

Vectors

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1 Vectors

1.1 Topics

- what is and why vectors
- how to use vectors
- various operations and methods provided by vectors
- applications and examples using vectors
- sorting vectors

1.2 Vectors

- vector is a collection of values where each value is identified by a number (index)
- anything that can be done by C-array (Array chapter) can be done using vectors
 - unlike C-array, vector is an advanced type like C++ string
- vector is defined in the C++ Standard Template Library (STL)
 - vector is one of my containers library - <https://en.cppreference.com/w/cpp/container>
 - array, set, map, queue, stack, priority_queue are some other containers provided in STL
- learning vector is similar to learning C++ string container
 - main difference is vector can store any type of element
 - learn all the operations provided by vector
 - * what they are; what they do; how to use them...
 - apply vectors to solve problems
- vector and other containers provided in STL are templated, hence “Template” in STL
 - the actual type that you’re storing in those containers need to be specified
 - very similar to template struct types covered in **Structures** chapter
 - to learn STL containers and more, follow these notebooks:
<https://github.com/rambasnet/STL-Notebooks>
- must include `<vector>` header to use vector type

1.3 Vector objects

- C++ vector is an advanced type defined in `<vector>` header
- objects must be instantiated or declared to allocate memory before we can store data into them
- since vector uses template type, you must provide the actual type of the data
- syntax:

```
#include <vector>
```

```
vector<type> objectName;
```

```
[1]: #include <iostream>
#include <vector>
#include <string>
#include <sstream>
#include <cassert>

using namespace std;
```

```
[2]: // declare empty vectors
vector<string> names;
vector<float> tests;
vector<int> numbers;
```

```
[3]: // let's see the contents
names
```

```
[3]: {}
```

```
[4]: // declare and initialize vectors
vector<string> words = {"i", "love", "c++", "vectors"};
vector<float> prices = {1.99, 199, 2.99, 200.85, 45.71};
```

```
[5]: // let's see the contents
words
```

```
[5]: { "i", "love", "c++", "vectors" }
```

```
[6]: prices
```

```
[6]: { 1.99000f, 199.000f, 2.99000f, 200.850f, 45.7100f }
```

1.4 Accessing elements

- elements accessed mostly using index just like in C-array or string
- index starts from 0 and goes to 1 less than the vector size or length
- the following methods are available:
 - **at(index)** : access specified element with bounds checking
 - **operator[index]** : access specified element by index
 - **front()** : access the first element
 - **back()** : access the last element
- *do they sound familiar? same method names as accessing characters in string objects*

```
[7]: // access elements
// change i to I in words
words[0] = "I";
cout << words[1] << endl; // print 2nd word
```

```
cout << prices.at(3) << endl;
cout << prices.front() << endl;
cout << prices.back() << endl;
```

```
love
200.85
1.99
45.71
```

1.5 Capacity

- unlike C-array, vector provides member functions to work with the capacity of the vector objects
- the following are the commonly used methods:
 - **empty()** : checks whether the container is empty; returns true if empty; false otherwise
 - **size()** : returns the number of elements or length of the vector
 - **max_size()** : returns the maximum possible number of elements that can be stored

```
[8]: cout << boolalpha; // convert boolean to text true/false
cout << "is prices vector empty? " << prices.empty() << endl;
cout << "size of words: " << prices.size() << endl;
cout << "size of prices: " << prices.size() << endl;
cout << "max size of words: " << words.max_size() << endl;
```

```
is prices vector empty? false
size of words: 5
size of prices: 5
max size of words: 768614336404564650
```

1.6 Modifying vectors

- vectors once created can be modified using various member functions or methods
- some commonly used methods are:
 - **clear()** : clears the contents
 - **push_back(element)** : adds an element to the end
 - **pop_back()** : removes the last element
- *Note: if C-array was used, programmers would have to implement these functions*

```
[9]: vector<int> age = {21, 34, 46, 48, 46};
```

```
[10]: // see the initial contents
age
```

```
[10]: { 21, 34, 46, 48, 46 }
```

```
[11]: // let's clear age vector
age.clear();
```

```
[12]: // is age cleared?  
age
```

```
[12]: {}
```

```
[13]: // double check!  
age.empty()
```

```
[13]: true
```

```
[14]: // let's add element into the empty age vector  
age.push_back(25);
```

```
[15]: age.push_back(39);
```

```
[16]: age.push_back(45.5); // can't correctly add double to int vector
```

```
input_line_31:2:16: warning: implicit conversion from  
'double' to 'std::__1::vector<int, std::__1::allocator<int> >::value_type'  
      (aka 'int') changes value from 45.5 to 45 [-Wliteral-conversion]  
age.push_back(45.5); // can't correctly add double to int vector  
~~~~~ ^~~~
```

```
[17]: age
```

```
[17]: { 25, 39, 45 }
```

```
[18]: // let's see the last element  
age.back()
```

```
[18]: 45
```

```
[19]: // let's remove the last element  
age.pop_back();
```

```
[20]: // check if last element is gone  
age
```

```
[20]: { 25, 39 }
```

1.7 Traversing vectors

- similar to string and C-array, vectors can be traversed from the first to last element
- can use loop with index or iterators

```
[21]: for(auto val: words)
      cout << val << "; ";
```

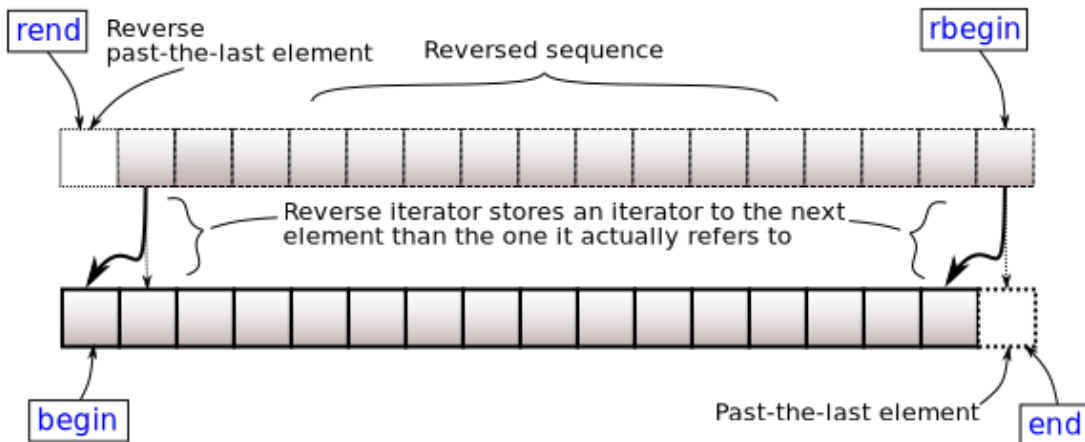
I; love; c++; vectors;

```
[22]: for(int i=0; i<words.size(); i++) {
      cout << words[i] << " is " << words[i].length() << " characters long." <<
      endl;
    }
```

I is 1 characters long.
 love is 4 characters long.
 c++ is 3 characters long.
 vectors is 7 characters long.

1.8 Iterators

- similar to string iterators, vector provides various iterators
- iterators are special pointers that let you manipulate vector
- several member function of vector uses iterator to do its operation
- let's revisit the iterators we went over in string chapter



- **begin()** - returns iterator to the first element
- **end()** - returns iterator to the end (past the last element)
- **rbegin()** - returns reverse iterator to the last element
- **rend()** - returns a reverse iterator to the beginning (prior to the first element)

```
[23]: // let's use iterator to traverse vectors
      // very similar to using for loop with index
      for(auto iter = words.begin(); iter != words.end(); iter++)
        cout << *iter << "; "; // iter is a pointer; so must dereference to access
        value pointed to by iter
```

I; love; c++; vectors;

```
[24]: // let's reverse traverse
for(auto iter = words.rbegin(); iter != words.rend(); iter++)
    cout << *iter << "; "; // iter is a pointer; so must dereference to access
    ↪ value pointed to by iter
```

```
vectors; c++; love; I;
```

1.9 Aggregate operations

- some aggregate operators such as assignment (=) and comparison (>, ==, etc.) are overloaded and work out of the box on vector objects as a whole
- sorta works! - depends on what type of vector and if there's a predefined ordering of values in that type for sorting!
- input, output (<<, >>) operators do not work on vector objects as a whole

