# 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 defned 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*

[13]:
```
// 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

[15]:
```
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;
cout << "max capacity of rectangles: " << rectangles.max_size() << endl;
```

```
is prices vector empty? false
size of words: 5
size of prices: 5
max size of words: 768614336404564650
max capacity of rectangles: 2305843009213693951
```

### 1.6 Modifiying 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 be have to implement these functions*

[16]:
```
vector<int> age = {21, 34, 46, 48, 46};
```

[17]:
```
// see the initial contents
age
```

[17]:
```
{ 21, 34, 46, 48, 46 }
```

[18]:
```
// let's clear age vector
age.clear();
```

[19]:
```
// is age cleared?
age
```

[19]:
```
{}
```

[20]:
```
// double check!
age.empty()
```

[20]:
```
true
```

[21]:
```
// let's add element into the empty age vector
age.push_back(25);
```

[22]:
```
age.push_back(39);
```

[23]:
```
age.push_back(45.5); // can't correctly add double to int vector
```

```
input_line_38:2:16: 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
     ~~~~~~~~~ ^~~~
```

[24]:
```
age
```

[24]:
```
{ 25, 39, 45 }
```

[25]:
```
// let's see the last element
age.back()
```

[25]:
```
45
```

[26]:
```
// let's remove the last element
age.pop_back();
```

[27]:
```
// check if last element is gone
age
```

[27]: { 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

[32]:
```
for(auto val: words)
    cout << val << "; ";
```

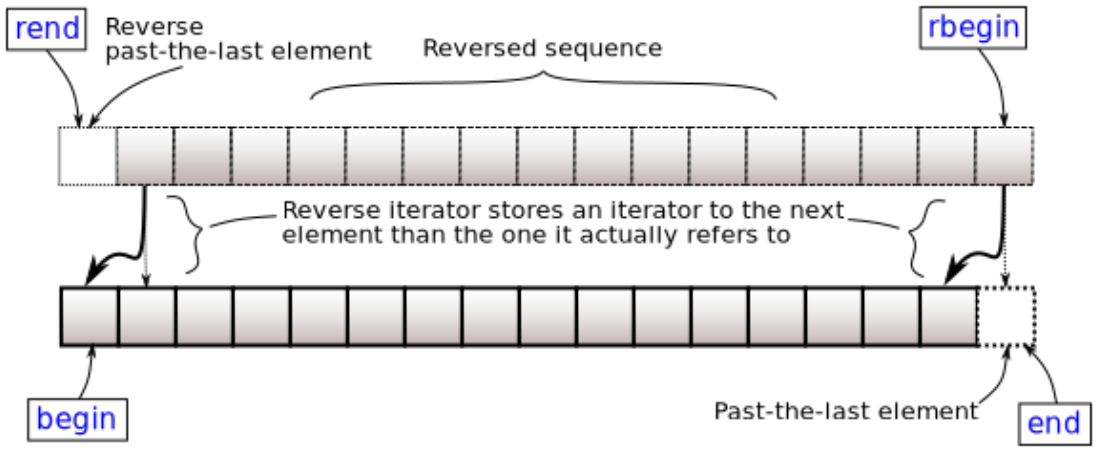
```
I; love; c++; vectors;
```

[33]:
```
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 revist 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)

[37]:
```
// 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 derefernce to access␣
 ↪value pointed to by iter
```

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

[38]:
```
// let's reverse traverse
for(auto iter = words.rbegin(); iter != words.rend(); iter++)
    cout << *iter << "; "; // iter is a pointer; so must derefernce to access␣
 ↪value pointed to by iter
```

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

### 1.9 Aggregagte operations

- some aggegate 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 predfined ordering of values in that type for sorting!
- input, output (<<, >>) operators do not work on vector objects as a whole

[39]:
```
// create words_copy vector with copy assignment
vector<string> words_copy = words; // deep copies words into words_copy
```

[42]:
```
// 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

[44]:
```
// 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();
```

```
}
```

[45]:
```
// let's see the values of age vector
age
```

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

[46]:
```
cout << "average age = " << findAverage(age);
```

```
average age = 32
```

[47]:
```
// 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";
}
```

[48]:
```
printVector(words);
```

```
[I, love, c++, vectors]
```

[49]:
```
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

[8]:
```
// 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);
}
```

[9]:
```
// create an empty vector
vector<int> my_numbers;
```

[10]:
```
getNumbers(my_numbers);
```

```
Enter as many whole numbers as you wish.
Enter 'done' when done:
10
19
100
345
56
45
66
999
4546
done
```

[11]:
```
my_numbers
```

[11]: { 10, 19, 100, 345, 56, 45, 66, 999, 4546 }

### 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

[10]:
```
// let's declare a 2-d vector of integers
vector< vector<int> > matrix;
```

[11]:
```
// add the first vector - first row
matrix.push_back({1, 2, 3, 4});
```

[12]:
```
matrix[0]
```

[12]: { 1, 2, 3, 4 }

[13]:
```
// let's add an empty vector as the second element or 2nd row
matrix.push_back(vector<int>());
```

[14]:
```
// 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);
```

[15]:
```
matrix[1]
```

[15]: { 5, 6, 7, 8 }

[16]:
```
// access element of vector elements
// first row, first column
matrix[0][0]
```

[16]: 1

[17]:
```
// 2nd row, fourth column
matrix[1][3]
```

[17]: 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

[2]:
```
#include <vector>
#include <algorithm> // sort()
#include <iterator> // begin() and end()
#include <functional> // greater<>();
#include <iostream>

using namespace std;
```

[3]:
```
vector<int> some_values = { 100, 99, 85, 40, 1233, 1};
```

[7]:
```
// let's sort some_values
sort(begin(some_values), end(some_values));
```

[8]:
```
some_values
```

[8]: { 1, 40, 85, 99, 100, 1233 }

[18]:
```
// let's sort 1st row of matrix in reverse order
matrix[0]
```

[18]: { 1, 2, 3, 4 }

[19]:
```
// sort in increasing order
sort(matrix[0].begin(), matrix[0].end());
```

[20]:
```
matrix[0]
```

[20]: { 1, 2, 3, 4 }

[21]:
```
// sort in on-increasing order
sort(matrix[0].begin(), matrix[0].end(), greater<int>());
```

[22]:
```
matrix[0]
```

[22]:
```
{ 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 Sove 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

[23]:
```
// Solution to Exercise 1
void splitString(vector<string> &words, string text) {
    string word;
    stringstream ss(text);
    while (ss >> word) {
        words.push_back(word);
    }
}
```

[24]:
```
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";
}
```

[25]:
```
test_splitString();
```

```
all test cases is passed for splitString()
```

[26]:
```
vector<string> tokens;
```

[27]:
```
// not needed but just in case!
tokens.clear();
```

[28]:
```
splitString(tokens, "This is a long sentence so long that it's hard to␣
 ↪comprehend!");
```

[29]:
```
tokens
```

[29]:
```
{ "This", "is", "a", "long", "sentence", "so", "long", "that", "it's", "hard",
"to", "comprehend!" }
```

#### 1.15.3 complete program can be found in demos/strings/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 provieds menu option to display all the avaialable seats
   - program provides menu option to let user pick any available seat
   - program provides menu option to creates total sales report
   - program provides menu option to update price of any seat

### 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

### 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 and advanced type that you can create/instantiate bojects 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
- probems and sample solutions

[ ]: