment statement** in the body of the constructor:
  - First, the member variable is created in memory.
  - Then, the assignment is carried out as a separate operation.
- When you **use an initializer list**, the initial value is used to initialize the member variable as it is created.
  This can be a more efficient process, particularly if the member variable is an object of another class.
- We will cover these cases in the following chapters (6 and 7).

Initializing Arrays of Objects

- When an array of objects is created, the default constructor of the class (if any exists) will be invoked for each object in the array.

```
Point  pointArray[10];      // Default constructor is called 10 times
```

- To invoke a constructor with arguments, a **list of initial values** should be used.

Example: There is a constructor that can be called with zero, one, or two arguments

```
Point (int = 0,  int  = 0) // Constructor with zero, one, or two arguments
```

The number of elements is not provided.

List of initial values

In main function:

```
Point pointArray[] = { 10 , 20 , {30,40} };       // An array with three objects
```

Alternatively, to make the program more readable:

```
Point array[] = { Point {10}, Point {20}, Point {30,40} }; // An array with three objects
```

Three objects of type `Point` have been created, and the constructor has been invoked three times with different arguments.

Objects:	Arguments:
`array[0]`	`firstX = 10 , firstY = 0`
`array[1]`	`firstX = 20 , firstY = 0`
`array[2]`	`firstX = 30 , firstY = 40`

Initializing Arrays of Objects (cont'd)

- If the class has a default constructor, the programmer may define an array of objects as follows:

  ```
  Point pointArray[5]= { 10 , 20 , {30,40} };     // An array with 5 elements
  ```

  Here, an array with five elements has been defined, but the list of initial values contains only three values. For the last two elements, the default constructor is called.

- To call the default constructor for an object which is not at the end of the array:

  ```
  Point array[5] = { 10, 20, {}, {30,40} };     // An array with 5 elements
  ```
  or
  ```
  Point array[5] = { 10, 20, Point{}, {30,40} };
  ```
  or
  ```
  Point array[5] = { 10, 20, Point(), {30,40} };
  ```
  Here, for objects `array[2]` and `array[4]`, the default constructor is invoked.

- The following statement causes a compiler error:

  ```
  Point array[5]= { 10 , 20 ,  ,  {30,40} };   // ERROR! Not readable
  ```

Initializing large arrays with hard-coded values is not advisable.
Instead, the initial values should be obtained from external resources, such as a file, database, or keyboard.

DESTRUCTORS

- The *destructor* is a special method of a class that gets **called automatically**
  1. When each of the objects goes out of scope or
  2. A dynamic object is deleted from memory using the `delete` operator.
- It is executed to handle any cleanup operations that may be necessary.
- You only need to define a destructor when something needs to be done when an object is destroyed.

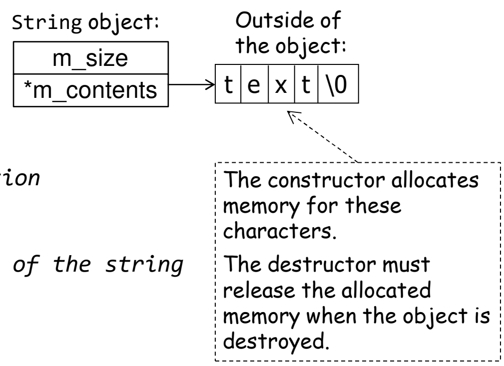
  For example,
  - Releasing memory that was allocated by a constructor using the `new` operator
  - Closing a file
  - Terminating a network connection
- The name of the destructor for a class is the tilde character (**~**) followed by the class name, e.g., **`~Point()`**.
- A destructor has no return type and cannot accept any parameters.
- A class can have only one destructor.
- The destructor for a class is always called automatically when an object is destroyed.

  Generally, you should not call a destructor explicitly. The circumstances where you need to call a destructor explicitly are so rare that you can ignore the possibility.

Example: A programmer (user)-defined String class

- Actually, the standard library of C++ contains a **`std::string`** class. Programmers do not need to write their own `String` classes.
- We write this class only to illustrate some concepts.
- A string is a sequence (array) of characters.

  It terminates with a null character `'\0'`.




```
class String{
public:
   String(const char *);  // Constructor
   void print() const;    // An ordinary member function
   ~String();             // Destructor
private:
   size_t m_size;         // Length (number of chars) of the string
   char *m_contents;      // Contents of the string
};
```

- Since the String class contains a pointer to strings (array characters), the constructor must allocate storage for characters, and the destructor must release memory when the object is destroyed.

Example: A user-defined String class (cont'd)

```
// Constructor
// Allocates memory and copies the input character array to contents
String::String(const char *in_data)
{
  size = std::strlen(inData);
  m_contents = new char[m_size + 1];          // Memory allocation, +1 for null character
  if (m_contents)                             // If memory is allocated,
      std::copy_n(inData, m_size + 1, m_contents);  // Copy the contents
  // else: if memory allocation fails, m_contents is nullptr; an exception can be thrown
}

// Destructor
// Memory is released
String::~String()
{
   delete[] m_contents;
}
```

```
int main()          // Test program
{
  String string1{"string 1"}; // Constructor
  String string2{"string 2"}; // Constructor
  string1.print();
  string2.print();
  return 0;     // Destructor is called twice
}
```

Example e04_4.cpp

The Copy Constructor

- Sometimes, we want to create a new object as a copy (with the same data) of an existing object.
- A **copy constructor** is a special type of constructor used to copy an object's contents to a new object during the construction of that new object.

Example: Creating an object as a copy of another object

```
Point point1 {0, 0, 10, 20};      // Define the point1 object using the constructor
Point point2 {point1};            // point2 is a copy of point1. Copy constructor runs
```

Newly created object | Existing object

`point1` and `point2` are two separate objects.
Their data members (usually) contain the same values.

- The input argument of the copy constructor is the existing object that will be copied into the new object.

Example: Defining the copy constructor (if necessary)

```
class Point {
public:
  Point(int, int, int, int);        // Constructor to initialize limits, x, and y
  Point(const Point&);              // Copy constructor
   :
```

The input parameter of a copy constructor is a *reference to a const object* of the same type (source object).

The Copy Constructor (cont'd)

Example (cont'd):

```
// The copy constructor copies limits and the coordinates but not the print count
Point::Point(const Point& originalPoint)
                    : MIN_x{originalPoint.MIN_x}, MIN_y{originalPoint.MIN_y},
                      m_x{originalPoint.m_x}, m_y{originalPoint.m_y}
{}
```

It does not copy the m_printCount

- The copy constructor may delegate to another constructor (i.e., call another of the class's constructors) using the initializer list.

```
// Copy constructor delegates to another constructor
Point::Point(const Point& originalPoint)
                    : Point { originalPoint.MIN_x, originalPoint.MIN_y,
                              originalPoint.m_x, originalPoint.m_y }
{}
```

The constructor with four parameters

Example e04_5.cpp

```
int main(){
  Point point2 {point1};      // Call copy constructor for point2
                              // point2 is created as a copy of point1

  // Other (older) notations to create copies of objects
  Point point3 = point2;      // Call copy constructor for point3, NOT assignment
  Point point4(point1);       // Call copy constructor for point4
```


The Copy Constructor (cont'd)

The compiler-generated default copy constructor:

- Usually, we do not need to write a copy constructor because the compiler already generates one by default.
- If the compiler generates it, it will simply copy the contents of the original into the new object byte by byte (memberwise).
- So, all data members are copied.
- In most cases, this memberwise copy is sufficient.

Example:

- What happens if we do not supply a copy constructor for our `Point` class?

Example e04_6.cpp

- Since the compiler-generated copy constructors copy all members, the print count is also copied. Therefore, the counter does not start from zero for the copies of the original object.
- In this case, we must write our own copy constructor.

If the compiler-generated copy constructor is sufficient, do not write a copy constructor for your class.

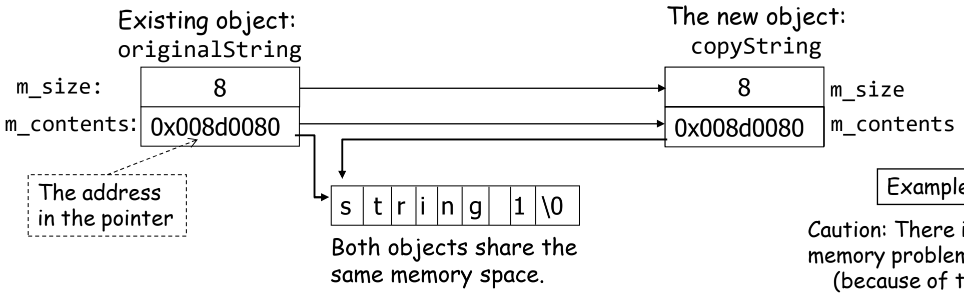
Compiler-generated copy constructor vs. programmer-written copy constructor:

- If a class has a member variable of a pointer type, the compiler-generated copy constructor will copy the address in the pointer to the other one.
- As a result, the pointers in different objects will be pointing to the same memory location (shared memory).

