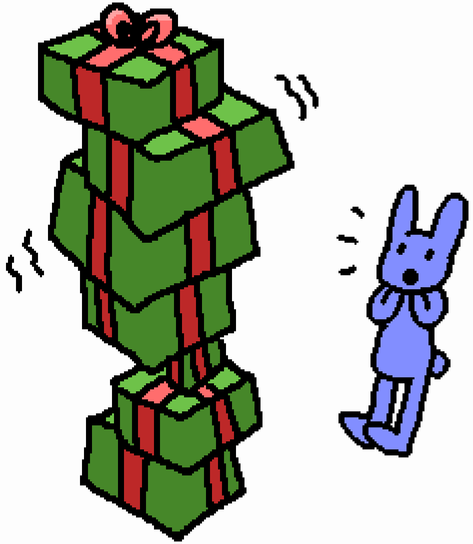
# The Standard Template Library

Written by Rachel J. Morris, last updated Aug 10, 2017

# About

C++ has some data structures already pre-built and available within the standard library. We can use these to get familiar with how these structures work from the outside, before we worry about how to implement them ourselves.



# About

Wait, if data structures already exist, why are we going to spend all semester learning how to write 'em?!

# About

- Well… learning about data structures & algorithm analysis is a big part of computer science.

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- You also need to know the inner-workings of these structures, so that when you're implementing solutions, you can choose the best structure for your particular problem – it isn't one size fits all!

- You might need to create your own data structures down the line, or customize an existing one!

# About

- Well… learning about data structures & algorithm analysis is a big part of computer science.

- You also need to know the inner-workings of these structures, so that when you're implementing solutions, you can choose the best structure for your particular problem – it isn't one size fits all!

- You might need to create your own data structures down the line, or customize an existing one!

- You'll be asked about them during job interviews. Interviewers love asking about data structures.

# About

So let's see how some of these structures work by utilizing the structures available in the Standard Template Library.

**In particular...**

- **STL Vector**
- **STL List**
- **STL Stack**
- **STL Queue**
- **STL Map**

# Topics

1. Vectors
2. Lists
3. Queues
4. Stacks
5. Maps

# 1. STL Vector

Vectors are a linear data structure, and they're implemented behind-the-scenes with a dynamic array. As a class, it has the functionality to handle certain things for us automatically, so we don't have to.

You can access specific items of the vector with the subscript operator, [ ]

```
cout << "Price: " << itemPrices[5] << endl;
```

**Notes**

Vectors are implemented with arrays, so you can access specific elements with the subscript operator [ ].

# 1. STL Vector

A perk of the vector object is that it handles resizing on its own.

Recall that with a static array, we had to know what its size was at compile time, and it couldn't be resized!

```
int sadArray[100];
for ( int i = 0; i < 100; i++ )
{
    sadArray[i] = i * 2;
}
cout << "sadArray is full and cannot store any more...";
```

**Notes**

Vectors are implemented with arrays, so you can access specific elements with the subscript operator [ ].

Vectors handle resizing its internal array automatically.

# 1. STL Vector

A perk of the vector object is that it handles resizing on its own.

Recall that with a static array, we had to know what its size was at compile time, and it couldn’t be resized!

And with a dynamic array, we had to manually deal with the memory management and “resizing” them took some work.

**Notes**

Vectors are implemented with arrays, so you can access specific elements with the subscript operator [ ].

Vectors handle resizing its internal array automatically.

# 1. STL Vector

Because the Vector is a class that “wraps” a dynamic array, when new items are added to the vector it will automatically check if its internal array is full and resize it for us so we don’t have to worry about it.

So here’s one example of how using a data structure makes a programmer’s life easier.

**Notes**

Vectors are implemented with arrays, so you can access specific elements with the subscript operator [ ].

Vectors handle resizing its internal array automatically.

# 1. STL Vector

To add items to a vector, we can use the **push_back** function and it will take care of the rest.

```
vector<float> itemPrices;

itemPrices.push_back( 9.99 );
itemPrices.push_back( 7.99 );
itemPrices.push_back( 6.99 );
```

Someone else has implemented the vector for us, so that we don't have to worry about *how* it works, it just does!

**Notes**

Vectors are implemented with arrays, so you can access specific elements with the subscript operator [ ].

Vectors handle resizing its internal array automatically.

push_back is the function used to insert items into the vector.

# 1. STL Vector

## A Vector can store any data-type...

```
vector<int> myNumbers;
myNumbers.push_back( 20 );

vector<string> studentNames;
studentNames.push_back( "Bob" );

vector<float> itemPrices;
itemPrices.push_back( 9.99 );
```

The <int>, <string>, and <float> bits of code are because vector has been implemented as a **template**.

If you haven't covered templates before, or don't quite remember how they work, don't worry – we will go over them more later on.

