C++

程式語言（二）

Introduction to Programming (II)

Templates

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Platform/IDE

- Dev-C++

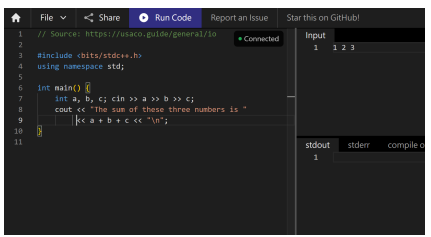
https://www.pngegg.com/en/search?q=Dev-C

- 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/

Template

- **Goal**: Pass **data type** as a **parameter** so that we don't have to write the same code or the same function for different data types.
- For example, we can write one function `sort()` and pass data type as a parameter so that we can sort data of many kinds of types.
- When does template expand/kick in?

Template

- **Goal**: Pass **data type** as a **parameter** so that we don't have to write the same code or the same function for different data types.
- For example, we can write one function `sort()` and pass data type as a parameter so that we can sort data of many kinds of types.
- When does template expand/kick in?
  - Compile time.
  - The source code contains only the function or class, yet the compiled code contains multiple copies of it.

Function Template

- A generic function that can be used for different data types.

```
template <class T> T flex_max(T x, T y) {
    return (x > y) ? x : y;
}
```

```
int main() {
    cout << flex_max<int>(3, 7) << endl;
    cout << flex_max<double>(3.0, 7.0)
         << endl;
    cout << flex_max<char>('g', 'e')
         << endl;

    return 0;
}
```

Function Template

- A generic function that can be used for different data types.

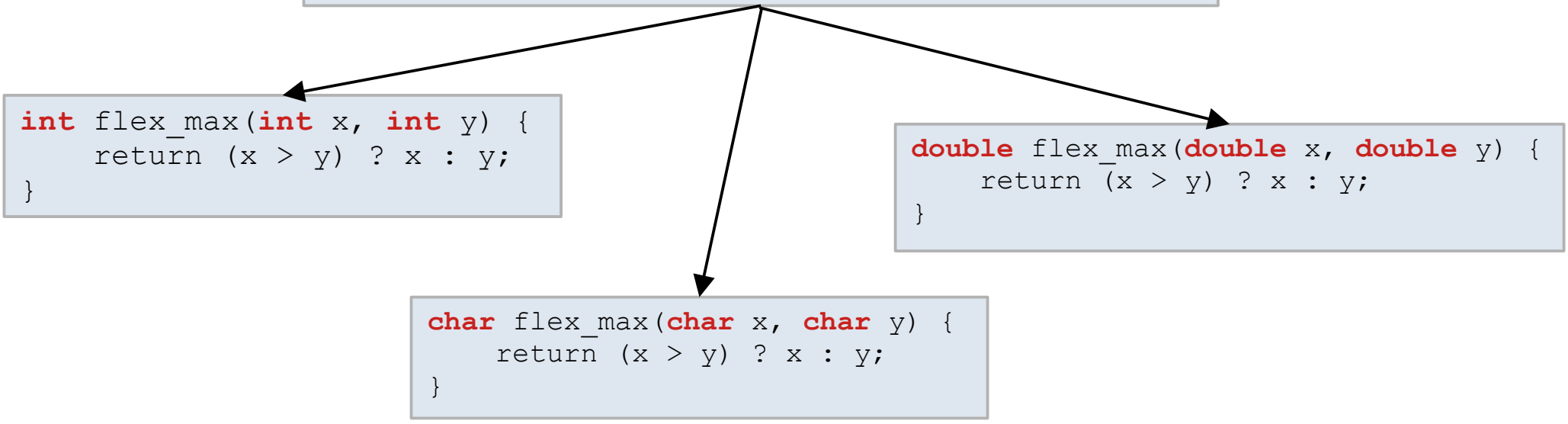
```
template <typename T> T flex_max(T x, T y) {
    return (x > y) ? x : y;
}
```

→ either "typename" or "class" will be fine

```
int main() {
    cout << flex_max<int>(3, 7) << endl;
    cout << flex_max<double>(3.0, 7.0)
         << endl;
    cout << flex_max<char>('g', 'e')
         << endl;

    return 0;
}
```

