C++

程式語言（二）

Introduction to Programming (II)

Resource Management

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Platform/IDE

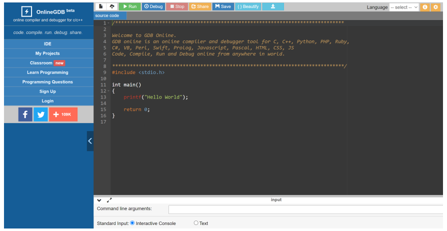
- Dev-C++

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

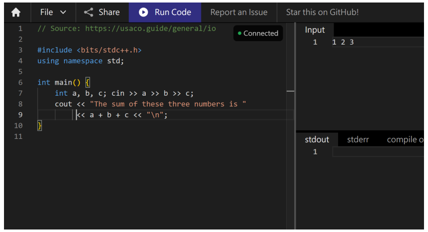
- Codeblocks

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/

Recall for Dynamic Memory Allocation in C++

Purpose of using dynamic memory

- Properly freeing dynamic objects turns out to be a surprisingly rich source of bugs.
- Programs tend to use dynamic memory for one of three purposes:
  1. They don’t know how many objects they’ll need.
  2. They don’t know the precise type of the objects they need.
  3. They want to share data between several objects.

`new` and `delete`?

- In C++, people are used to use `new` operator (cf., `malloc()` in C) to allocate memory and `delete` (cf., `free()` in C) to free memory allocated by `new`.
- However, using these operators to manage memory is considerably more error-prone.
- From C++ 11 and newer versions, we are encouraged to use **smart pointers** to manage dynamic objects.
  - They are safer and easier.

Smart Pointers (the `shared_ptr class`)

```
shared_ptr<string> p1;
unique_ptr<int> p2;
```

*Actually there is also `make_unique` but it's in C++ 14 standard.

```
// 使用 make_shared 函式
shared_ptr<int> p3 = make_shared<int>(42);
//42
shared_ptr<string> p4 = make_shared<string>(10, '9');
//9999999999
shared_ptr<int> p5 = make_shared<int>();
```

```
// 前面也可以使用 auto
auto p3 = make_shared<int>(42);
//42
auto p4 = make_shared<string>(10, '9');
//9999999999
auto p5 = make_shared<int>();
```

An Example

https://onlinegdb.com/dSS35GJ2l

```
#include <iostream>
#include <memory>

using namespace std;

class Grade {
private:
    int math;
    int eng;
    int sum;
public:
    Grade() = default;
    Grade(int m, int e): math(m), eng(e) {};
    ~Grade() { cout << "destructor of 'Grade' works here" << endl; } ;
    void SumUp() { sum = math + eng; }
    int ShowSum() { return sum; }
};
```

```
int main()
{
    auto ptr = make_shared<Grade>(100, 90);
    ptr->SumUp();
    cout << "The total grades: "
         << ptr->ShowSum() << endl;
    return 0;
}
```

```
The total grades: 190
destructor of 'Grade' works here
```

Copying and Assigning `shared_ptr`

- When we copy or assign a `shared_ptr`, each `shared_ptr` keeps track of **how many** other `shared_ptrs` point to the same object.

```
auto p = make_shared<int>(42); // object to which p points has one user
auto q(p); // p and q point to the same object; q is a copy of p
// object to which p and q point has two users

auto r = make_shared<int>(42); // int to which r points has one user
r = q; // assign to r, making it point to a different address
// increase the use count for the object to which q points
// reduce the use count of the object to which r had pointed
// the object r had pointed to has no users; that object is
// automatically freed
cout << r.unique(); // print out whether p.use_count() is 1 or not
cout << r.use_count(); // print out number of objects sharing with r
```

More on shared_ptr

- shared_ptrs **automatically**
  - **destroy** their objects (by a destructor of the class).
  - **free** the associated memory.

```
// factory returns a shared_ptr pointing to a dynamically allocated object
shared_ptr<Foo> factory(T arg)
{
    // process arg as appropriate
    // shared_ptr will take care of deleting this memory
    return make_shared<Foo>(arg);
}// the object will be appropriately deleted with the allocated memory freed
```

```
void use_factory(T arg)
{
    shared_ptr<Foo> p = factory(arg); // use p
} // p goes out of scope; the memory to which p points is automatically freed
```

More on `shared_ptr`

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```
// factory returns a shared_ptr pointing to a dynamically allocated object
shared_ptr<Foo> factory(T arg)
{
    // process arg as appropriate
    // shared_ptr will take care of deleting this memory
    return make_shared<Foo>(arg);
}
```

```
// factory returns a shared_ptr pointing to a dynamically allocated object
shared_ptr<Foo> use_factory(T arg)
{
    shared_ptr<Foo> p = factory(arg); // use p
    return p; // reference count is incremented when we return p
} // p goes out of scope; the memory to which p points is NOT freed
```

Managing Memory Directly (`new` & `delete`)

```
int *pi = new int;
string *ps = new string;
int *pi = new int(1024);
string *ps2 = new string(10, '9');
// allocate and initialize a const int
const int *pci = new const int(1024);
// allocate and initialize an empty string
const string *pcs = new const string;
```

```
int i, *pi1 = &i, *pi2 = nullptr;
double *pd = new double(33), *pd2 = pd;
delete i; // error: i is not a pointer
delete pi1; // undefined: pi1 refers to a local
delete pd; // ok
delete pd2; // undefined: the memory pointed to by pd2 was already freed
delete pi2; // ok: it is always ok to delete a null pointer
```

Using shared_ptrs with new

```
shared_ptr<double> p1;
shared_ptr<int> p2(new int(42)); //direct initialization
```

Note that the following initialization is wrong:

```
shared_ptr<int> p1 = new int(42);
//error: we must use direct initialization
```

Note that the following implicit conversion is also wrong:

```
shared_ptr<int> clone(int p) {
    return new int(p);
}
```

correction

```
shared_ptr<int> clone(int p) {
    return shared_ptr<int>(new int(p));
}
```

Dynamic Arrays

```
int *pia = new int[10]; // uninitialized 10 ints
int *pia2 = new int[10](); //initialized to be 10 0’s;
string *psa = new string[10]; // block of 10 empty strings
string *psa2 = new string[10](); // block of 10 empty strings
int *pia3 = new int[5]{0,1,2,3,4};
string *psa3 = new string[10]{"a", "b", string(3,'x')};
// the first three elements are initialized from given initializers
// remaining elements are value initialized
```

```
// Freeing dynamic arrays
delete [] pia;
delete [] psa;
...
```

Challenges of Resource Management

Resource Management

- Managing memory, file (handles), network connection, etc.
- **Goal:** Efficiently to prevent:
  - Memory leaks (memory not deallocated)
  - Dangling pointers (assessing deleted memory)
  - Double deletion errors.

Examples of Memory Leaks

```
void leaky() {
    int *p = new int(16);
    std::cout << "value= " << *p << endl;
    // memory pointed by p is not deleted
}
void leaky_array() {
    for (int i = 0; i<100; i++) {
        arr = new int[10];
    }
    delete[] arr;
    // Only last allocation is freed!
}
```

⇨

```
void leaky() {
    int *p = new int(16);
    std::cout << "value= " << *p << endl;
    delete p;
}
void leaky_array() {
    for (int i = 0; i<100; i++) {
        arr = new int[10];
        ...
        delete[] arr;
    }
}
```

Examples of Dangling Pointers

Pointers that points to memory which has been freed or deallocated.

```
void dangling() {
    int *p = new int(16);
    std::cout << "value= " << *p << endl;
    delete p;
    std::cout << "value= " << *p << endl;
}
int* getPointer() {
    int x = 37;
    return &x;
    // returning address of a
    // local variable!
}
int main() {
    int *ptr = getPointer();
    std::cout << *ptr << endl; // error!
}
```

```
void dangling() {
    int *p = new int(16);
    std::cout << "value= " << *p << endl;
    delete p;
    p = nullptr; // safier!
}
int* getPointer() {
    static int x = 37;
    return &x;
    // though not recommended...
}
int main() {
    int *ptr = getPointer();
    std::cout << *ptr << endl; // fine
}
```

Examples of Dangling Pointers

Pointers that points to memory which has been freed or deallocated.

```
void dangling() {
    int *p = new int(16);
    std::cout << "value= " << *p << endl;
    delete p;
    std::cout << "value= " << *p << endl;
}
int* getPointer() {
    int x = 37;
    return &x;
    // returning address of a
    // local variable!
}
int main() {
    int *ptr = getPointer();
    std::cout << *ptr << endl; // error!
}
```

⇒

```
void dangling() {
    auto p = std::make_unique<int>(16);
    std::cout << "value= " << *p << endl;
    // no need for manual delete
}
std::unique_ptr<int> getPointer() {
    return std::make_unique<int>(37);
    // Safe. No need for manual delete
}
int main() {
    auto ptr = getPointer();
    std::cout << *ptr << endl; // fine
}
```

Examples of Double Deletion

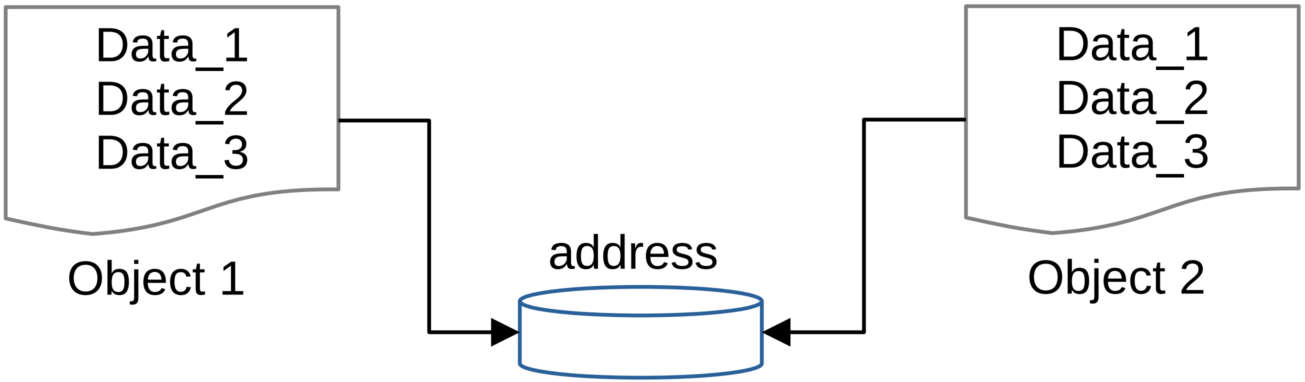
```cpp
int main() {
    int* ptr = new int(10);
    delete ptr; // OK for first deletion
    delete ptr; // undefined for the
                // second deletion
}
```

⇨

```cpp
int main() {
    int* ptr = new int(10);
    delete ptr; // OK for first deletion
    ptr = nullptr;
    delete ptr; // safe now
}
```

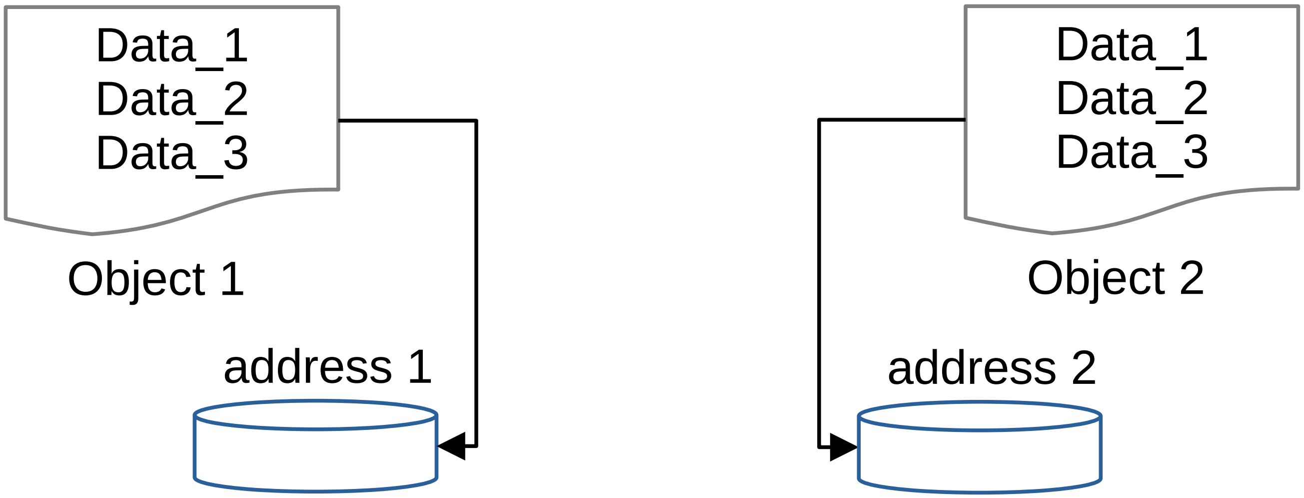
```cpp
class ShallowCopy {
public:
    int* data;
    ShallowCopy(int val) { data = new int(val); }
    ~ShallowCopy() { delete data; }  // GOOD. Destructor deletes memory.
};

int main() {
    ShallowCopy obj1(10);
    ShallowCopy obj2 = obj1;  // NO GOOD! Shallow copy here
                              // Both share same `data` pointer
    return 0;  // NO GOOD! Destructor called twice -> Double deletion occurs!
```

Shallow Copy vs. Deep Copy



Shallow Copy

Shallow Copy vs. Deep Copy



Deep Copy

Solving Double Deletion in a Shallow Copy: Deep Copy

```
class DeepCopy {
public:
    int* data;
    DeepCopy(int val) { data = new int(val); }
    ~DeepCopy() { delete data; }
    DeepCopy(const DeepCopy& other) { data = new int(*other.data); }
    // create a new memory copy

    DeepCopy& operator=(const DeepCopy& other) {
        if (this == &other) return *this; // self-assignment check
        delete data; // free old memory here
        data = new int(*other.data);
        return *this;
    }
};

int main() {
    DeepCopy obj1(10);
    DeepCopy obj2 = obj1;  // Nice! Deep copy is applied here
    return 0;  // Safe! Destructor called twice but no double deletion occurs!
}
```

Solving Double Deletion in a Shallow Copy: Deep Copy (using smart pointers)

```
class DeepCopy {
public:
    std::unique_ptr<int> data;
    DeepCopy(int val) { data = std::make_unique<int>(val); }
    ~DeepCopy() = default; // no need for manual deletion
    DeepCopy(const DeepCopy& other) {
        data = make_unique<int>(*other.data); // create a new copy
    }
    DeepCopy& operator=(const DeepCopy& other) {
        if (this == &other) return *this; // self-assignment check
        data = make_unique<int>(*other.data);
        return *this;
    }
};

int main() {
    DeepCopy obj1(10);
    DeepCopy obj2 = obj1;  // Nice! Deep copy is applied here
    return 0;  // Safe! Destructor called twice but no double deletion occurs!
}
```

Rule of Three
- for Classes Managing Resources

- Whenever you design a class which uses dynamic memory, implement:

  (1). Destructor

  ```
  ~className()
  ```

  - Freeing memory.

  (2). Copy Constructor

  ```
  className(const ClassName &)
  ```

  - Creating deep copy.

  (3). Copy Assignment Operator

  ```
  operator=(className &)
  ```

  - Ensuring correct copy behavior.

Discussions & Questions