**Notes**

Vectors can contain *any* data-type.

# 1. STL Vector

## A Vector can store any data-type...

```
struct CoordPair
{
    float x, y;
};
```

```
vector<CoordPair> coordinatePairs;
```

If we write a **struct** or a **class**, a vector can even store those!

### Notes

Vectors can contain *any* data-type.

During declaration, the data-type the vector will store goes in < >.

# 1. STL Vector

## Some handy functions of a vector are…

- **push_back**
  Insert an item at the end of the vector
- **size**
  Returns the amount of items in the vector
- **empty**
  Returns whether the vector is empty or not (size == 0?)
- **operator[]**
  Access an item in the vector at any index
- **clear**
  Clears out all the elements of the vector.

### Notes

Functions:
*("T" refers to the data-type the vector stores)*

- `void push_back ( T& item )`
- `size_type size()`
- `bool empty()`
- `T& operator[] ( size_type n )`
- `void clear()`

# 1. STL Vector

Vectors are implemented with a **dynamic array**, which is why we can treat them *like* arrays.

By using a class to *wrap-around* a dynamic array, we can automatically have the structure handle resizing whenever space runs out, or when the user tries to use the subscript operator [ ].

## Notes

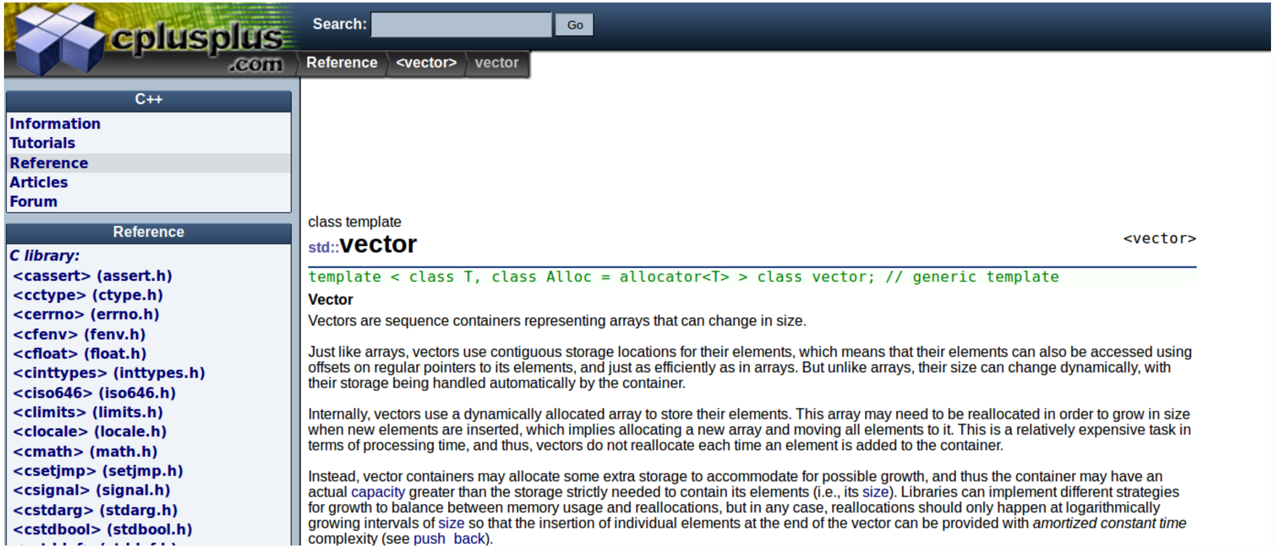
Functions:
*("T" refers to the data-type the vector stores)*

- `void push_back ( T& item )`
- `size_type size()`
- `bool empty()`
- `T& operator[] ( size_type n )`
- `void clear()`

# 1. STL Vector

**cplusplus.com** has useful reference pages on all the Standard Template Library structures that you can use to get more information on the vector and its functions.

http://www.cplusplus.com/reference/vector/vector/



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<clocale> (locale.h)
<cmath> (math.h)
<csetjmp> (setjmp.h)
<csignal> (signal.h)
<cstdarg> (stdarg.h)
<cstdbool> (stdbool.h)

class template

std::**vector** <vector>

```
template < class T, class Alloc = allocator<T> > class vector; // generic template
```

**Vector**

Vectors are sequence containers representing arrays that can change in size.

Just like arrays, vectors use contiguous storage locations for their elements, which means that their elements can also be accessed using offsets on regular pointers to its elements, and just as efficiently as in arrays. But unlike arrays, their size can change dynamically, with their storage being handled automatically by the container.

Internally, vectors use a dynamically allocated array to store their elements. This array may need to be reallocated in order to grow in size when new elements are inserted, which implies allocating a new array and moving all elements to it. This is a relatively expensive task in terms of processing time, and thus, vectors do not reallocate each time an element is added to the container.

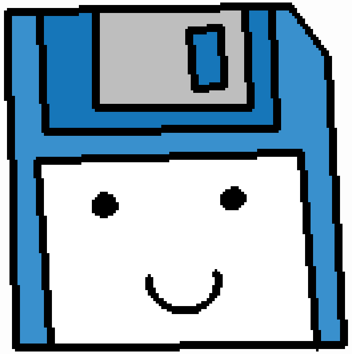
Instead, vector containers may allocate some extra storage to accommodate for possible growth, and thus the container may have an actual capacity greater than the storage strictly needed to contain its elements (i.e., its size). Libraries can implement different strategies for growth to balance between memory usage and reallocations, but in any case, reallocations should only happen at logarithmically growing intervals of size so that the insertion of individual elements at the end of the vector can be provided with *amortized constant time* complexity (see push_back).

## Notes

Functions:
*("T" refers to the data-type the vector stores)*

- `void push_back ( T& item )`
- `size_type size()`
- `bool empty()`
- `T& operator[] ( size_type n )`
- `void clear()`

Example Time!



# 1. STL Vector

Using a Static Array…

```
int myNumbers[3];
myNumbers[0] = 2;
myNumbers[1] = 3;
myNumbers[2] = 6;

for ( int i = 0; i < 3; i++ )
{
    cout << i << "\t" << myNumbers[i] << endl;
}
```

Declaring an int array

Assigning values to array

Displaying elements of the array

# 1. STL Vector

### Using a STL Vector…

```
vector<int> myNumbers2;
myNumbers2.push_back( 2 );
myNumbers2.push_back( 3 );
myNumbers2.push_back( 6 );

myNumbers2[0] = 1;

for ( unsigned int i = 0; i < myNumbers2.size(); i++ )
{
    cout << i << "\t" << myNumbers2[i] << endl;
}
```

Declaring an int vector

Assigning values to vector

Overwriting value at index 0

Displaying elements of the vector

The size() function returns an *unsigned int* value, which is essentially a non-negative integer. This is why my for loop uses an unsigned int for *i*.

# 2. STL *List*

Lists also store a linear series of data, but they're a little different from vectors.

For one, you cannot randomly access data with the subscript operator [ ].

Generally, to step through a list, you have to start at the beginning and keep stepping through, one at a time.

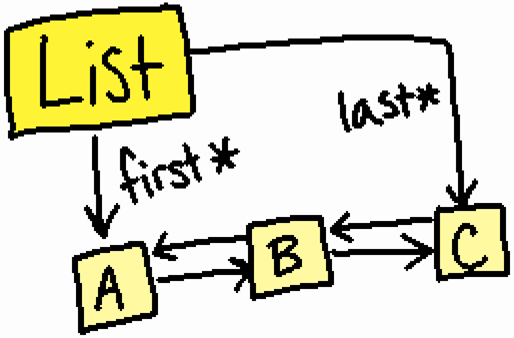
The STL List does contain a sort() function and reverse() function, though!

**Notes**

Lists are also a *linear* data type, but you cannot *randomly access* items in the list because of how it is implemented.

# 2. STL *List*

We cannot randomly access data in a List because it isn't implemented with an array, like vector is.




STL Lists use **pointers**. The list keeps track of what its starting element is, and each element points to the next element in the list.

Therefore, unlike an array, the elements are not in contiguous memory slots.

(This is why it's important to stay familiar with pointers for this class!)

**Notes**

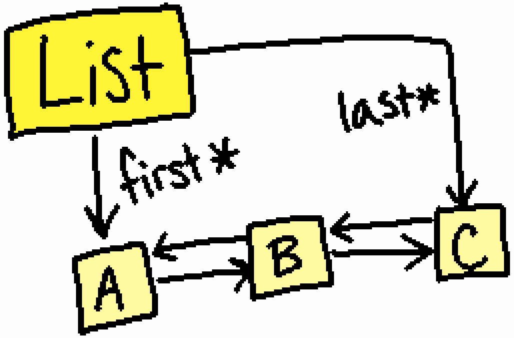
Lists are also a *linear* data type, but you cannot *randomly access* items in the list because of how it is implemented.

Lists are implemented with Nodes that contain pointers to the previous and next items in the list.

# 2. STL *List*

We will discuss the pointer and memory aspect of lists later on, once we're implementing linked lists.

For now…
onto the STL List functionality!




**Notes**

Lists are also a *linear* data type, but you cannot *randomly access* items in the list because of how it is implemented.

Lists are implemented with Nodes that contain pointers to the previous and next items in the list.