Function Template

```
template <class T> T flex_max(T x, T y) {
    return (x > y) ? x : y;
}
```



```
int flex_max(int x, int y) {
    return (x > y) ? x : y;
}
```

```
double flex_max(double x, double y) {
    return (x > y) ? x : y;
}
```

```
char flex_max(char x, char y) {
    return (x > y) ? x : y;
}
```

Function Template

- A generic function that can be used for different data types.

```
template <class T> void try_swap(T& x, T& y) {
    T temp = x;
    x = y;
    y = temp;
}
```

```
int main() {
    int a = 5, b = 3;
    double c = 11.2, d = 23.7;
    try_swap<int>(a, b);
    try_swap<double>(c, d);
    cout << a << ", " << b << endl;
    cout << c << ", " << d << endl;
    return 0;
}
```

Function Template

- A generic function that can be used for different data types.

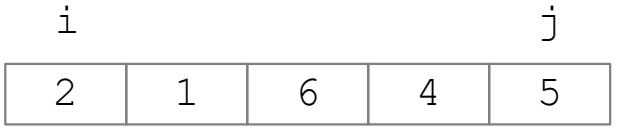
```
template <class T>
void try_swap(T& x, T& y) {
    T temp = x;
    x = y;
    y = temp;
}
```

```
int main() {
    int a = 5, b = 3;
    double c = 11.2, d = 23.7;
    try_swap<int>(a, b);
    try_swap<double>(c, d);
    cout << a << ", " << b << endl;
    cout << c << ", " << d << endl;
    return 0;
}
```

Example: Bubble sort

https://www.geeksforgeeks.org/templates-cpp/

```
template <class T> void bubbleSort(T a[], int n) {
    for (int i=0; i<n-1; i++)
        for (int j=n-1; i<j; j--)
            if (a[j] < a[j-1])
                swap(a[j], a[j-1]);
}
```

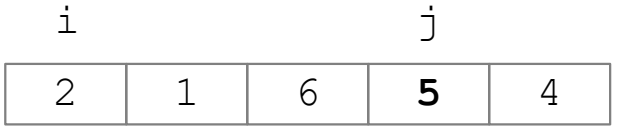



```
int main() {
    int a[5] = { 10, 50, 30, 40, 20 };
    int n = sizeof(a) / sizeof(a[0]);

    bubbleSort<int>(a, n);
    for (int i = 0; i < n; i++) // print the sorted array
        cout << a[i] << " ";
    cout << endl;

    return 0;
}
```

Example: Bubble sort

https://www.geeksforgeeks.org/templates-cpp/

```
template <class T> void bubbleSort(T a[], int n) {
    for (int i=0; i<n-1; i++)
        for (int j=n-1; i<j; j--)
            if (a[j] < a[j-1])
                swap(a[j], a[j-1]);
}
```

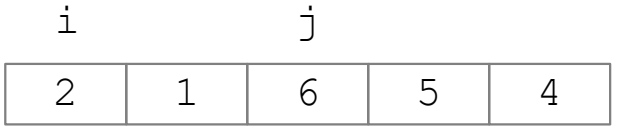



```
int main() {
    int a[5] = { 10, 50, 30, 40, 20 };
    int n = sizeof(a) / sizeof(a[0]);

    bubbleSort<int>(a, n);
    for (int i = 0; i < n; i++) // print the sorted array
        cout << a[i] << " ";
    cout << endl;

    return 0;
}
```

Example: Bubble sort

https://www.geeksforgeeks.org/templates-cpp/

```
template <class T> void bubbleSort(T a[], int n) {
    for (int i=0; i<n-1; i++)
        for (int j=n-1; i<j; j--)
            if (a[j] < a[j-1])
                swap(a[j], a[j-1]);
}
```

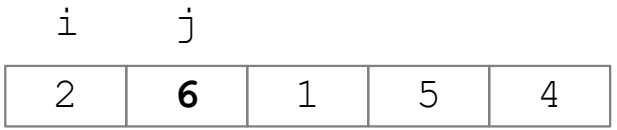



```
int main() {
    int a[5] = { 10, 50, 30, 40, 20 };
    int n = sizeof(a) / sizeof(a[0]);

    bubbleSort<int>(a, n);
    for (int i = 0; i < n; i++) // print the sorted array
        cout << a[i] << " ";
    cout << endl;

    return 0;
}
```

Example: Bubble sort

https://www.geeksforgeeks.org/templates-cpp/

```
template <class T> void bubbleSort(T a[], int n) {
    for (int i=0; i<n-1; i++)
        for (int j=n-1; i<j; j--)
            if (a[j] < a[j-1])
                swap(a[j], a[j-1]);
}
```




```
int main() {
    int a[5] = { 10, 50, 30, 40, 20 };
    int n = sizeof(a) / sizeof(a[0]);

    bubbleSort<int>(a, n);
    for (int i = 0; i < n; i++) // print the sorted array
        cout << a[i] << " ";
    cout << endl;

    return 0;
}
```

Example: Bubble sort

https://www.geeksforgeeks.org/templates-cpp/

```
template <class T> void bubbleSort(T a[], int n) {
    for (int i=0; i<n-1; i++)
        for (int j=n-1; i<j; j--)
            if (a[j] < a[j-1])
                swap(a[j], a[j-1]);
}
```

j

i

6	2	1	5	4

```
int main() {
    int a[5] = { 10, 50, 30, 40, 20 };
    int n = sizeof(a) / sizeof(a[0]);

    bubbleSort<int>(a, n);
    for (int i = 0; i < n; i++) // print the sorted array
        cout << a[i] << " ";
    cout << endl;

    return 0;
}
```

Class Template

- Similar to function templates, but useful for **classes** (e.g., LinkedList, BinaryTree, Stack, Queue, ...)

Example: A Generic Array

```
template <class T> class Array {
private:
    T* ptr;
    int size;

public:
    Array(T arr[], int s);
    void print();
};
```

```
template <class T>
void Array<T>::print() {
    for (int i = 0; i < size; i++)
        cout << " " << *(ptr + i);//OK!
    cout << endl;
}
```

```
template <class T>
Array<T>::Array(T arr[], int s) {
    ptr = new T[s];
    size = s;
    for (int i = 0; i < size; i++)
        ptr[i] = arr[i];
}
```

```
int main() {
    int arr[5] = { 1, 2, 3 };
    Array<int> a(arr, 3);
    a.print();
    return 0;
}
```

Example: A Generic Array

```
template <class T> class Array {
private:
    T* ptr;
    int size;

public:
    Array(T arr[], int s);
    void print();
};
```

```
template <class T>
void Array<T>::print() {
    for (int i = 0; i < size; i++)
        cout << " " << ptr[i]; // OK!
    cout << endl;
}
```

```
template <class T>
Array<T>::Array(T arr[], int s) {
    ptr = new T[s];
    size = s;
    for (int i = 0; i < size; i++)
        ptr[i] = arr[i];
}
```

```
int main() {
    int arr[5] = { 1, 2, 3 };
    Array<int> a(arr, 3);
    a.print();
    return 0;
}
```

Another Example: Matrix

https://www.cs.uregina.ca/Links/class-info/115/07-templates/

```
class Matrix {
  private:
    int twoDimArray[MAXROWS][MAXCOLS];
    int rows;
    int cols;
  public:
    Matrix(); // constructor
    void printMatrix();
    void setElement(int row, int col, int value); //set an element of the matrix
    void setMatrix(int [][MAXCOLS]); //set the twoDimArray to what is sent
    void addMatrix(int [][MAXCOLS]); //add an array to twoDimArray
    void addMatrix(int [][MAXCOLS], int[][MAXCOLS]); //add two arrays together
};
```

Try to make it a template class

Another Example: Matrix

https://www.cs.uregina.ca/Links/class-info/115/07-templates/

```
template <typename M_type>
class Matrix {
  private:
    M_type twoDimArray[MAXROWS][MAXCOLS];
    int rows;
    int cols;
  public:
    Matrix();
    void printMatrix();
    void setElement(int row, int col, M_type value); //set an element of the matrix
    void setMatrix(M_type [][MAXCOLS]); //set the twoDimArray to what is sent
    void addMatrix(M_type [][MAXCOLS]); //add an array to twoDimArray
    void addMatrix(M_type [][MAXCOLS], M_type[][MAXCOLS]); //add two arrays together
};
```

Class Instantiation

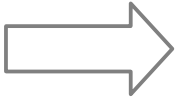
https://www.cs.uregina.ca/Links/class-info/115/07-templates/

```
Matrix<float> floatMatrix;
```

Member Function Definition

https://www.cs.uregina.ca/Links/class-info/115/07-templates/

```
void Matrix::addMatrix(int otherArray[][MAXCOLS]) {
    for (int i=0; i< rows; i++) {
        for(int j=0; j< cols; j++) {
         twoDimArray[i][j] += otherArray[i][j];
        }
    }
}
```



```
template <typename M_type>
void Matrix<M_type>::addMatrix(M_type otherArray[][MAXCOLS]) {
    for (int i=0; i< rows; i++) {
        for(int j=0; j< cols; j++) {
         twoDimArray[i][j] += otherArray[i][j];
        }
    }
}
```

Function Overloading vs. Templates

- When should we use templates?
  - When we want to perform **the same action** just on different types.

```
template <typename T>
T foo(const T& a, const T& b) { return a + b; }
```

Function Overloading vs. Templates

- When should we use templates?
  - When we want to perform **the same action** just on different types.
- When should we use function overloading?
  - When we may apply **different operations on different types**.

```
class Foo{ void run() const {} };

void foo(int i) { std::cout << "i = " << i << "\n"; }
void foo(const Foo& f) { f.run(); }
```

Exercise: print_max()

```
Template ... {
/* implement the function template print_max*/
}
```

```
int main() {
    int a[6] = { 10, 50, 30, 40, 20, -20 };
    float b[] = { 2.3, 0.0, -1.2, 17.2 };
    char c[] = "TKUCS";
    int n1 = sizeof(a) / sizeof(a[0]);
    int n2 = sizeof(b) / sizeof(b[0]);
    int n3 = sizeof(c) / sizeof(c[0]);
    print_max<int>(a, n1);
    print_max<float>(b, n2);
    print_max<char>(c, n3);
    return 0;
}
```

Output:

```
50
17.2
U
```

Combining Operator Overloading

Combining operator overloading

```
struct Node {
    int data;
    int order; // the order of generation
    Node *next;
    Node() { // constructor }
    ~Node() { // destructor }
    static int counter;
    // overloading '<' and '<<'
};

int Node::counter = 0; // total #objects
```

```
template <class T>
void bubbleSort(T a[], int n) {
    for (int i=0; i<n-1; i++)
        for (int j=n-1; i<j; j--)
            if (a[j] < a[j-1])
                swap(a[j], a[j-1]);
}
```

```
int main() {
    int n = 5;
    Node *dataList = new Node[n];
    bubbleSort<Node>(dataList, n);
    for (int i = 0; i < n; i++)
        cout << dataList[i] << " ";
    cout << endl;
    delete [] dataList;
    return 0;
}
```

Sample input :

```
10 20 -5 77 29
```

Sample output :

```
2:-5 0:10 1:20 4:29 3:77
```

More Arguments to Templates

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

template <class T, class U> class A {
    T x;
    U y;
public:
    A() { cout << "Constructor Called\n"; }
    A(T a, U b): x(a), y(b) {
        cout << x << ", " << y << endl;
    }
};

int main() {
    A<char, char> a;
    A<int, double> b;
    A<int, char>c(100, 'T');
    return 0;
}
```

Example: A Generic Array

```
template <class T, int size>
class Array {
private:
    T myArr[size];

public:
    Array(T arr[]);
    void print();
};
```

```
template <class T, int size>
void Array<T,size>::print() {
    int i = 0;
    for (int i = 0; i < s; i++)
        cout << " " << myArr[i];
    cout << endl;
}
```

```
template <class T, int size>
Array<T,size>::Array(T arr[]) {
    ptr = new T[size];
    for (int i = 0; i < size; i++)
        myArr[i] = arr[i];
}
```

```
int main() {
    int arr[3] = { 1, 2, 3};
    Array<int, 3> a(arr, 3);
    a.print();
    return 0;
}
```

Remark

- Both function overloading and templates are examples of polymorphism of OOP.
  - *Function overloading*: multiple functions do similar tasks.
  - *Templates*: multiple functions do **identical** tasks.

Inheritance of a Template

