

std::pair

Storing two pieces of different data

Basic

Program memory

```
#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

```
#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

`std::pair<int, float>`

Class Template

What “first”
shoul be

What “second”
shoul be

- 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

```
#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;
}
```

```
#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

Basic



```
#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;
}
```

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

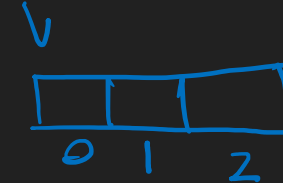
```
Size of v1 is 0
v1 is empty
3
20, 3, 4
4
```

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); ← copy constructor
    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

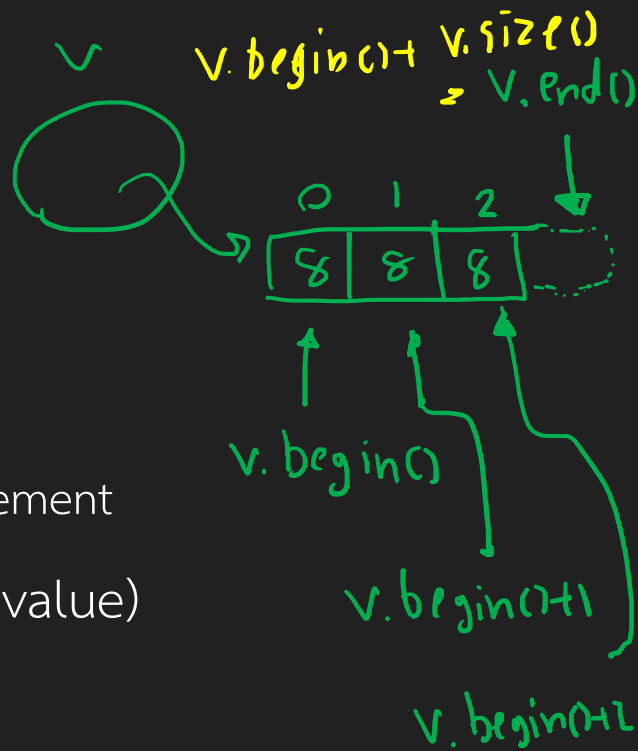
- Resize change the size
 - Enlarge will fill with default

```
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,
```

```
#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);  
}
```

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



```

#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);
}
    
```

(iterators)

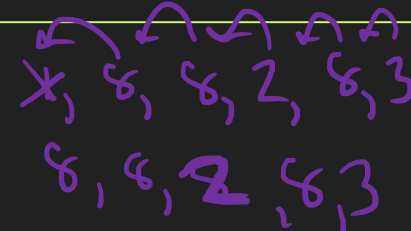
push-back

1, 8, 8, 8
 1, 8, 8, 2, 8
 1, 8, 8, 2, 8, 3

erase()

8, 8, 8
 begin, begin+1, begin+2

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



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>

```
#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;
}
```

Handwritten annotations in the code:

- `v.begin()` is written in red above the first parameter of the first `find` call.
- An arrow points from `v.begin()` to the first element (9) in the vector initialization.
- `v.begin()+3` is written in red above the third parameter of the second `find` call.
- An arrow points from `v.begin()+3` to the third element (3) in the vector initialization.
- The value `3` in the second `find` call is circled in red.

Sort

```
#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

v1[0]

v2[0]

- 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 (--)

```
#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;
}
```

Handwritten annotations in the code:

- Green arrows pointing to `30` in `v1` and `2.73` in `v2` from `it1` and `it3` respectively.
- Green arrows pointing to `it4` and `it2` from `it4` and `it2` respectively.
- Green box around `*it1+2` with `30` written below it.
- Green arrow pointing to `2` from `it4` and `it2` respectively.

Iterate all element by iterator

```
#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

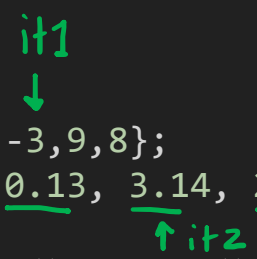
Some functions that use iterators

```
#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;
}
```



The diagram illustrates the operation of the `min_element` and `max_element` functions. A green arrow labeled `it1` points to the element `-3` in the `v1` vector, which is the minimum value. Another green arrow labeled `it2` points to the element `3.14` in the `v2` vector, which is the maximum value within the range starting from the third element (`v2.begin()+2`).

- `min_element` and `max_element` get the iterator of min, max element

New idiom that iterate all elements

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

For (:)

begin
end

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

int main() {
    vector<string> v1 = {"somechai", "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

```
#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
 - For vector, this include any **addition** and **deletion** of element (including **resize**)