# 2. STL *List*

- **push_back**
  Insert an item at the end of the list
- **size**
  Returns the amount of items in the list
- **empty**
  Returns whether the list is empty or not (size == 0?)
- **clear**
  Clears out all the elements of the list.
- **sort**
  Sorts the elements of the list
- **reverse**
  Reverses the order of elements in the list.

## Notes

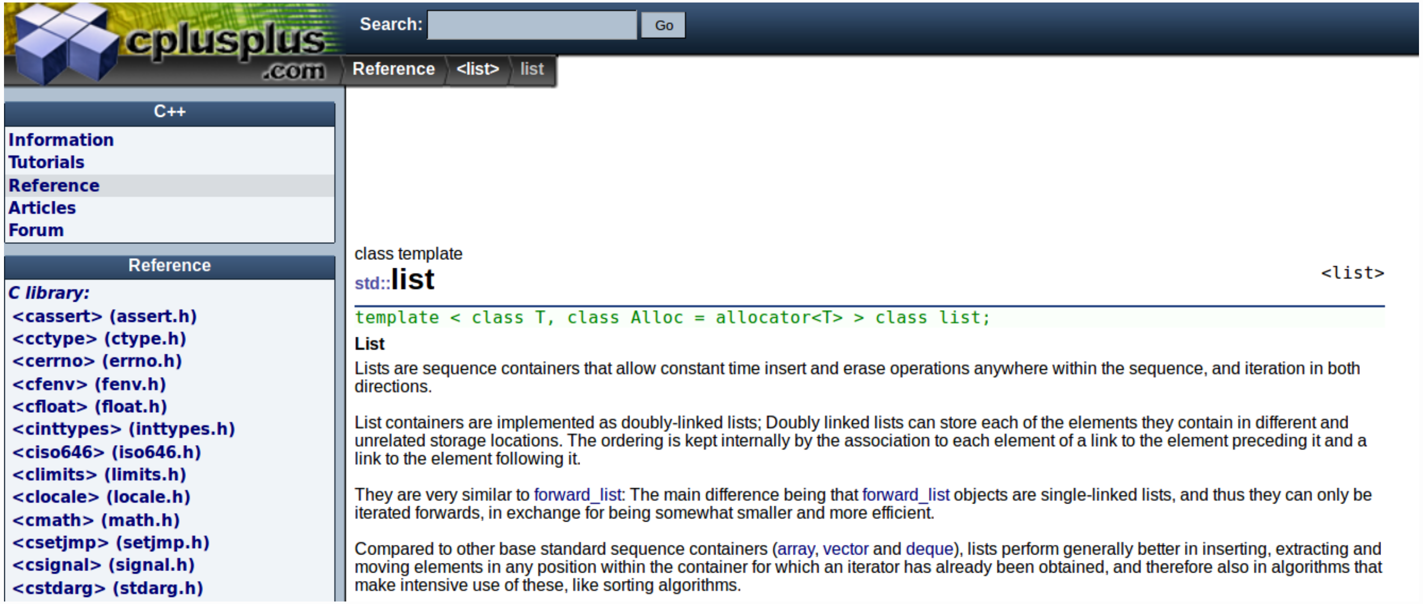
Functions:
*("T" refers to the data-type the list stores)*

- `void push_back ( T& item )`
- `size_type size()`
- `bool empty()`
- `void clear()`
- `void sort()`
- `void reverse()`

# 2. STL List

Access documentation about the STL List at **cplusplus.com:**

http://www.cplusplus.com/reference/list/list/



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<cstdarg> (stdarg.h)

class template
std::**list**

<list>

```
template < class T, class Alloc = allocator<T> > class list;
```

**List**

Lists are sequence containers that allow constant time insert and erase operations anywhere within the sequence, and iteration in both directions.

List containers are implemented as doubly-linked lists; Doubly linked lists can store each of the elements they contain in different and unrelated storage locations. The ordering is kept internally by the association to each element of a link to the element preceding it and a link to the element following it.

They are very similar to forward_list: The main difference being that forward_list objects are single-linked lists, and thus they can only be iterated forwards, in exchange for being somewhat smaller and more efficient.

Compared to other base standard sequence containers (array, vector and deque), lists perform generally better in inserting, extracting and moving elements in any position within the container for which an iterator has already been obtained, and therefore also in algorithms that make intensive use of these, like sorting algorithms.

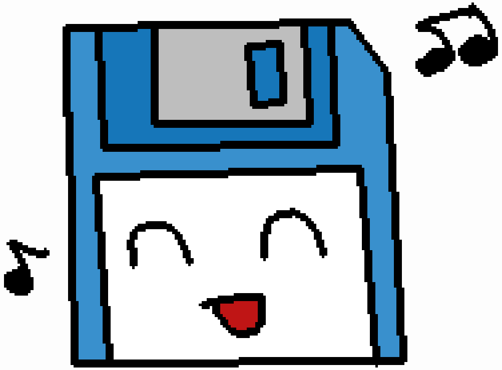
## Notes

Functions:
*("T" refers to the data-type the list stores)*

- `void push_back ( T& item )`
- `size_type size()`
- `bool empty()`
- `void clear()`
- `void sort()`
- `void reverse()`

# 2. STL List

Example Time!