Example:

- The copy constructor, generated by the compiler for the user-defined `String` class (e04_3.cpp), will perform the following copy operation:

```
String originalString {"string 1"};
String copyString {originalString}; // Copy constructor
```



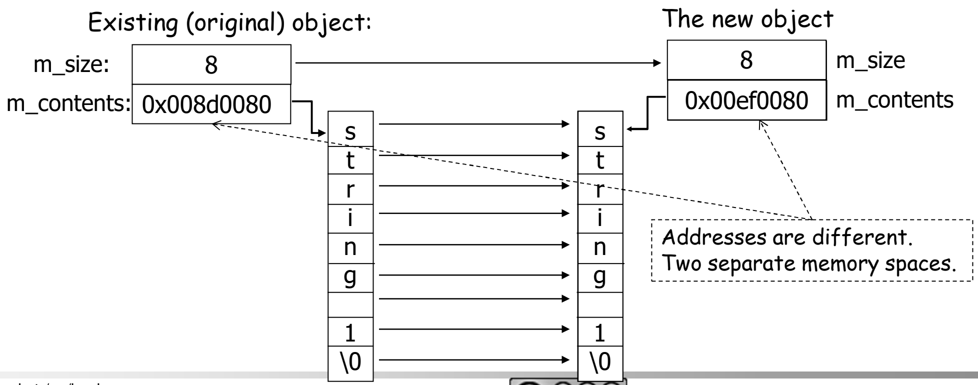
Example e04_7.cpp

Caution: There is a runtime memory problem in this program! (because of the destructor)

Example (cont'd):

- The copy constructor, generated by the compiler, cannot allocate memory or copy the memory locations to which member pointers point.
- Since both pointers point to the same memory space, the `delete` operation in the destructor causes a runtime error.
- The programmer must write the copy constructor for the class to allocate memory for the pointer and perform copy operations between two memory spaces.

Example: **Programmer-written copy constructor**



Example: The **programmer-written** copy constructor of the String class

```
class String{
public:
  String(const char*);                // Constructor
  String(const String&);              // Copy constructor
    :
};
// Copy Constructor
// Allocates memory and copies the contents of the existing object to
// the newly constructed object
String::String(const String& originalString)
{
  m_size = originalString.m_size;
  m_contents = new char[m_size + 1];            // memory allocation
  if (m_contents)                               // If memory is allocated, copy the contents
     std::copy_n(originalString.m_contents, m_size + 1, m_contents);
  :
}
int main() {
  String originalString{"string 1"};
  String copyString{originalString};            // Programmer-defined copy constructor
  String otherString = originalString;          // Another notation, NOT assignment
  ...
```

Example e04_8.cpp

Deleting the Copy Constructor:

- If the class creator does not want the objects of this class to be copied, they can prevent the compiler from generating a copy constructor.
- They can instruct the compiler not to generate a copy constructor by adding "= **delete**;" next to the signature of the copy constructor in the class declaration.

Example: **Deleting the copy constructor of the user-defined String class**

```
class String{
public:
String(const char*);             // Constructor
String(const String&) = delete;  // Copy constructor is deleted
  :
};
```

- Another solution is to make the signature of the copy constructor private.

Example: **Private copy constructor**

```
class String{
public:
 String(const char*);        // Constructor
private:
 String(const String&);      // Copy Constructor is private
 :
```

```
int main() {
 // Compiler Error!
 String copyString{originalString};
 :
```

Example e04_9.cpp

Passing objects to functions as arguments and the role of the copy constructor

- Objects should generally be passed or returned by reference unless there are compelling reasons to pass or return them by value.
- Recall that the object passed or returned by value must be *copied* into the stack.
- The compiler uses **the copy constructor** to copy the object into the stack.
- If the class contains a programmer-written copy constructor, the compiler uses this function to copy the object into the stack.
- Passing or returning by value can be especially inefficient for objects.

  Recall that the data may be large, thus wasting storage, and the copying itself takes time.

