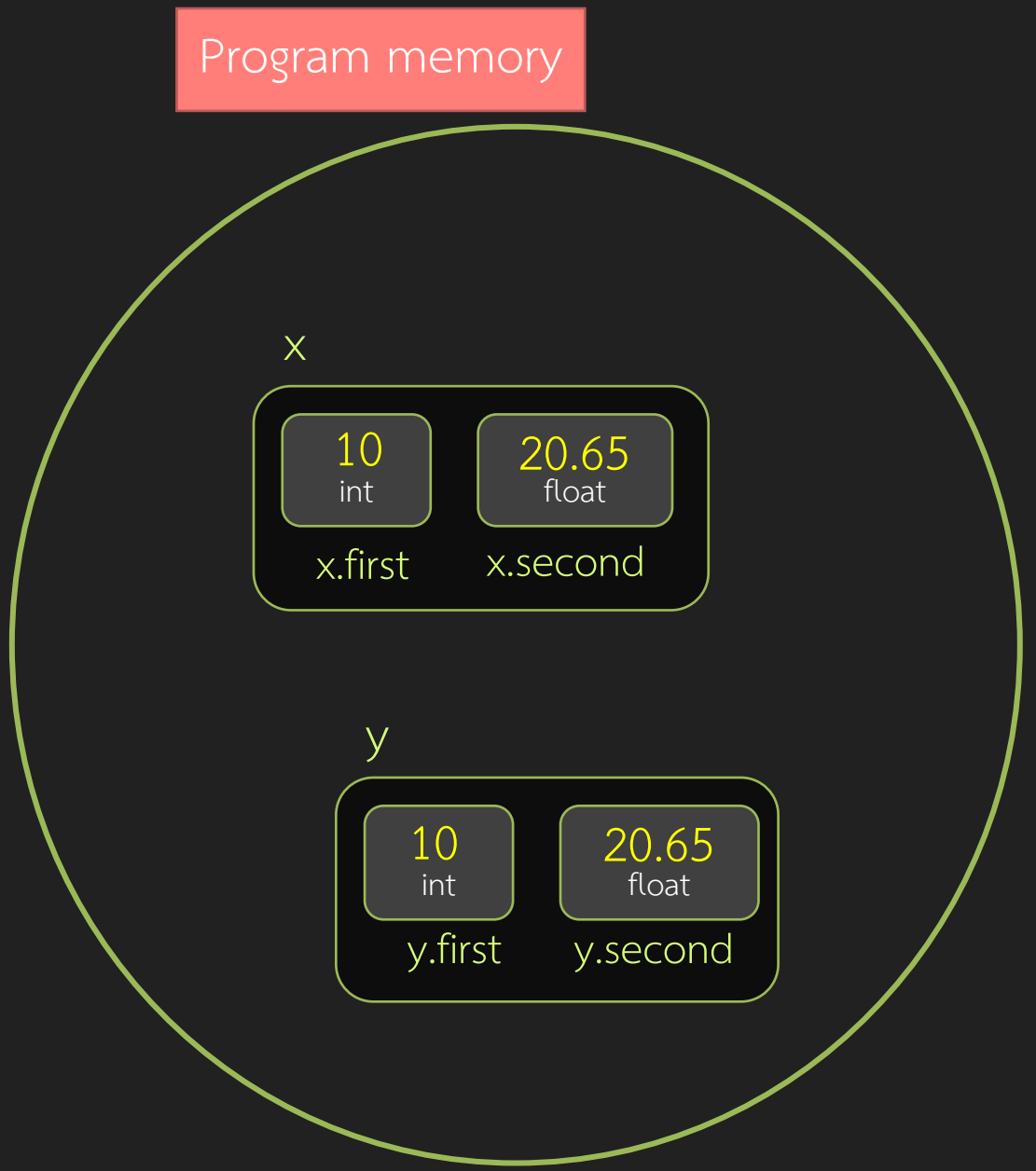
std::pair

Storing two pieces of different data

Basic

```cpp
#include <iostream>

int main() {
    std::pair<int,float> x;
    std::pair<int,float> y;

    x.first = 10;
    x.second = 20.65;

    std::cout << x.first << " "
    std::cout << x.second << std::endl;

    y = x;

    std::cout << y.first << " "
    std::cout << y.second + 20 << std::endl;
}
```



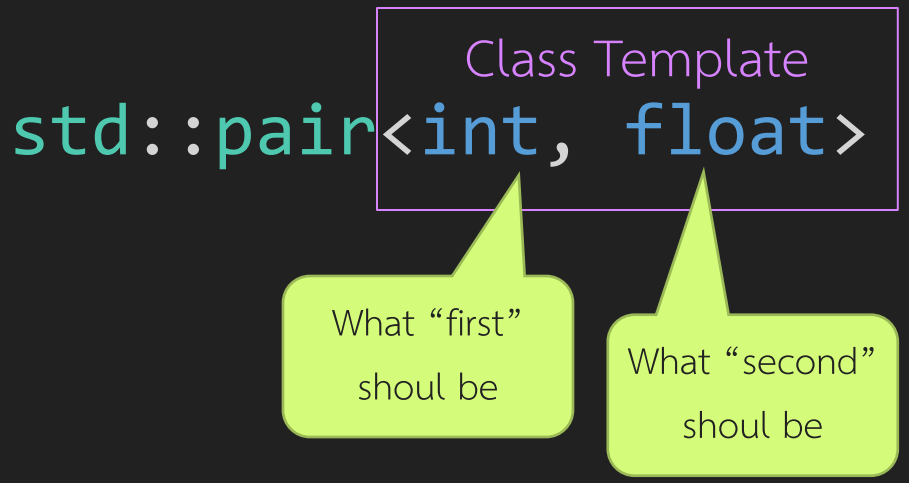
Initialize

```cpp
#include <iostream>

int main() {
    //default constructor
    std::pair<std::string,bool> p;
    std::cout << "default [" << p.first << "] [" << p.second << "]" << std::endl;

    //initialize by { }
    std::pair<std::string,bool> p1 = { "somchai", true };

    //create pair without specifying type by "make_pair"
    std::pair<bool,int> p2;
    p2 = std::make_pair(false,10);

    std::pair<bool,int> p3(p2);

    //more complex pair
    std::pair< std::pair<float, int>, std::string >  p4 = { {20.5, -3}, "abc"};
    std::cout << p4.first.first << " " << p4.first.second << " " << p4.second << std::endl;
}
```

Template

- Template allows “same code, different data type”

- std::pair is a “class template”
  - In generic term, pair is defined as
    - pair<T1, T2>
    - “first” member is of type T1
    - “second” member is of type T2



- To use std::pair, we must supply “Type Information” to the template
  - What T1 and T2 should be.

STL and Namespace

- The “Fullname” of cout is std::cout
- std is a namespace
- We need to use fullname
  - Too lazy? use “using” keywords

```cpp
#include <iostream>

//this tell C++ that when we say cout, we mean std::cout
using std::cout;

int main() {
    //we still need to use std::endl
    cout << "Yes" << std::endl;
}
```

```cpp
#include <iostream>

//this tell C++ that when we say something
// that it does not understand, C++ should
// try to use std as its namespace

//this is VERY BAD PRACTICE in real world.
//10/10 not recommend
//.... but it's ok for this class
using namespace std;

int main() {
    cout << "Yes" << endl;
}
```

std::vector

A linear storage of a single data type

Nattee Niparnan

Basic


```cpp
#include <iostream>
#include <vector>

using namespace std;

int main() {
   vector<int> v1;
   cout << "Size of v1 is " << v1.size() << endl;

   vector<int> v2 = {2,3,4};

   cout << v2[1] << endl;
   v1 = v2;
   v1[0] = 20;

   cout << v1[0] << ", " << v1[1] << ", " << v1[2] << endl;

   v1.push_back(99);
   cout << v1.size() << endl;
}
```

```
Size of v1 is 0
v1 is empty
3
20, 3, 4
4
```

- Vector start with empty element
- Use `size()` to get the number of element
- Use `empty()` to check if a vector has any element

Initialize

- With specific size
- With specific size and starting value

```
#include <iostream>
#include <vector>

using namespace std;

void print_vector(vector<float> v) {
   for (size_t i = 0;i < v.size(); i++) {
      cout << v[i] << " ";
   }
   cout << endl;
}

int main() {
   vector<float> v1(10);
   print_vector(v1);

   vector<float> v2(5,3.55);
   print_vector(v2);

   vector<float> v3(v2);
   print_vector(v3);
}
```

Access

```
#include <iostream>
#include <vector>

using namespace std;

int main() {
   vector<float> v1(2);
   vector<float> v2(2);

   cout << "-- v1 --" << endl;
   for (int i = 0;i < 7; i++) {
      v1[i] = i;
      cout << i << ": " << v1[i] << endl;
   }
   cout << "-- v2 --" << endl;
   for (int i = 0;i < 7; i++) {
      cout << i << ": " << v2[i] << endl;
   }
   //cout << "using at" << endl;
   //v2.at(1) = 99;
   //this will cause exception
   //for (int i = 0;i < 7; i++) {
   //   cout << i << ": " << v2.at(i) << endl;
   //}
}
```

- Operator [ ] won't check for 'out-of-range'
  - Reading, writing beyond size is undefined
  - Might crash
  - Grader will give 'x'
- at() method will check bound
  - But slower

Resizing

- Resize change the size
  - Enlarge will fill with default

```
#include <iostream>
#include <vector>

using namespace std;

void print(vector<int> v) {
   cout << "Size of V is " << v.size() << ":";
   for (int i = 0;i < v.size();i++) cout << v[i] << ", ";
   cout << endl;
}

int main() {
   vector<int> v(3,10);
   print(v);
   v.resize(6);
   print(v);
   v.resize(1);
   print(v);
   v.resize(7);
   print(v);
}
```

```
Size of V is 3:10,10,10,
Size of V is 6:10,10,10,0,0,0,
Size of V is 1:10,
Size of V is 7:10,0,0,0,0,0,0,
```

Modify

- pop_back
  - Erase last element
- insert(position, value)
- erase(position)
- Careful!
  - Both insert and erase position must be valid
  - If not valid, it can crash

```
Size of V is 6: 1, 8, 8, 2, 8, 3,
```

```cpp
#include <iostream>
#include <vector>

using namespace std;

void print(vector<int> v) {
   cout << "Size of V is " << v.size() << ": ";
   for (int i = 0;i < v.size();i++) cout << v[i] << ", ";
   cout << endl;
}

int main() {
   vector<int> v(3,8);
   v.insert( v.begin(), 1);
   v.insert( v.begin()+3, 2);
   v.insert( v.end(), 3);
   print(v);
   v.erase(v.begin());
   v.erase(v.begin()+2);
   //print(v);
   //v.pop_back();
   //print(v);
}
```

Functions that work with vector

- sort
- find
- min_element
- max_element
- lower_bound
- upper_bound

Need to use iterator

Find

- find(a, b, c)
  - a and b are position (iterator)
  - find c from a to before b
  - If not found, return b
- Must #include <algorithm>

```cpp
#include <iostream>
#include <vector>
#include <algorithm>

using namespace std;

int main() {
   vector<int> v = {9,-1,3,7,5,2,1,4};

   int x = 5;
   if ( find(v.begin(), v.end(), x) != v.end() ) {
      cout << "found" << endl;
   } else {
      cout << "not found" << endl;
   }

   if (find(v.begin(), v.begin()+3, 3) != v.begin()+ ) cout << "FOUND" << endl;

   //how many "YES" will be printed? (CHEAT QUESTION)
   //if (find(v.begin()  , v.begin()+2, x) != v.end()) cout << "YES" << endl;
   //if (find(v.begin()  , v.begin()+4, x) != v.end()) cout << "YES" << endl;
   //if (find(v.begin()+4, v.begin()+2, x) != v.end()) cout << "YES" << endl;
   //if (find(v.begin()+4, v.begin()+8, x) != v.end()) cout << "YES" << endl;
}
```

Sort

```cpp
#include <iostream>
#include <vector>
#include <algorithm>

using namespace std;

void print(vector<int> v) {
   cout << "Size of V is " << v.size() << ": ";
   for (int i = 0;i < v.size();i++) cout << v[i] << ", ";
   cout << endl;
}

int main() {
   vector<int> v = {9,-1,3,7,5,2,1,4};

   print(v);
   sort(v.begin()+2, v.begin()+6);
   print(v);
 }
```

- sort(a,b)
  - sort everything from a to before b
- Must #include <algorithm>

Vector iterator

Iterator

- Iterator is a pointer to position
- First element is begin()
- The one after the last element is end()
- For insert, valid position is from begin() to end(), inclusive
- For erase, valid position is from begin() up to before end()
- Different vector, different iterator
  - v1.end() is not the same as v2.end()

Iterator arithmetic

- We can add by integer to an iterator
- We can subtract two iterators of the same type
- We can use increment (++) and decrement (--)

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

int main() {
  vector<int>   v1 = {0, 10, 20 ,30, 40, 50, 60, 70, 80};
  vector<float> v2 = {0.2, -4, 0.13, 3.14, 2.73};

  vector<int>::iterator it1 = v1.begin() + 3;
  vector<float>::iterator it2 = v2.end();

  //getting value at iterator by using "*" operator
  cout << *it1 << endl;
  cout << *(it2-1) << endl;
  cout << *it1+2 << endl;

  //iterator arithmetics
  vector<int>::iterator it3 = it1 + 2;
  cout << "data at it3: " << *it3 << endl;
  cout << "different of it3,it1: " << (it3 - it1) << endl;

  vector<float>::iterator it4 = v2.end();
  it4--;
  cout << "data at it4: " << *it4 << endl;

  //this cannot be done
  //cout << (it2 - it1) << endl;
}
```

Iterate all elements by iterator

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

int main() {
  vector<int>   v1 = {0, 10, 20 ,30, 40, 50, 60, 70, 80};
  vector<float> v2 = {0.2, -4, 0.13, 3.14, 2.73};

  cout << "----v1----" << endl;
  auto it = v1.begin();
  while (it < v1.end() ) {
    cout << it - v1.begin() << ": " << *it << endl;
    it++;
  }

  cout << "----v2----" << endl;
  for (auto it = v2.begin(); it < v2.end(); it++) {
    cout << it - v2.begin() << ": " << *it << endl;
  }
}
```

- We can compare iterator
  - Beware!! Iterator of some data structure does not support > or < comparator
  - But for vector, its' ok
- We can use auto keyword to automatically define a type of a variable

Some functions that use iterators

```cpp
#include <iostream>
#include <vector>
#include <algorithm>
using namespace std;

int main() {
  vector<int>   v1 = {3,0,1,2,4,-3,9,8};
  vector<float> v2 = {10.2, -4, 0.13, 3.14, 2.73};

  auto it1 = min_element(v1.begin(),v1.end());
  auto it2 = max_element(v2.begin()+2,v2.end());

  cout << *it1 << endl;
  cout << *it2 << endl;
}
```

- min_element and max_element get the iterator of the minimum (and maximum) element.

New idiom that iterates all elements

- Shorter syntax for-loop
- Called range-based for loop
- Can use reference operator (&)

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

int main() {
  vector<string> v1 = {"somchai", "somying", "somsak"};

  //range-based for loop
  for (string x : v1) {
    // x is a copy of each element in v1
    cout << x << ", ";
  }
  cout << endl;

  //using reference
  // x is THE element of v1, meaning we can modify it
  for (auto &x : v1) { x.replace(0,4,"--"); }
  for (auto &x : v1) { cout << x << " ";}
  cout << endl;
}
```

Iterator Invalidation

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

int main() {
  vector<int> v1 = {10,20};

  auto it = v1.end()-1;  // this point to 20
  // we resize (enlarge) v1, now [it] is invalidated
  v1.resize(10);

  //this might not crash
  //but it actually points to somewhere not in v1
  cout << *it << endl;

  //this will crash the program
  v1.insert(it,99);
  for (auto &x: v1) {cout << x << " ";}

}
```

- Some operation on the data structure invalidate existing iterators
- When an iterator is invalidated, it must not be used
- For vector, this include any addition and deletion of element (including resize)
- Another example: when we call v.erase(it), the iterator it is invalidated, because we have already deleted it.

std::set

Storing “distinct” element with fast look up

Nattee Niparnan

Set

- Storing distinct data of same type
  - The data type must be comparable, i.e., we can tell if a is more or less than b
- Somewhat slow insert
- Fast look up
- Fast erase
- Iterator starts from “minimum element” and goes in increasing value direction
  - Can be used to (somewhat) fast sorting

Basic

- Notice that s does not include duplicate elements
- Also see that when we iterate, member is sorted
  - This is distinct characteristic of set

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

int main() {
  set<int> s = {4,1,3,2,1,1,3,4};

  cout << "Size of s is " << s.size() << endl;

  s.insert(10);
  s.insert(5);
  s.erase(3);

  cout << "member of s: ";
  for (auto it = s.begin(); it != s.end(); it++)
    cout << *it << " ";
}
```

```
Size of s is 4
Member of s: 1 2 4 5 10
```

Somewhat slow insert, iterate but fast find

- We will see this in the detail around last part of this course
  - For now, please believe that
    - If there is N elements in the set
    - Insert take times directly proportional to log(N)
    - Each it++ or it-- take times directly proportional to log(N)
    - Each find takes times directly proportional to log(N)

Demo Comparing Vector & Set

See set-2.cpp and set-3.cpp

Set iterator

- We cannot do s.begin() + x
  - Because, going to the next element (which is the successor) in set is not as fast as vector, c++ forbids begin() + x
  - We cannot compare by > or <
- We can still use it++ or it-- to go to the next or previous (successor or predecessor) or x

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

int main() {
  set< pair<string,int> > s = { {"somchai",5},
    {"abc",6}, {"abcd",-3}, {"somchai",-4},
    {"z",0}, {"z", -1}, {"z",9} };

  for (auto &x : s) {
    cout << x.first << "," << x.second << endl;
  }

  cout << "-- find -- " << endl;
  auto it =  s.find( {"z",-1});
  cout << (*it).first << "," << (*it).second << endl;
  it--;
  it--;
  cout << it->first << "," << it->second << endl;
  it++;
  cout << it->first << "," << it->second << endl;
```

```
abc,6
abcd,-3
somchai,-4
somchai,5
z,-1
z,0
z,9
-- find --
z,-1
somchai,-4
somchai,5
```

Additional Function

- set.lower_bound
- set.upper_bound
- set.count

std::map

Association data structure with same property as set

Map

- Is very similar to Python's dict in usage
- Is internally implemented as a set with "pair" data type
  - Same properties, same limitations as set but more convenience to use as associative data structure
- Associative (mapping) between a Key Type and a Mapped Type

Basic

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

int main() {
  //map between "Key Type" string and "Mapped Type" int
  map<string,int> m;
  m["somchai"] = 10;
  m["somying"] = -5;
  cout << "Size = " << m.size() << endl;

  //accessing unseen Key create a map with default value
  cout << "m[\"xxx\"] = " << m["xxx"] << endl;
  //each element is a pair of Key Type and Mapped Type
  for (auto it = m.begin(); it != m.end();it++) {
    cout << it->first << " is mapped to " << it->second << endl;
  }

  //this will create mapping "abc" to 0 first and then increase it
  m["abc"]++;
  cout << "now size = " << m.size() << endl;
  for (auto &x : m) {
    cout << x.first << " is mapped to " << x.second << endl;
  }
}
```

```
Size = 2
m["xxx"] = 0
somchai is mapped to 10
somying is mapped to -5
xxx is mapped to 0
now size = 4
abc is mapped to 1
somchai is mapped to 10
somying is mapped to -5
xxx is mapped to 0
```

Checking if map has this key?

- Use find()

```
Key 99 is mapped to nattee
exists
```

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

int main() {
  //map between "Key Type" string and "Mapped Type" int
  map<int,string> m;
  m[1] = "somchai";
  m[99] = "nattee";

  int k = 99;
  map<int,string>::iterator it;
  if ((it = m.find(k)) != m.end()) {
    cout << "Key " << it->first << " is mapped to " << it->second << endl;
  } else {
    cout << "Key " << k << " is not exists in m." << endl;
  }

  //this is not the correct way to check if key exists why??
  if (m[k] != "") {
    cout << "exists" << endl;
  } else {
    cout << "does not exists" << endl;
  }
}
```

Requirement of std::set and std::map

- Set data type and map Key Type must be comparable
  - We must be able to compare order of two element
- Type that we can use directly
  - int, bool, float, string, double, char... and most of other numerical data type
  - Pair can also be used if both the type of first and second are comparable
    - Pair compare first then second

Practice reading c++ docs

- Both map and set has insert and erase function
- What is the return value of both function of each data structure?
  - For set<int> s, we can do s.erase(20)
  - For map<string,bool> m, can we do m.erase("Somchai") ??
- If we wish to erase element from index 3 to index 4096 in a vector
  - Is there any function from vector that we can easily use?

Problem

- Pair Sum
  - Given an array of integers, our task is to find whether there exists a pair of elements in the array such that their summation equal to X
- Input:
  - Array of integer (our main array) <-- this is a large array
  - M values of X, for each value X, we have to determine if a pair whose sum equal to X exists.
- Output:
  - For each value of X, print “YES” if we found such pair; print “NO” otherwise