# 2. STL *List*

Using a STL List...

```
list<string> states;

states.push_back( "Maine" );
states.push_back( "Hawaii" );
states.push_back( "Kansas" );
states.push_back( "Missouri" );
states.push_back( "Washington" );
states.push_back( "Alaska" );

states.sort();
states.reverse();

for ( list<string>::iterator it = states.begin();
        it != states.end(); it++ )
{
    cout << *it << endl;
}
```

Declaring a list of strings

Adding strings to the list

Sort the list

Reverse the list

Use iterators to display the contents of the list

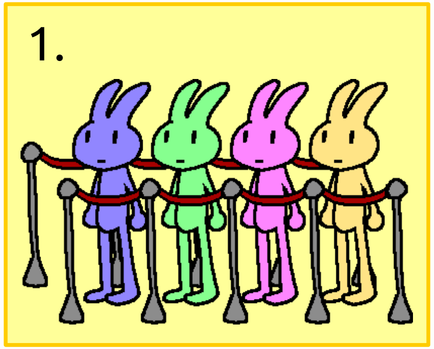
To iterate through the STL List, we must use an iterator. You probably haven't seen one of these before, but it's a topic for another time.

# 3. STL Queue

A queue is a type of **restricted-access** data structure.

It stores its contents in a linear order, but you're only able to **remove items at the front of the queue**, and to **add new items to the back of the queue.**

A queue is known as a **First In, First Out (FIFO)** structure.



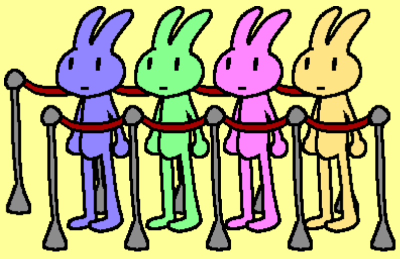

**Notes**

Queues are first-in-first-out.

# 3. STL Queue

The first item that enters the queue, who sits at the front of the line, is the first one to get removed, just like in a grocery-store line.

1.



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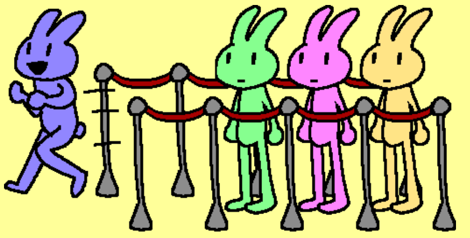
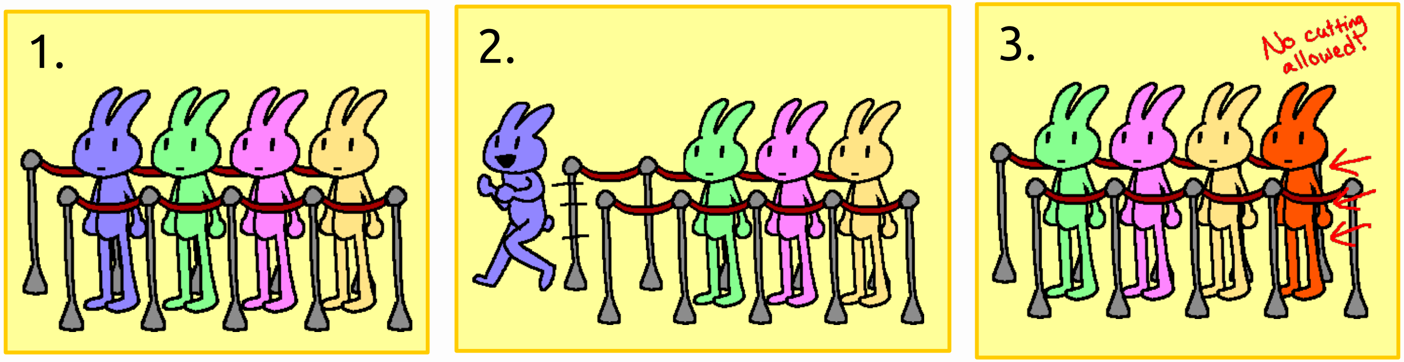


**Notes**

Queues are first-in-first-out.

# 3. STL Queue

And when a new item is added to the queue, it enters at the end (or back) of the queue.




**Notes**

Queues are first-in-first-out.

# 3. STL Queue

## Some handy queue functions are…

- **push**
  Pushes an item to the <u>back</u> of the queue.

- **pop**
  Removes an item from the <u>front</u> of the queue.