```
[25]: // create words_copy vector with copy assignment
vector<string> words_copy = words; // deep copies words into words_copy
```

```
[26]: // string can be compared out of the box
if (words == words_copy)
    cout << "two vectors are equal!";
else
    cout << "two vectors are not equal!";
```

```
two vectors are equal!
```

1.10 Passing vectors to functions

- vector can be passed to functions by value or by reference
- unless required, it's always efficient to pass containers type such as vectors to function by reference
 - copying data can be costly (can take a long time) depending on the amount of data vector is storing

```
[27]: // given a vector of values find and return average
float findAverage(const vector<int> & v) {
    float sum = 0;
    for (auto val: v)
        sum += val;
    return sum/v.size();
}
```

```
[28]: // let's see the values of age vector
age
```

```
[28]: { 25, 39 }
```

```
[29]: cout << "average age = " << findAverage(age);
```

average age = 32

```
[30]: // printVector function
template<class T>
void printVector(const vector<T>& v) {
    char comma[3] = {'\\0', ' ', '\\0'};
    cout << '[';
    for (const auto& e: v) {
        cout << comma << e;
        comma[0] = ',';
    }
    cout << "]\n";
}
```

```
[31]: printVector(words);
```

[I, love, c++, vectors]

```
[32]: printVector(age)
```

[25, 39]

1.11 Returning vector from functions

- since vector supports = copy operator, returning vector from functions is possible
- since returned vector needs to be copied it can be costly
 - it's best practice to pass vector as reference to get the data/results out of functions

```
[33]: // function that gets vector of integers from standard input
void getNumbers(vector<int> & numbers) {
    cout << "Enter as many whole numbers as you wish.\nEnter 'done' when done:
    ↵\n";
    int num;
    while(cin >> num) // cin returns false when it fails to parse 'done'
        numbers.push_back(num);
}
```

```
[34]: // create an empty vector
vector<int> my_numbers;
```

```
[35]: getNumbers(my_numbers);
```

Enter as many whole numbers as you wish.
Enter 'done' when done:
10
20
100
99

-66
done

```
[36]: my_numbers
```

```
[36]: { 10, 20, 100, 99, -66 }
```

1.12 Two-dimensional vector

- if we insert vectors as an element to a vector, we essentially get a 2-D vector
 - works similar to 2-D array

```
[37]: // let's declare a 2-d vector of integers  
vector< vector<int> > matrix;
```

```
[38]: // add the first vector - first row  
matrix.push_back({1, 2, 3, 4});
```

```
[39]: matrix[0]
```

```
[39]: { 1, 2, 3, 4 }
```

```
[40]: // let's add an empty vector as the second element or 2nd row  
matrix.push_back(vector<int>());
```

```
[41]: // let's add elements to the 2nd vector or 2nd row  
matrix[1].push_back(5);  
matrix[1].push_back(6);  
matrix[1].push_back(7);  
matrix[1].push_back(8);
```

```
[42]: matrix[1]
```

```
[42]: { 5, 6, 7, 8 }
```

```
[43]: // access element of vector elements  
// first row, first column  
matrix[0][0]
```

```
[43]: 1
```

```
[44]: // 2nd row, fourth column  
matrix[1][3]
```

```
[44]: 8
```


1.13 Sort vector

- vector like array needs to be sorted often to solve many problems
- let's use built-in `sort` function in `algorithm` library
 - `sort` function implements one of the fastest sorting algorithms

```
[45]: #include <vector>
#include <algorithm> // sort()
#include <iterator> // begin() and end()
#include <functional> // greater<>();
#include <iostream>

using namespace std;
```

```
[46]: vector<int> some_values = { 100, 99, 85, 40, 1233, 1};
```

```
[47]: // let's sort some_values
sort(begin(some_values), end(some_values));
```

```
[48]: some_values
```

```
[48]: { 1, 40, 85, 99, 100, 1233 }
```

```
[49]: // let's sort 1st row of matrix in reverse order
matrix[0]
```

```
[49]: { 1, 2, 3, 4 }
```

```
[50]: // sort in increasing order
sort(matrix[0].begin(), matrix[0].end());
```