```
template<typename T>
class Base {
public:
    Base(T data): mData(data) { }
    virtual void print() {
        cout << mData << endl;
    }
protected:
    T mData;
};
```

```
template<typename T>
class Derived : public Base<T> {
public:
    Derived() = default;
    Derived(T data) : Base<T>(data) { }

    void print() override {
        cout << "data = "
             << this->mData << endl;
    }
};
```

```
int main() {
    Derived<float> d1(5.2f);
    Derived<std::string> d2("NTOU_CSE");
    d1.print();
    d2.print();
    return 0;
}
```

Exercise

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

class List {
public:
    List() : head_(nullptr) { }
    virtual void add(int n) {
        Link *p = new Link(n, head_);
        head_ = p;
    }
    void print_head() {
        cout << "head: " << head_->val << endl;
    }
private:
    struct Link {
        int val;
        Link *next;
        Link(int n, Link* nxt): val(n), next(nxt) { }
    };
    Link * head_;
};
```

- Please modify the following class `List` so that the main function can run successfully.

```
int main() {
    List<int> nums;
    nums.add(1);
    nums.add(2);
    nums.print_head();
    return 0;
}
```

Sample output

```
head: 2
```

Class Template Specialization

Class Template Specialization

- **Template Specialization**:
  - It is possible to override the template-generated code by providing specific definitions for specific types.

Template Specialization

https://onlinegdb.com/UQn8nDP9o

```
template <class T>
class CHECK {
    public:
        void f() { cout << "CHECK<T>::f()"<< endl ;}
};
```

```
template <>
class CHECK<char> {
    public:
        void f() { cout << "CHECK<char>::f()"<< endl ;}
};
```

```
int main() {
    CHECK<int> c1;
    CHECK<char> c2;

    c1.f();
    c2.f();
    return 0;
}
```

Template Class Partial Specialization

- **Template Partial Specialization**:
  - Generate a specialization of a template class for fewer parameters.

Partial Specialization

https://onlinegdb.com/KPkpfMzQ4

```
template<class T, class U, class V> struct S {
    void foo() {
        cout << "General case" << endl;
    }
};
```

```
template<class U, class V> struct S<int, U, V> {
    void foo() {
        cout << "T = int" << endl;
    }
};
```

```
template<class V> struct S<int, double, V> {
    void foo() {
        cout << "T = int, U = double" << endl;
    }
};
```

```
int main() {
    S<string, int, double> obj1;
    S<int, float, string> obj2;
    S<int, double, string> obj3;

    obj1.foo();
    obj2.foo();
    obj3.foo();
    return 0;
}
```

```
General case
T = int
T = int, U = double
```

Exercise

- Problem 2 of the page here (https://tinyurl.com/2p93tw37).
- **Goal:** Convert a class that is *specialized for integers* into a templated class that can *handle many types*.
- Requirement:
  - Create a templated class named `List` and correctly *initializes*, *manages*, and *de-allocated* an array of *specified length.*
  - Use the **designated** main function:

```
int main() {
    List<int> integers(10);
    for (int i = 0; i < integers.length; i++) {
        integers.set(i, i * 100);
        printf("%d ", integers.get(i));
    }
    printf("\n");
    // this loop should print: 0 100 200 300 400 500 600 700 800 900

    List<Point *> points(5);
    for (int i = 0; i < points.length; i++) {
        Point *p = new Point;
        p->x = i * 10;
        p->y = i * 100;
        points.set(i, p);
        printf("(%d, %d) ", points.get(i)->x, points.get(i)->y);
        delete p;
    }
    printf("\n");
    // this loop should print: (0, 0) (10, 100) (20, 200) (30, 300) (40, 400)
}
```

A typedef struct

```
typedef struct
Point_ {
    int x;
    int y;
} Point;
```

The Output

```
0 100 200 300 400 500 600 700 800 900
(0, 0) (10, 100) (20, 200) (30, 300) (40, 400)
```

Hint

You may refer to the code here as a reference.

```
class IntList {
    int * list;

public:
    int length;
    IntList(int len) {
        list = new int[len];
        length = len;
    }
    ~IntList() {
        delete[] list;
    }
    int get(int index) {
        return list[index];
    }
    void set(int index, int val) {
        list[index] = val;
    }
};
```

Discussions & Questions