- **front**
  Returns the item that is at the <u>front</u> of the queue.

- **size**
  Returns the amount of items in the queue.

- **empty**
  Returns whether the queue is empty or not.

### Notes

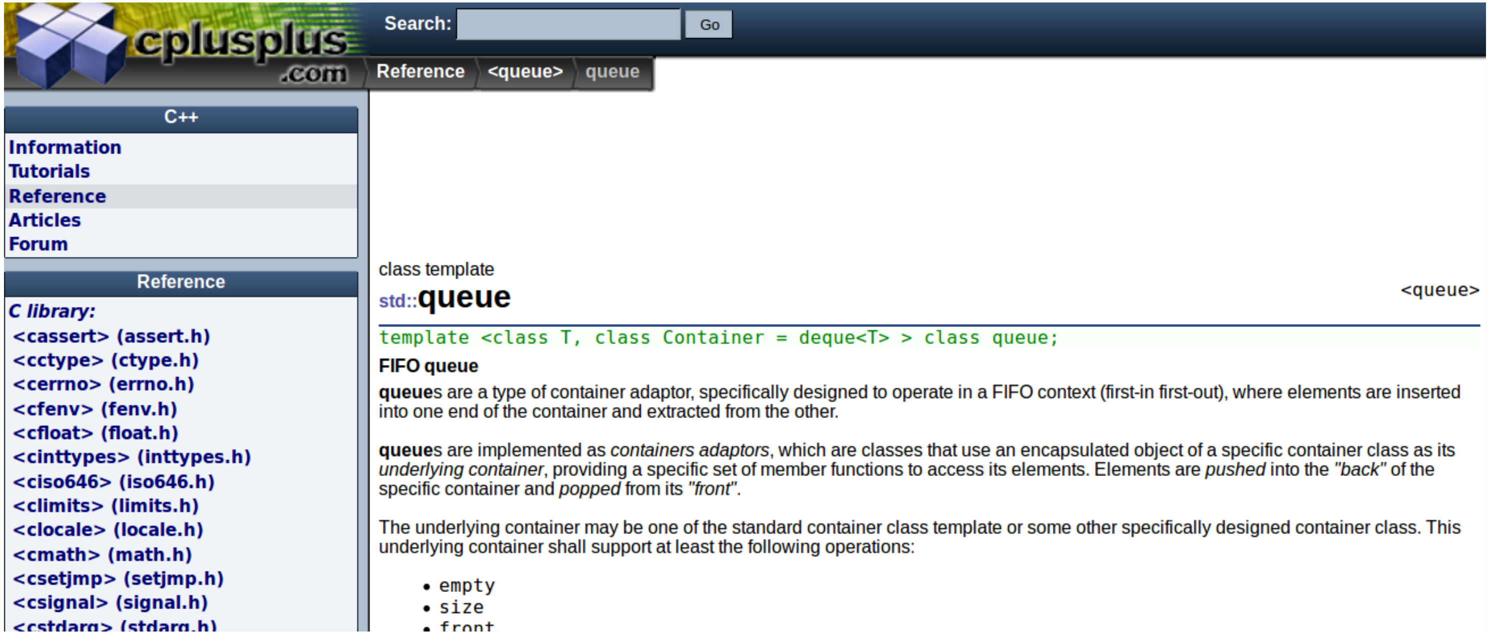
Functions:
*("T" refers to the data-type the queue stores)*

- `void push( T& item )`
- `void pop()`
- `T& front()`
- `size_type size()`
- `bool empty()`

# 3. STL Queue

Access documentation about the STL Queue at **cplusplus.com:**

http://www.cplusplus.com/reference/queue/queue/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<clocale> (locale.h)
<cmath> (math.h)
<csetjmp> (setjmp.h)
<csignal> (signal.h)
<cstdarg> (stdarg.h)

class template

std::**queue**

<queue>

```
template <class T, class Container = deque<T> > class queue;
```

**FIFO queue**

**queue**s are a type of container adaptor, specifically designed to operate in a FIFO context (first-in first-out), where elements are inserted into one end of the container and extracted from the other.

**queue**s are implemented as *containers adaptors*, which are classes that use an encapsulated object of a specific container class as its *underlying container*, providing a specific set of member functions to access its elements. Elements are *pushed* into the *"back"* of the specific container and *popped* from its *"front"*.

The underlying container may be one of the standard container class template or some other specifically designed container class. This underlying container shall support at least the following operations:

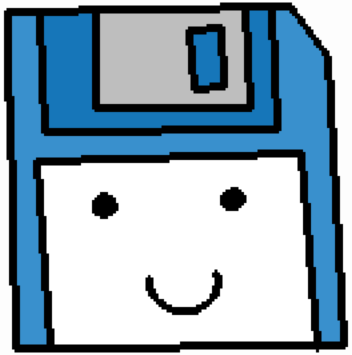
- empty
- size
- front

## Notes

Functions:
*("T" refers to the data-type the queue stores)*

- `void push( T& item )`
- `void pop()`
- `T& front()`
- `size_type size()`
- `bool empty()`

Example Time!



# 3. STL Queue

Using a STL Queue…

```
queue<string> commands;

commands.push( "mkdir newFolder" );
commands.push( "touch newFile" );
commands.push( "ping google.com -c 5" );
commands.push( "ping yahoo.com -c 3" );

while ( !commands.empty() )
{
    string command = commands.front();

    cout << endl << command << endl;

    system( command.c_str() );

    commands.pop();
}
```

Declaring a queue of strings

Pushing strings into the queue

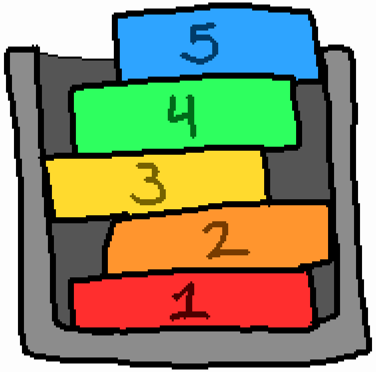
Checking if the queue is empty

Accessing the front-most item

Removing the front-most item

# 4. STL Stack

A Stack is a type of data structure that is linear, like a list or vector is, but it also restricts access to the internal data.



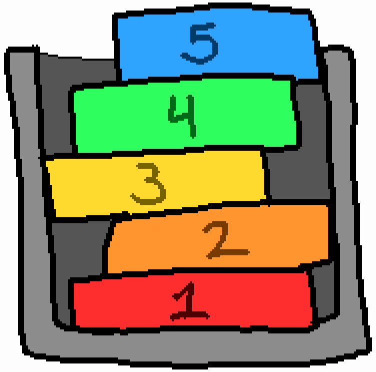

The main characteristic of a stack is that it is a First In Last Out (or) Last In First Out structure.

**Notes**

Stacks are a restricted-access data type that is Last-In-First-Out

# 4. STL Stack

At any time, you're only able to access one item from the stack – the top-most item.



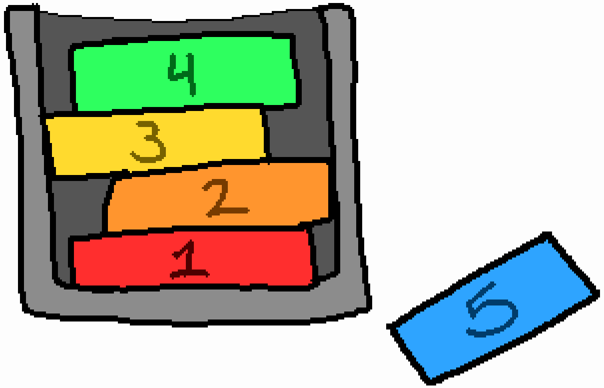

And, as items are pushed onto the stack, the older items are on the bottom, and the newer items are on the top.

**Notes**

Stacks are a restricted-access data type that is Last-In-First-Out

# 4. STL Stack

As you remove items from the stack, you pull the newest item that was added to the stack.



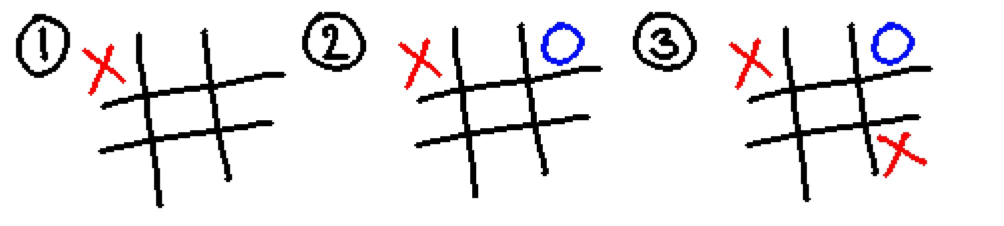

The first item on the stack is the last one to be removed.

**Notes**

Stacks are a restricted-access data type that is Last-In-First-Out

# 4. STL Stack

One example of using a Stack is to keep track of moves in a game of tic-tac-toe.