Example:

- We have a class called `GraphicTools`, which contains tools that can be used to perform operations on `Point` objects.

  For example, the method `maxDistanceFromOrigin` compares two `Point` objects and returns the object that has the larger distance from the origin (`0,0`).
- We will consider two different cases regarding passing and returning objects:
  - Case 1: call-by-value, return-by-value
  - Case 2: call-by-reference (to constant), return-by-reference (to constant)

Case 1 (call-by-value, return-by-value. Inefficient!):

Example:

In this program, the method `maxDistanceFromOrigin`

1. gets two `Point` objects using the **call-by-value** technique.
2. finds the object that has the larger distance from the origin, and
3. returns the object using the **call-by-value** technique.

```
Point GraphicTools::maxDistanceFromOrigin(Point in_point1, Point in_point2) {
```

Examine the output:

Example e04_10.cpp

- The constructor is called twice (once for `point1` and once for `point2`).
- The default constructor is called once for `point3`.
- These are objects defined by the programmer in the `main` function.
- When the `maxDistanceFromOrigin` function is called, the copy constructor is called three times (twice for input parameters and once for the return value).
- In total, six `Point` objects have been created.

  The three additional objects are created solely due to the call-by-value technique.
- As expected, the destructor is called six times because six objects were created.

Case 2 (call-by-reference, return-by-reference. Efficient!):
Example:

In this program, the method `maxDistanceFromOrigin`

1. gets two `Point` objects using the **call-by-reference** technique,
2. finds the object that has the larger distance from the origin, and
3. returns the object using the **call-by-reference** technique.

```
const Point& GraphicTools::maxDistanceFromOrigin(const Point& in_point1, const Point& in_point2) {
```

Examine the output:

Example e04_11a.cpp

- The constructor is called twice (once for `point1` and once for `point2`).
- The default constructor is called once for `point3`.
- These are objects defined by the programmer in the main function.
- In total, three `Point` objects have been created.
- **No other constructor is called.**
- Additional objects are not created.
- As expected, the destructor is called only three times.

- A reference type can be used to receive the returned reference to the object.

```
const Point& point3{ tool.maxDistanceFromOrigin(point1, point2) };
```

Example e04_11b.cpp

this Pointer

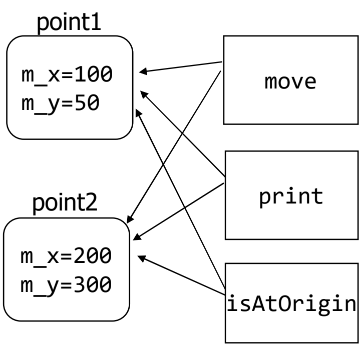
- Each object has its own data space in a computer's memory system. When an object is defined, memory is allocated only for its data members.
- The code of member functions is created only once. Each object of the class uses **the same function code**.

Example:

```
class Point {
 public:
   Point(int, int);
   void move(int, int);
   void print() const;
   bool isAtOrigin() const;
 private:
   int m_x{}, m_y{};
};

int main(){
  Point point1{100, 50};
  Point point2{200, 300};
  :
```

Point objects in memory:



How does C++ ensure that the functions reference the proper object?

this Pointer (cont'd)

- The *C++* compiler defines an object pointer called **this**.
- When a member function is called, this hidden pointer contains the address of the object for which the function is invoked.
- So, member functions can access the data members using the pointer **this**.
- The compiler compiles our Point methods as follows:

```
// A function to move the points
void Point::move(int new_x, int new_y)
{
  this->m_x = new_x;
  this->m_y = new_y;
}

// is the point at the origin (0,0)
bool Point::isAtOrigin()
{
  return (this->m_x == 0) && (this->m_y == 0);
}
```

You could write the function explicitly using the pointer this if you wanted, but it is not necessary.

this Pointer (cont'd)

- When you call a method for a particular Point object, the this pointer will contain the address of that object.
- This means that when the member variable m_x is accessed in the move method during execution, it actually refers to this->m_x, which is the fully specified reference to the object member being used.

For example, when we call the move method for point1:

```
point1.move(50,100);
point2.move(0,0);
```

The compiler considers this code as follows (pseudocode):

```
this = &point1;     // the address of object point1 is assigned to this,
move(50,100);       // and the method move is called.
this = &point2;     // the address of object point2 is assigned to this,
move(0,0);          // and the same move method is called.
```

This is not valid *C++* code. This pseudocode is given only to explain how the compiler uses this pointer to access member data.

Returning this (as a pointer)

Example:

- We add a new method to the Point class: maxDistanceFromOrigin that compares a point object to a second object and returns a pointer to the object with the larger distance from the origin (0,0).
- For example, the following piece of code calls the method for the point1 object and compares it to the object point2 in terms of distance from (0,0).
- Depending on the comparison result, the code returns a pointer to one of these two objects.

```
const Point* pointPtr;                              // pointer to Point objects
pointPtr = point1.maxDistanceFromOrigin(point2);   // method runs for point1
pointPtr->print();                                  // pointPtr points either to point1 or point2
point1.maxDistanceFromOrigin(point2)->print();     // chain of calls

// Definition of the method that returns a pointer to Point objects
const Point* Point::maxDistanceFromOrigin(const Point& in_point) const
{
  if (distanceFromOrigin() > in_point.distanceFromOrigin())
     return this;            // the pointer to the object for which the method is called
  else
     return &in_point;       // the address of the input object
}
```

Example e04_12.cpp

Returning this (as a reference)

Remember: Passing and returning references (instead of pointers) make the code easier to read (slide 2.42).

The maxDistanceFromOrigin method could return a reference to the Point object as follows:

```
const Point& Point::maxDistanceFromOrigin(const Point& in_point) const {
  if (distanceFromOrigin() > in_point.distanceFromOrigin())
     return *this;           // the reference to the object for which the method is called
  else
     return in_point;        // the reference to the input object
}

const Point point3;                               // point3 is an object
point3 = point1.maxDistanceFromOrigin(point2);   // Assign the result (object) to point3
point3.print();
```

- You can chain method calls based on their return types.
- Do not overuse method chaining. Chaining too many methods can make code more difficult to understand.

```
point1.maxDistanceFromOrigin(point2).print();

     result (point1 or point2).print()
```

Example e04_13.cpp

```
double distance = point1.maxDistanceFromOrigin(point2).distanceFromOrigin();
```

Static Class Members

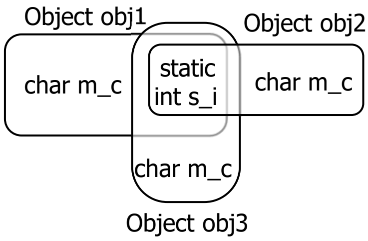
Static data members:

- Each object of a class has its own copy of the ordinary data members.
  For example, `point1` and `point2` objects of the `Point` class have different `m_x` and `m_y` variables in memory.
- When you declare a member variable of a class as **`static`**, the static member variable is defined only once, regardless of how many class objects have been defined.
- Each `static` member variable is accessible by any object of the class and shared among all existing objects in memory.
  Such a variable represents "class-wide" information (i.e., a property that is shared by all instances and is not specific to any one object of the class).
- The `static` members exist even if no class objects have been created.

Example:

```
class StaticExample{
  :
   char m_c;
   static int s_i;
};

int main()
{
  StaticExample obj1, obj2, obj3;
   :
```



Static data members (cont'd):

- In certain cases, all objects of a class should share <u>only one copy</u> of a particular data member.

Example:

- Requirement: We need to determine the number of active objects of a specific class (e.g. `Point`).
- Solution: We can use a static counter. Constructors will increment this counter, and the destructor will decrement it.

```
class Point {
   :
 private:
   int m_x{}, m_y{};                               // Coordinates
   static inline unsigned int s_point_count{};   // A static counter; initialized to zero
};
```

The `inline` keyword is used during the initialization of static variables. Details are outside the scope of this course.

Initializing static member variables:

- Inline variables have been supported since C++17.
- Before C++17, we would have had to declare the counter as follows:
  `static unsigned int s_point_count;            // A static counter`
  Then, we would have had to define and initialize the static member outside the class with a definition:
  `unsigned int Point::s_point_count {};         // This is still valid today`
- Starting with C++17, the `inline` keyword has been used during the initialization of static variables.

Example: Determining the number of active objects of the `Point` class (cont'd)

- All constructors of the `Point` class will increment the counter, and the destructor will decrement it.

```
Point::Point() {                      // The default constructor
:
  s_point_count++;                    // increments the static counter
}

Point::Point(int in_x, int in_y) {    // Constructor to initialize x and y coordinates
:
  s_point_count++;                    // increments the static counter
}

Point::Point(const Point& in_point){   // Copy Constructor
:
  s_point_count++;                    // increments the static counter
}

Point::~Point() {                     // Destructor
:
  s_point_count--;                    // decrements the static counter
}
```

Example e04_14.cpp

Static constant data members:

- Constant data members are usually declared `static`. However, defining constants as `static` members depends on the requirements of the project.

  A) Static constants:

  If you define a **constant as a static member**, only a single instance of that constant is shared between all objects.

  B) Non-static constants:

  If you define a **constant as a non-static member** variable, an exact copy of this constant will be made for every single object.

  So, each object of the same class can have copies of a constant with different values, which is usually pointless. However, sometimes we have reasons to do this.

Example: Limits of the `Point` class

- In our `Point` class, we have constant data members to represent the limits of the coordinates, `MIN_x` and `MIN_y`.

  Case A: If the class has limits that are valid for all class objects, these constants should be declared `static`.

  Case B: However, if each object should have its own limits specific to itself, then these constants should not be declared `static`.

Example: Static constant data members (Case A):

- All Point objects have the same limit values.

```
class Point {        // Declaration of the Point Class with lower bounds
public:
  // Static constants
  // Lower bounds of x and y coordinates for all objects
  static inline const int MIN_x{};         // Same (zero) for all objects of Point
  static inline const int MIN_y{};         // Same (zero) for all objects of Point
   :
```

- The keywords static, inline, and const may appear in any order you like.
- Unlike regular member variables, there is no harm in making constants public because class users can read but not modify them.
- It is common to define public constants for boundary values.
- Outside the class, class users can read these values directly using the class name and the scope resolution operator ::.

Example:

Example e04_15a.cpp

Class name::static variable/constant

```
int main(){
   if (input_x < Point::MIN_x) ...    // makes a decision using the limit. MIN_x is public
   // Define an object using the limits
   Point point1 { Point::MIN_x, Point::MIN_y };    // m_x = MIN_x, m_y = MIN_y
```


Example: Non-static constant data members (Case A):

- Point objects can have different limit values.
- Remember: Constant members can be initialized in a constructor using the member initializer list.

```
class Point {        // Declaration of the Point Class with lower bounds
public:
  // Non-static constants
  // Point objects can have different lower bounds
  const int MIN_x{};         // Initialized to zero. This can be changed in the constructor
  const int MIN_y{};
   :

// The Constructor initializes the constant limit values using the member initializer list
Point::Point(int newMIN_x, int newMIN_y) : MIN_x{ newMIN_x }, MIN_y{ newMIN_y }
{ ... }
```

Constant members are initialized using the member initializer list.

- Now, the class user can create Point objects with different limit values

```
int main(){
  Point point1 {10, 20};      // MIN_x = 10, MIN_y = 20
  Point point2 {-5, 100};     // MIN_x = -5, MIN_y = 100
```

Example e04_15b.cpp

Static Class Members (cont'd)

Static methods (member functions):

- A public **static** method can be called even if no class objects have been created.
- It can also be invoked from outside the class.
- A static method can operate on static member variables, regardless of whether any objects of the class have been defined.

  For example, a static method can be used to initialize static data members before any objects have been created.
- A static method is independent of any individual class object but can be invoked by any class object if necessary.

  For example, we can write a static initPointCounter method for the Point class to initialize the counter.

Example e04_16.cpp

```
class Point {
 public:
 static void initPointCount(unsigned int);  // static method to initialize the counter value
 static unsigned int getPointCount();       // static method to read the counter value
   :
};

Point::initPointCount(100);                 // Set counter to 100
if (Point::getPointCount > 500){...         // Make a decision using the counter
```

Class name::static method

A simple example:

Example e04_17.cpp

The Unified Modeling Language - UML

- UML is a visual language for specifying, constructing, and documenting the artifacts (models) of software.
- UML is not a method to design systems; it is used to **visualize** the analysis and the design models.
- Benefits:
  - It makes it easier to understand and document software systems.
  - It supports teamwork. Since UML diagrams are more understandable than the program code, team members (e.g., project leader, software architect, and developers) can discuss the design.
  - Some tests and quality measurements can be conducted on UML diagrams, and design flaws can be detected before coding.
  - There are tools that can create the code from UML diagrams and draw UML diagrams for a given code.

The Unified Modeling Language – UML (cont'd)

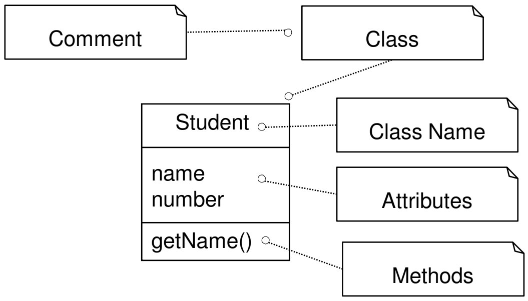
- UML has evolved from the work of Grady Booch, James Rumbaugh, and Ivar Jacobson (known as the three amigos) for object-oriented design.
- It has been extended as a general-purpose, developmental modeling language to cover a wider variety of software engineering projects.
- The Object Management Group (OMG) adopted UML as a standard in 1997 and has managed it ever since.
  https://www.uml.org/
- In 2005, UML was also published by the International Organization for Standardization (ISO) as an approved ISO standard.
  ISO/IEC 19505-1:2012
  Information technology —Object Management Group Unified Modeling Language (OMG UML)
- The latest version of UML is 2.5.1, published in December 2017.
- You can get the specifications for the current version from the website of OMG.
  https://www.omg.org/spec/UML/

The Unified Modeling Language – UML (cont'd)

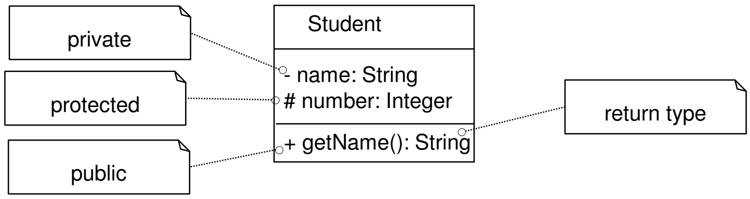
- There are different kinds of UML diagrams, which are used in various phases of a software development process.
- In the latest version of UML, there are 14 diagram types.
- There are two main categories: **structure diagrams** and **behavior (interaction)** diagrams.
  - **Structure diagrams** show the static structure of the objects in a system.
    In this course, we will draw **class diagrams** (a type of structure diagram) to represent the (compile-time) structure of our programs.
    The **class diagram** displays the attributes and operations of each class and the relationships between them.
  - **Behavior diagrams** illustrate the elements of a system that are dependent on time. We can see how the components of the system relate to each other dynamically during its execution (runtime).
    In this course, we will draw **sequence diagrams** and **communication diagrams** to represent how objects in our program interact in runtime.
- As we cover various concepts in the course, we will see how they are represented using UML diagrams.

Class Diagrams

A class diagram shows the structure of the classes and the relationships between them.



If necessary, it can also show access modes and data types.



Class Diagrams (cont'd)

Comments: Comments in UML are placed in dog-eared rectangles.

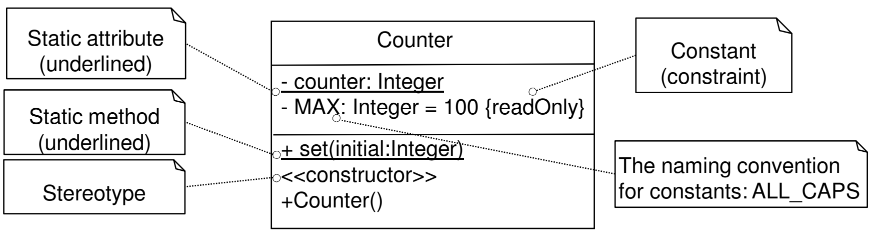
You can use comments to

- put anything you want in a diagram
- add application- and program-specific details

Stereotypes: A stereotype is a way of extending UML in a uniform manner and remaining within the standard.

You indicate a stereotype using <<stereotype name>>

Constraints: A constraint in UML is a text string in curly braces ({usually language-specific}). UML defines a language (Object Constraint Language –OCL) that you can use to write constraints.



Example: The `Point` Class

```
Point
--------------------------------
- MIN_x: Integer = 0
- m_x: Integer = MIN_x
- s_point_count: Integer = 0
     :
--------------------------------
+ Point(Integer, Integer)
+ distanceFromOrigin(): double
          :
```

- Since the primary purpose of UML is to demonstrate design, the details of data and methods are not crucial.
- Sometimes, we only show attributes without their types and the methods without their parameters.
- In the following chapters, we will use UML diagrams to represent static and dynamic relations between classes/objects.