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 definition of the class 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 shows that the users of the Point class have to supply two integer arguments while defining objects of that class.

    For example, `Point point1 {10, 20};` or `Point point1 (10, 20);`
  - Otherwise, a compiler error is generated: `Point point1; // Error!`

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 parametrized constructors, the client programmer cannot create objects without providing parameters.
- 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
```

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.

Member Initializer List

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

Example:

```
// Definition of the default constructor
Point::Point() : m_x {}, m_y {}          // m_x = 0, m_y = 0
{
        Member initializer lists starts with ":"
  ...
}      // The body can be empty

// 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

}
```


Member Initializer List (cont'd)

Initializing constant data members:

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

Example: Constant data members of the `Point` class are initialized by the objects

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

```
const int MIN_x {};
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}
{
  ... // Code to initialize x and y coordinates according to given minimum values
}
```

Member initializer list

- 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
```

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 a class.
- We will cover these cases in the following chapters.

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.

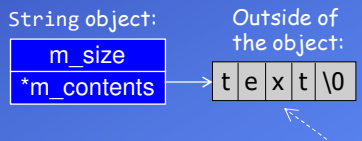
  For example,
  - Releasing memory that was allocated by a constructor using the `new` operator
  - Closing a file
  - Terminating a network connection
- The name of the destructor for a class is the tilde character (**~**) followed by the class name, e.g., **`~Point()`**.
- A destructor has no return 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();          // 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
};
```

The constructor allocates memory for these characters.

The destructor must release the allocated memory when the object is destroyed.

- 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(in_data);
  m_contents = new char[m_size + 1];          // Memory allocation, +1 for null character
  if (m_contents)                             // If memory is allocated, copy the contents
     for (unsigned index = 0; index < m_size + 1; index++)
        m_contents[index] = inData[index];    // copy the contents
 }

// 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_3.cpp

Constant Objects and const Member Functions

Constant (const) objects:

- The programmer may use the keyword **const** to specify that an object is constant (not modifiable).
- Any attempt to modify (to change) the attributes of a const object directly or indirectly (by calling a function) results in a **compilation** error.
- Any member variable of a const object is itself a const variable and thus immutable.
- For example:

```
const Point fixedPoint {10, 20};        // fixedPoint is a constant object
```

The object fixedPoint has the coordinates (10, 20), and this point cannot be moved to another location.

Constant (const) member functions:

- C++ compilers disallow member function calls for const objects.
- The programmer may define as **const** some member functions that do not modify any data members (attributes) of the object.
- Only const methods can operate on const objects.

Constant (const) Member Functions (cont'd):

Example:

- We specify methods that do not modify an object's attributes as const.

```
class Point {
public:
  Point(int, int);                      // Constructor to initialize x and y coordinates
  double distanceFromOrigin() const;    // const method. The distance of a point from (0,0)
  void print() const;                   // const method prints coordinates to the screen
  // Getters are constant
  int getX() const { return m_x; }      // Accessor for x coordinate
  int getY() const { return m_y; }      // Accessor for y coordinate
  // Setters are not constant
  void setX(int);
  void setY(int);
  bool move(int, int);                  // A nonconstant method to move points
};

// Constant method calculates and returns the distance of a point from (0,0)
double Point::distanceFromOrigin() const {
  return std::sqrt(m_x * m_x + m_y * m_y);    // distance from (0,0)
}
```


Constant Objects and const Member Functions (cont'd)

Example (cont'd):

```
int main()
{
  const Point fixedPoint {10, 20};                                    // Constant object
  std::print("Distance from Origin = {}", fixedPoint.distanceFromOrigin());  //OK
  fixedPoint.print();                              // OK. Print the constant point
  fixedPoint.move(15, 25);                         // ERROR! fixedPoint is constant (cannot move)
  Point nonFixedPoint{ 30, 40 };                   // Nonconstant object
  nonFixedPoint.move(100, 200);                    // OK, nonconstant object can move
}
```

- A const method can invoke only other const methods because a const method is not allowed to alter an object's state either directly or indirectly (i.e., by invoking some non-const method).

Specify all member functions that do not change the object's attributes as const to avoid possible errors and to allow users of the class to define constant objects.

Constant Objects and const Member Functions (cont'd)

The mutable Keyword:

- Sometimes, we want to allow particular class members to be modifiable even for a const object.
- We can do this by specifying such attributes as **mutable**.

Example:

- We want to count how many times a point object is printed.
- We will add a mutable variable, m_printCount, to the Point class.

```
class Point {
public:
 Point(int, int);            // Constructor with two parameters to initialize x and y
 bool move(int, int);        // A nonconstant function to move points
 void print() const;         // A constant function to print
  :
private:
  :
 int m_x{ MIN_x }, m_y{ MIN_y };          // x and y coordinates are initialized
 mutable unsigned int m_printCount{};     // Mutable data member
};
```


The mutable Keyword (cont'd):

Example (cont'd):

```
// This method prints the coordinates to the screen and increments the m_printCount
void Point::print() const
{
  std::println("X= {} , Y= {}", m_x, m_y);
  std::println("Print count= {}", ++m_printCount);
}
```

Although the print method is specified as const, it can modify the mutable attribute printCount.

```
int main()
{
  const Point fixedPoint{ 10, 20 };   // Constant object
  fixedPoint.print();                 // m_printCount is incremented
  :
}
```

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.

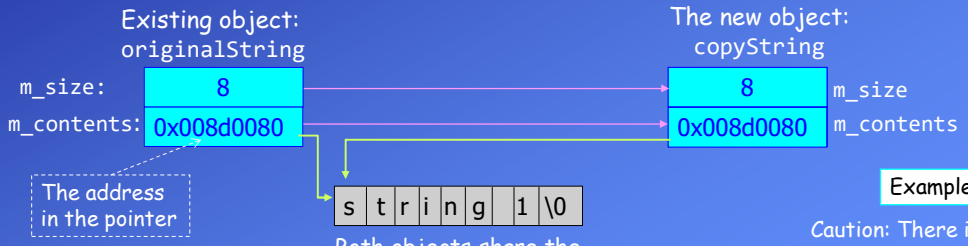
Compiler-generated copy constructor vs. programmer-written copy constructor:

- 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
```



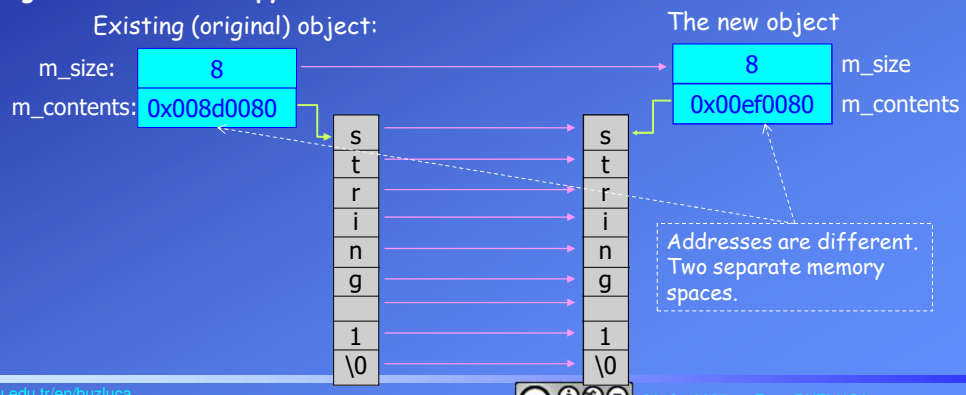
Example e04_7.cpp

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
     for (std::size_t index = 0; index < m_size + 1; index++)
         m_contents[index] = originalString.m_contents[index];
}
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

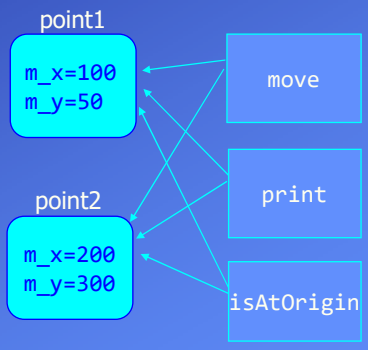
- Each object has its own data space in a computer's memory system. When an object is defined, memory is allocated only for its data members.
- The code of member functions is created only once. Each object of the class uses **the same function code**.

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

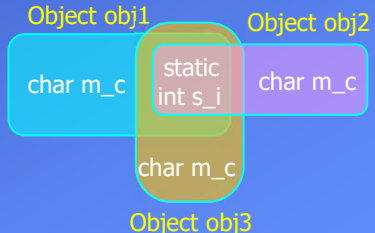
Static data members:

- 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 only one copy 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
    :
};
```

Class name::static method

A simple example:

Example e04_17.cpp

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

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.

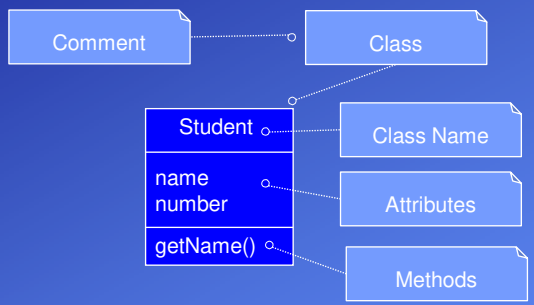
    In this course, we will draw **class diagrams** (a type of structure diagram) to represent the (compile-time) structure of our programs.

    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).

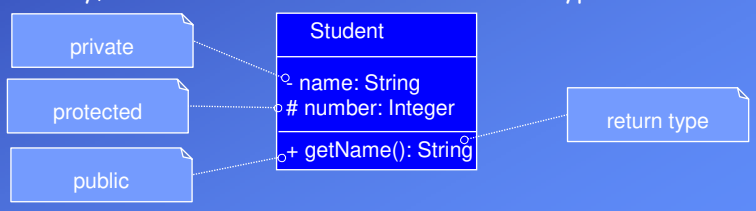
    In this course, we will draw **sequence diagrams** and **communication diagrams** to represent how objects in our program interact in runtime.
- As we cover various concepts in the course, we will see how they are represented using UML diagrams.

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.

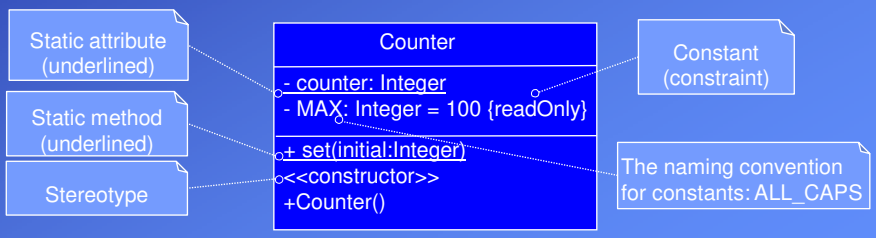
You can use comments to

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

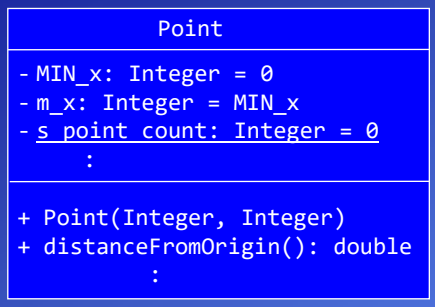
Stereotypes: A stereotype is a way of extending UML in a uniform manner and remaining within the standard.

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



- 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.