```
[51]: matrix[0]
```

```
[51]: { 1, 2, 3, 4 }
```

```
[52]: // sort in on-increasing order
sort(matrix[0].begin(), matrix[0].end(), greater<int>());
```

```
[53]: matrix[0]
```

```
[53]: { 4, 3, 2, 1 }
```

1.14 Labs

1. The following lab demonstrates the usage of vector data structure and some operations on vectors.
 - use partial solution `numberSystem.cpp` file in [labs/vectors/](#) folder
 - use Makefile to compile and debug the program

- fixe all the FIXMEs and write #FIXED# next to each FIXME once fixed

1.15 Exercises

1.15.1 Solve all exercises listed in Array chapter using vector instead.

1.15.2 More exercises

1. Write a function that splits a given text/string into a vector of individual words
 - each word is sequence of characters separated by a whitespace
 - write 3 test cases

```
[54]: // Solution to Exercise 1
void splitString(vector<string> &words, string text) {
    string word;
    stringstream ss(text);
    while (ss >> word) {
        words.push_back(word);
    }
}
```

```
[55]: void test_splitString() {
    vector<string> answer;
    splitString(answer, "word");
    vector<string> actual = {"word"};
    assert(answer == actual);
    answer.clear();
    splitString(answer, "two word");
    vector<string> actual1 = {"two", "word"};
    assert(answer == actual1);
    answer.clear();
    splitString(answer, "A sentence with multiple words!");
    vector<string> actual2 = {"A", "sentence", "with", "multiple", "words!"};
    assert(answer == actual2);
    answer.clear();
    cerr << "all test cases is passed for splitString()\n";
}
```

```
[56]: test_splitString();
```

all test cases is passed for splitString()

```
[57]: vector<string> tokens;
```

```
[58]: // not needed but just in case!
tokens.clear();
```

```
[59]: splitString(tokens, "This is a long sentence so long that it's hard to_
↳comprehend!");
```

```
[60]: tokens
```

```
[60]: { "This", "is", "a", "long", "sentence", "so", "long", "that", "it's", "hard",  
      "to", "comprehend!" }
```

1.15.3 complete program can be found in [demos/vectors/splitString/](#)

2. Airline Reservation System

- Write a C++ menu-driven CLI-based program that let's an airline company manage airline reservation on a single aircraft they own with the following requirements:
- aircraft has 10 rows with 2 seat on each row
- program provides menu option to display all the available seats
- program provides menu option to let user pick any available seat
- program provides menu option to create total sales report
- program provides menu option to update price of any seat

3. Triangle

- write a program to compute area and perimeter of a triangle given 3 sides using vector
- prompt user to enter 3 sides of a triangle
 - implement input validation and validate the triangle
- use as many function(s) as possible
- write at least 3 test cases for each computing functions
- a sample solution can be found in [demos/vectors/triangle/](#)

1.16 Kattis problems

- problems that require to store large amount of data in sequential order in memory can use vector very effectively
- design your solutions in a way that it can be tested writing automated test cases

1. Dice Game - <https://open.kattis.com/problems/dicegame>
2. Falling Apart - <https://open.kattis.com/problems/fallingapart>
3. Height Ordering - <https://open.kattis.com/problems/height>
4. What does the fox say? - <https://open.kattis.com/problems/whatdoesthefoxsay>
5. Army Strength (Easy) - <https://open.kattis.com/problems/armystrengtheasy>
6. Army Strength (Hard) - <https://open.kattis.com/problems/armystrengthhard>
7. Black Friday - <https://open.kattis.com/problems/blackfriday>
8. Bacon, Eggs and Spam - <https://open.kattis.com/problems/baconeggsandspam>
9. To flur - <https://open.kattis.com/problems/toflur>

1.16.1 sorting vectors with two keys

1. Roll Call - <https://open.kattis.com/problems/rollcall>
2. Cooking Water - <https://open.kattis.com/problems/cookingwater>

1.17 Summary

- this chapter covered C++ vector container STL
- vector is an easier alternative to C-array
- vector is an advanced type that you can create/instantiate objects from

- the type of the data must be mentioned as a template parameter while declaring vectors
- provides many out-of the box common operations in the form of member functions or methods
- vector can be passed to functions; returning a large vector may not be effective due to copying of data
- problems and sample solutions

[]: