C++

程式語言（二）

Introduction to Programming (II)

Constructors & Destructors

Joseph Chuang-Chieh Lin

Dept. CSE, NTOU

Platform/IDE

- Dev-C++

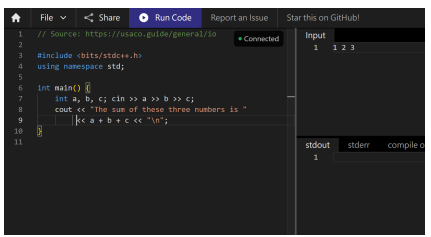
https://www.pngegg.com/en/search?q=Dev-C

- Codeblocks

https://icons8.com/icons/set/code-blocks

- OnlineGDB (https://www.onlinegdb.com/)

- Real-Time Collaborative Online IDE (https://ide.usaco.guide/)



Textbooks (We focusing on C++11)

- ***Learn C++ Programming by Refactoring* (由重構學習 C++ 程式設計). Pang-Feng Liu (劉邦鋒). NTU Press. 2023.**
- ***C++ Primer. 5th Edition.* Stanley B. Lippman, Josée Lajoie, Barbara E. Moo. 2019.**
- *Effective C++*. Scott Meyers. O'Reilly. 2016.
- *Thinking in C++. Vol. 1: Introducing to Standard C++*. 2nd Edition. Bruce Eckel. Prentice Hall PTR. 2000.

Useful Resources

- Tutorialspoint
  - https://www.tutorialspoint.com/cplusplus/index.htm
  - Online C++ Compiler
- Programiz
  - https://www.programiz.com/cpp-programming
- LEARN C++
  - https://www.learncpp.com/
- MIT OpenCourseWare - Introduction to C++
  - https://ocw.mit.edu/courses/6-096-introduction-to-c-january-iap-2011/pages/lecture-notes/
- Learning C++ Programming
  - https://www.programiz.com/cpp-programming
- GeeksforGeeks
  - https://www.geeksforgeeks.org/c-plus-plus/

Constructors and Destructors

Constructors

- Each class defines how objects of its type can be **initialized**.
- Classes control object initialization by defining one or more special member functions known as **constructors**.
  - **NO** return type.
- A constructor: **initialize the data members of a class object**.
  - A constructor is run whenever an object of a class type is created.
- It's very useful for setting initial values for certain member variables.

Default Constructors

- The compiler generates a default constructor, called **synthesized default constructor**, automatically only if a class declares no constructors.
- **Note:** for some classes, the synthesized default constructor does the wrong thing.

Constructors

Refer to: https://www.tutorialspoint.com/cplusplus/cpp_constructor_destructor.htm

```
#include <iostream>
using namespace std;

class Line {
   public:
      void setLength( double len );
      double getLength();
      Line(); // the constructor
   private:
      double length;
};
```

```
Line::Line() {
   cout << "Object is being created\n";
}
void Line::setLength(double len) {
   length = len;
}
double Line::getLength() {
   return length;
}
```

```
int main() {
   Line line;

   line.setLength(6.0); // set line length
   cout << "Length of line: " << line.getLength() <<endl;

   return 0;
}
```

```
Object is being created
Length of line : 6
```

Constructors

Refer to: https://www.tutorialspoint.com/cplusplus/cpp_constructor_destructor.htm

```
#include <iostream>
using namespace std;

class Line {
   public:
      void setLength( double len );
      double getLength();
      Line() = default;
     // synthesized default constructor
   private:
      double length;
};
```

```
void Line::setLength(double len) {
   length = len;
}
double Line::getLength() {
   return length;
}
```

```
int main() {
   Line line;

   line.setLength(6.0); // set line length
   cout << "Length of line: " << line.getLength() <<endl;

   return 0;
}
```

```
Length of line : 6
```

Parameterized Constructors

Refer to: https://www.tutorialspoint.com/cplusplus/cpp_constructor_destructor.htm

```
#include <iostream>
using namespace std;

class Line {
   public:
      void setLength( double len );
      double getLength();
      Line(double len);
      // constructor with parameters
   private:
      double length;
};
```

```
Line::Line(double len) {
    cout << "Object is being created, "
         << "length = " << len << endl;
    length = len;
}
void Line::setLength(double len) {
    length = len;
}
double Line::getLength() {
    return length;
}
```

```
int main() {
   Line line(10.0);

   cout << "Length of line: " << line.getLength() <<endl;
   line.setLength(6.0);
   cout << "Length of line: " << line.getLength() <<endl;
   return 0;
}
```

```
Object is being created, length = 10
Length of line : 10
Length of line : 6
```

Constructor Initializer List

Refer to: https://www.tutorialspoint.com/cplusplus/cpp_constructor_destructor.htm

```
#include <iostream>
using namespace std;

class Line {
   public:
      void setLength( double len );
      double getLength();
      Line() = default;
      Line(double len): length(len) {};
   private:
      double length;
};
```

```
void Line::setLength(double len) {
   length = len;
}
double Line::getLength() {
   return length;
}
```

Constructor Initializer List

=> **Initialize** the data members, instead of **assigning** their values afterwards

```
int main() {
   Line line1, line2(10.0);
   cout << "Length of line1: " << line1.getLength() <<endl;
   cout << "Length of line2: " << line2.getLength() <<endl;
   line1.setLength(6.0);
   cout << "Length of line1: " << line1.getLength() <<endl;
   return 0;
}
```

```
Length of line1: 4.68426e-310
Length of line2: 10
Length of line1: 6
```

const or references must be initialized

- For example,

https://onlinegdb.com/7x8SHvUZ1

```
class ConstRef {
public:
    ConstRef(int ii);
private:
    int i;
    const int ci; // must be initialized
    int &ri; // must be initialized
};

ConstRef::ConstRef(int ii) { // assignment...
    i = ii; // ok
    ci = ii; // error: cannot assign to a const
    ri = i; // error: ri is a reference and was
            // never initialized...
}
```

`const` or references must be initialized

- The modified example:

https://onlinegdb.com/7qttH-HrT

```
class ConstRef {
public:
    ConstRef(): i(0), ci(0), ri(i) {}
    ConstRef(int ii): i(ii), ci(ii), ri(i) { }
private:
    int i;
    const int ci; // must be initialized
    int &ri; // must be initialized
};
```

```
int main() {
    ConstRef r1(0), r2;
    return 0;
}
```

Destructors (1/3)

- **Destructors** do whatever work is needed to **free** the resources used by an object and **destroy** the **nonstatic data members** of the object.
- The destructor is a member function with the name of the class prefixed by a tilde **(~)**.
- It has **no return value** and takes **no parameters**.
  - Cannot be overloaded.
  - There is always only one destructor for a given class.

```
class Foo {
public:
    ~Foo(); // destructor
// ...
};
```

Destructors (2/3)

- A destructor also has a function body and a destruction part.
- In a destructor:
  - The function body is executed first, and then the members are destroyed.
  - Members are destroyed in reverse order from the order in which they were initialized.
- The function body of a destructor does whatever operations the class designer wishes to have executed subsequent to the last use of an object.
  - Typically, the destructor **frees resources** an object allocated during its lifetime.

Destructors (3/3)

- The destruction part is implicit.
  - What happens when a member is destroyed depends on the type of the member.
  - Members of class type are destroyed by running the member's own destructor.
- The built-in types do not have destructors, so nothing is done to destroy members of built-in type.

Destructor Examples

Refer to: https://www.tutorialspoint.com/cplusplus/cpp_constructor_destructor.htm

```
#include <iostream>
using namespace std;

class Line {
   public:
      void setLength( double len );
      double getLength( void );
      Line();   // constructor
      ~Line();  // destructor

   private:
      double length;
};
```

```
Line::Line(void) {
   cout << "Object is being created"
        << endl;
}
Line::~Line(void) {
   cout << "Object is being deleted"
        << endl;
}
void Line::setLength(double len) {
   length = len;
}
double Line::getLength(void) {
   return length;
}
```

```
int main() {
   Line line;
   line.setLength(6.0);
   cout << "Length of line : "
        << line.getLength() << endl;
   return 0;
}
```

```
Object is being created
Length of line : 6
Object is being deleted
```

Destructor Examples

Refer to: https://onlinegdb.com/QK8YB6RBP

```
#include <iostream>
using namespace std;

class Line {
   public:
      void setLength( double len );
      double getLength( void );
      Line();   // constructor
      ~Line() { cout << "An object with length " << length << " is out!" << endl;} ;

   private:
      double length;
};
```

```
void Line::setLength(double len) {
   length = len;
}
double Line::getLength(void) {
   return length;
}
```

```
int main() {
   Line line1, line2(10.0);
   cout << "Length of line1: " << line1.getLength() << endl;
   cout << "Length of line2: " << line2.getLength() << endl;
   line1.setLength(6.0);
   cout << "Length of line1: " << line1.getLength() <<endl;
   return 0;
}
```

```
Length of line2: 10
Length of line1: 6
An object with length 10 is out!
An object with length 6 is out!
```

Exercise

- Add constructor(s) and a destructor to the following class

```
class rectangle {
public:
     typedef int unit;
     void area();
     void set(unit wd, unit ht);
private:
     unit width;
     unit height;
};
```

```
void rectangle::set(unit wd, unit ht)
{
     width = wd;
     height = ht;
}
```

```
void rectangle::area()
{
  cout << "The area: " << width * height << endl;
}
```

```
int main() // DO NOT modify main()
{
     rectangle obj, obj2(2,5); //creating object of rectangle class
     rectangle::unit x, y;
     cin >> x;
     cin >> y;
     obj.set(x, y);
     obj.area();
     obj2.area();
     return 0;
}
```

Copy Constructor

- Reference:
  - https://courses.cs.washington.edu/courses/cse333/12su/lectures/lec11.pdf
- An Example of "**`Person`**":
  - https://onlinegdb.com/8EeWdA3zv

When and Why make a copy constructor?

- Timing:
  - e.g., variable assignment.
    - `some_class obj2(obj1);`
    - `some_class obj3 = obj1;`
- Why?
  - Assigning all fields (data members) of a class may NOT be what you really want.

Point (An Easy Example)

https://onlinegdb.com/tBlRDQbrH

```
class Point {
public:
    double x, y;
    Point(): x(0.0), y(0.0) {
        cout << "default constructor"
             << endl;
    }
    Point(double nx, double ny): x(nx), y(ny) {
        cout << "2-parameter constructor"
             << endl;
    }
};
```

```
int main() {
    Point q(1.0, 2.0);
    // 2-parameter constructor
    Point r = q;
    cout << "(" << r.x << ", "
         << r.y << ")" << endl;
    return 0;
}
```

```
2-parameter
constructor
(1, 2)
```

* Using the default copy constructor.

Point (An Easy Example)

https://onlinegdb.com/Dpr2qSKcK

```
class Point {
public:
    double x, y;
    Point(): x(0.0), y(0.0) {
        cout << "default constructor"
             << endl;
    }
    Point(double nx, double ny): x(nx), y(ny) {
        cout << "2-parameter constructor"
             << endl;
    }
    Point(Point &o): x(o.x), y(o.y) {
        //x = o.x; y = o.y;
        cout << "custom copy constructor"
             << endl;
    }
};
```

```
int main() {
    Point q(1.0, 2.0);
    // 2-parameter constructor
    Point r = q;
    cout << "(" << r.x << ", "
         << r.y << ")" << endl;
    return 0;
}
```

```
2-parameter constructor
custom copy constructor
(1, 2)
```

Copy constructor with a “specific” use

```
class Person {
    double height;
    double weight;
    int ID;
public:
    Person() = default;
    Person(double h, double w, int id): height(h), weight(w), ID(id) {}
    Person(Person &p) {
        this->height = p.height;
        this->weight = p.weight;
        this->ID = p.ID+1; // not simply "copy", but increase the id
    }
    void showInfo();
    ~Person() {
        /* do nothing */
    };
};
```

Another Example
-from cplusplus.com

```
#include <iostream>
#include <string>
using namespace std;

class Example {
    string* ptr;
  public:
    // constructors:
    Example(): ptr(new string) {}
    Example (const string& str): ptr(new string(str)) {}
    // destructor:
    // since we dynamically allocate a string
    ~Example () {delete ptr;}
    // access content:
    const string& content() const {return *ptr;}
};

int main () {
  Example foo;
  Example bar ("NTOU CSE IS THE BEST!");
  cout << "bar's content: " << bar.content() << endl;
  return 0;
}
```

More on the Copy Constructor

https://www.cplusplus.com/doc/tutorial/classes2/

```
MyClass::MyClass (const MyClass&);
```

If a class has no custom copy nor move constructors (or assignments) defined, an *implicit copy constructor* is provided.

This copy constructor simply performs a copy of its own members.
For example,

```
class MyClass {
public:
    int a, b;
    string c;
};
```

An implicit copy constructor is automatically defined and is equivalent to

```
MyClass::MyClass(const MyClass& x):
a(x.a), b(x.b), c(x.c) {}
```

When is the copy constructor called?

https://www.cplusplus.com/doc/tutorial/classes2/

```
MyClass foo;
MyClass bar {foo};     // object initialization: copy constructor called
MyClass baz = foo;     // object initialization: copy constructor called
foo = bar;             // object already initialized: copy assignment called
```

```
MyClass& operator= (const MyClass& x) {
    delete ptr;
    ptr = new string (x.content());
    return *this;
}
```

Operator overloaded
(We will discuss about it in the future.

Another Example (Destructor + Copy Constructor)

-from cplusplus.com

```
#include <iostream>
#include <string>
using namespace std;

class Example {
    string* ptr;
  public:
    // constructors:
    Example(): ptr(new string) {}
    Example (const string& str): ptr(new string(str)) {}
    Example (const Example& x): ptr(new string(x.content())) {}
    // destructor:
    ~Example () {delete ptr;}
    // access content:
    const string& content() const {return *ptr;}
};

void main () {
  Example foo("NTOU CSE IS THE BEST!");
  Example bar = foo;

  cout << "bar's content: " << bar.content() << '\n';
}
```

Lvalue & Rvalue

- Lvalue:
  - an object that has a **name** and a **memory address**.
    - Persistent; can appear at the **left**-hand side of an assignment.
- Rvalue:
  - a **temporary** object that does **NOT** have a persistent memory address.
    - It can only appear at the **right**-hand side of an assignment.

```
int x = 10;  // '10' is an rvalue
int y = x + 5;  // 'x + 5' is an rvalue (temporary)
10 = x;  // invalid! 10 is not an lvalue
```

```
int x = 10;  // 'x' is an lvalue (has a name and memory)
int& ref = x;  // lvalue reference (int&) can bind to x
int& ref2 = 10;  // Invalid: Lvalue reference (int&) cannot bind to an rvalue
int&& rref = 10; // OK: Rvalue reference (int&&) can bind to an rvalue
```

*Move Constructor

https://www.cplusplus.com/doc/tutorial/classes2/

```
MyClass (MyClass&&);                // move-constructor
MyClass& operator= (MyClass&&);     // move-assignment
```

- Similar to copying, moving also uses the value of an object to set the value to another object.
- But, unlike copying, the content is actually transferred from one object (the source) to the other (the destination):
  - **The source loses that content**, which is taken over by the destination.
  - This moving only happens when the source of the value is an ***unnamed*** object.

```
MyClass fn();               // function returning a MyClass object
MyClass foo;                // default constructor
MyClass bar = foo;          // copy constructor
MyClass baz = fn();         // move constructor
foo = bar;                  // copy assignment
baz = MyClass();            // move assignment
```

Move Constructor with Rvalue

https://onlinegdb.com/FN2Q4Om7t

```
class Data {
public:
    Data() { cout << "Constructor (no parameter)." << endl; }
    Data(Data&&) { cout << "Move constructor here!" << endl; }
};
```

```
Data createData() {
    return Data();  // Returns an Rvalue (temporary object)
}

int main() {
    Data d1 = createData();  // Move constructor may NOT be invoked
    Data d2 = std::move(createData()); // Move constructor is invoked
    return 0;
}
```

`std::move()` converts an object into an rvalue, forcing the move constructor!

Supplementary*

- Modern C++ compilers applies copy elision, which optimizes your codes by omitting unnecessary copies and moves.
  - A move constructor or a copy constructor is avoided in this case.
- For "`Data d2 = std::move(createData());`"
  - `createData()` returns a temporary rvalue.
  - `std::move(createData())` explicitly converts the return value into an rvalue reference.
  - The move constructor (if it works) is invoked to construct `d1` from this rvalue.
- If we use `Data&& d2 = std::move(createData());`
  - `d2` is now an rvalue reference bound to the temporary object.
  - No constructor is called.

Another Example of Move Constructors

https://onlinegdb.com/6_5wftTY_

```
class Number {
private:
    int value;
public:
    // Constructors
    Number() = default;
    Number(int val): value(val) { cout << "Constructed (para)" << value << endl; }

    // Destructor
    ~Number() { std::cout << "Destroyed" << endl; }

    // Copy Constructor (Deep Copy)
    Number(const Number& other): value(other.value) {
        std::cout << "Copied" << endl;
    }

    // Move Constructor (Transfers Ownership)
    Number(Number&& other): value(other.value) {
        std::cout << "Moved" << endl;
    }
};
```

```
int main() {
    Number n1(10); // constructor
    Number n2 = std::move(n1); // move
    Number n3 = n1; // copy
    Number n4(n1); // copy
    Number n5(std::move(n1)); // move
}
```

Notes on the "reference" &

Example

```
#include <iostream>
#include <string>
using namespace std;

int main () {
     int i, j;
     int &ref1 {i};
     int &ref2 {ref1};

     cin >> i;
     cout << "i = " << i << endl;
     cout << "&i = " << &i << endl;
     cout << "&j = " << &j << endl;
     cout << "ref1 = " << ref1 << endl;
     cout << "&ref1 = " << &ref1 << endl;
     cout << "ref2 = " << ref2 << endl;
     cout << "&ref2 = " << &ref2 << endl;

     ref1 = 8;
     cout << "i = " << i << endl;
     j = ref2 + 3;
     cout << "j = " << j << endl;
     return 0;
}
```

```
5
i = 5
&i = 0x7ffff9ff72c0
&j = 0x7ffff9ff72c4
ref1 = 5
&ref1 = 0x7ffff9ff72c0
ref2 = 5
&ref2 = 0x7ffff9ff72c0
i = 8
j = 11
```

https://onlinegdb.com/I3PeEt-0jT

Example (Loop)

```
#include <iostream>
using namespace std;
#define N 5

int main () {
    int nums[N];
    int sum{0}; //initialization
    for (int &v: nums)
        cin >> v;
    for (int &v: nums)
        sum += v;
    cout << "sum = " << sum << endl;
    return 0;
}
```

```
1 2 3 4 5
sum = 15
```

Example (Loop)

```
#include <iostream>
using namespace std;
#define N 5

int main () {
     int nums[N];
     int sum{0}; //initialization
     for (int &v: nums)
          cin >> v;
     for (int v: nums)
          sum += v;
     cout << "sum = " << sum << endl;
     return 0;
}
```

```
1 2 3 4 5
sum = 15
```

Do we need the '&' here?

Do we need the '&' here?

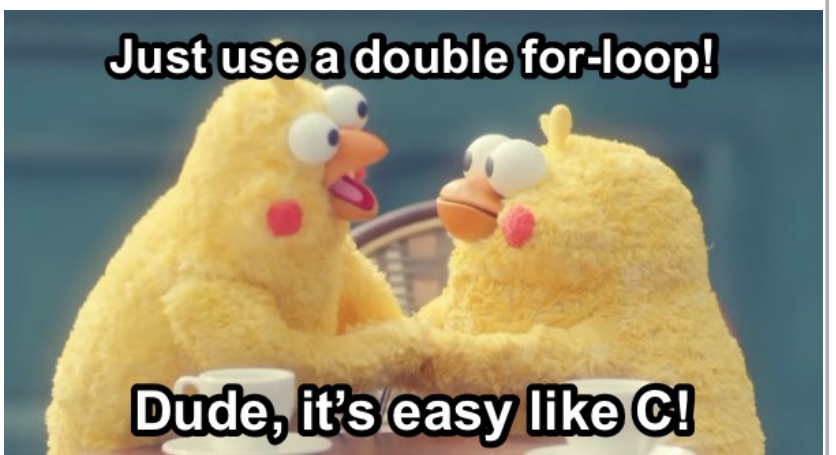
Example (2D array)

https://onlinegdb.com/hoPbLjqyX

```
#include <iostream>
#define SIZE 3
using namespace std;

int main() {
    int array[SIZE][SIZE] = {{0, 1, 2}, {3, 4, 5}, {6, 7, 8}};
    for (int i=0; i<SIZE; i++) {
        for (int j=0; j<SIZE; j++) {
            if (array[i][j] % 2 == 0)
                cout << " 0 ";
            else
                cout << " 1 ";
        }
        cout << endl;
    }
    return 0;
}
```

```
 0  1  0
 1  0  1
 0  1  0
```



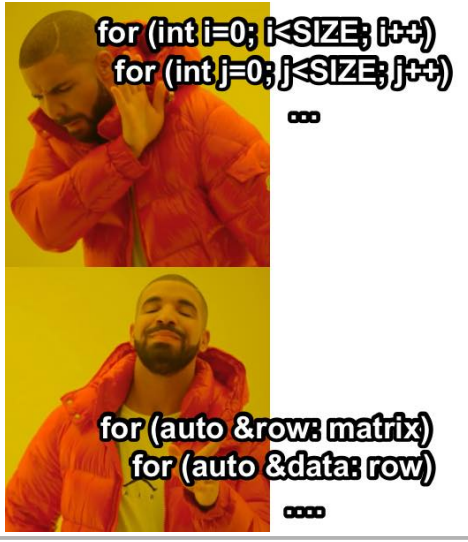
Another approach (Modern C++)

https://onlinegdb.com/hoPbLjqyX

```
#include <iostream>
#define SIZE 3
using namespace std;

int main() {
    int array[SIZE][SIZE] = {{0, 1, 2}, {3, 4, 5}, {6, 7, 8}};
    for (auto &row: array) {
        for (auto entry: row) {
            if (entry % 2 == 0)
                cout << " 0 ";
            else
                cout << " 1 ";
        }
        cout << endl;
    }
    return 0;
}
```

```
 0  1  0
 1  0  1
 0  1  0
```

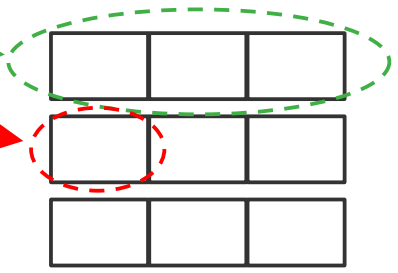


Example (2D array)

https://onlinegdb.com/hoPbLjqyX

```
#include <iostream>
#define SIZE 3
using namespace std;

int main() {
    int array[SIZE][SIZE] = {{0, 1, 2}, {3, 4, 5}, {6, 7, 8}};
    for (auto &row: array) {
        for (auto entry: row) {
            if (entry % 2 == 0)
                cout << " 0 ";
            else
                cout << " 1 ";
        }
        cout << endl;
    }
    return 0;
}
```



```
 0  1  0
 1  0  1
 0  1  0
```

Pass by Reference

https://github.com/pangfengliu/Cplusplus-refactor/blob/main/structure/rational-ref.cc

```
struct Rational {
  int q, p;  // q/p
};
int gcd(int a, int b) {
  if (a % b == 0)
    return b;
  else
    return gcd(b, a % b);
}
void simplify(Rational &a) {
  int factor {
    gcd(abs(a.p), abs(a.q))
  };
  a.p /= factor;
  a.q /= factor;
  if (a.p < 0) {
    a.p = -a.p;
    a.q = -a.q;
  }
}
```

```
Rational add(Rational &a, Rational &b) {
  Rational sum {b.p * a.q + b.q * a.p, b.p * a.p};
  simplify(sum);
  return sum;
}


void print(Rational &a) {
  cout << a.q << '/' << a.p << endl;
}
```

```
int main() {
  Rational a, b;
  cin >> a.q >> a.p >> b.q >> b.p;
  Rational c {add(a,b)};
  print(c);
  return 0;
}
```

```
2 3 1 6
5/6
```

Discussions & Questions