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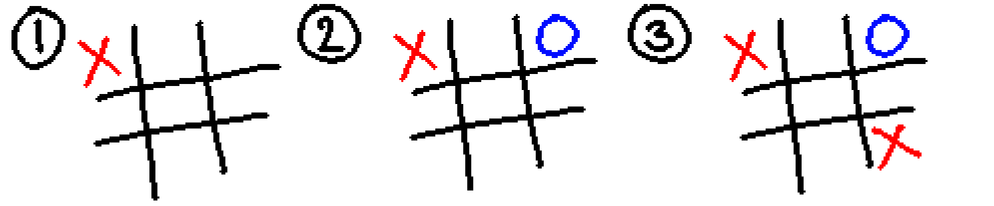
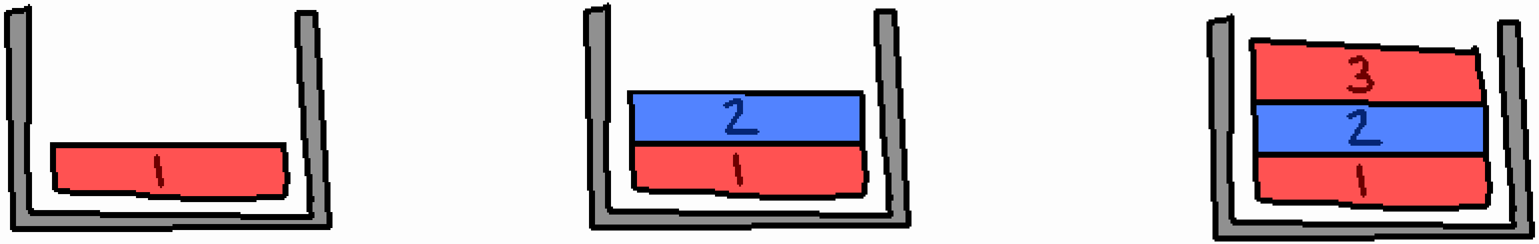



Every time a move is made, we could push the game board's current state onto a stack…

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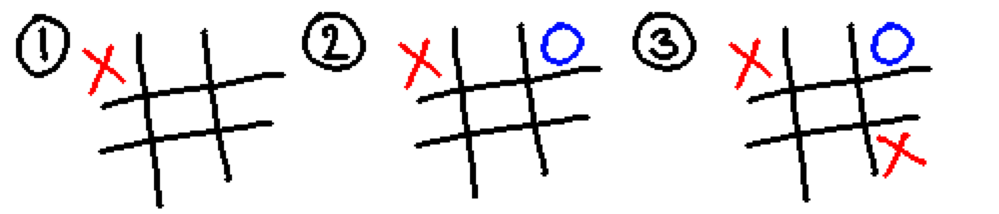
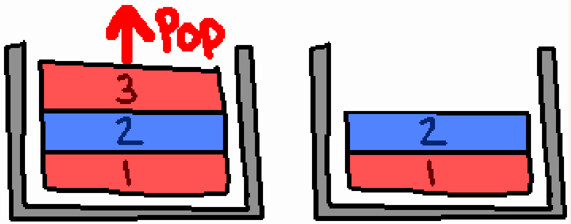



Then if we want to undo a turn, we can pop the most recent state off the stack...

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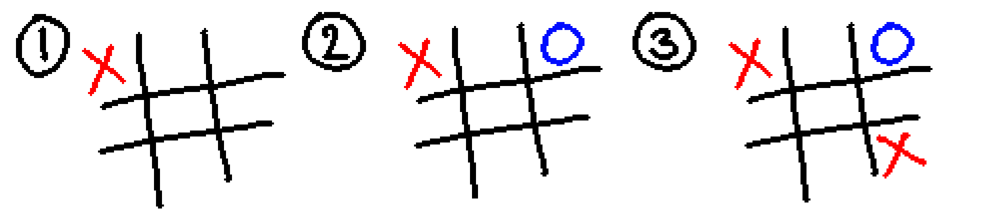
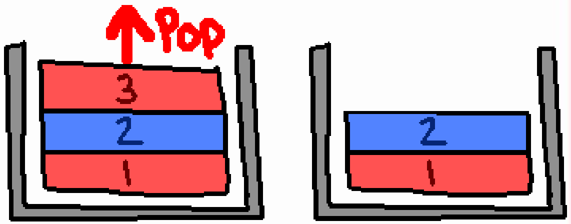
# 4. STL Stack

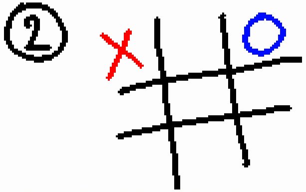
One example of using a Stack is to keep track of moves in a game of tic-tac-toe.




Then if we want to undo a turn, we can pop the most recent state off the stack…




And the game board reverts to the state before.




**Notes**

Stacks are a restricted-access data type that is Last-In-First-Out

# 4. STL Stack

## Some handy stack functions are…

- **push**
  Pushes an item to the top of the stack.
- **pop**
  Removes an item from the top of the stack.
- **top**
  Returns the item that is at the top of the stack.
- **size**
  Returns the amount of items in the stack.
- **empty**
  Returns whether the stack is empty or not.

### Notes

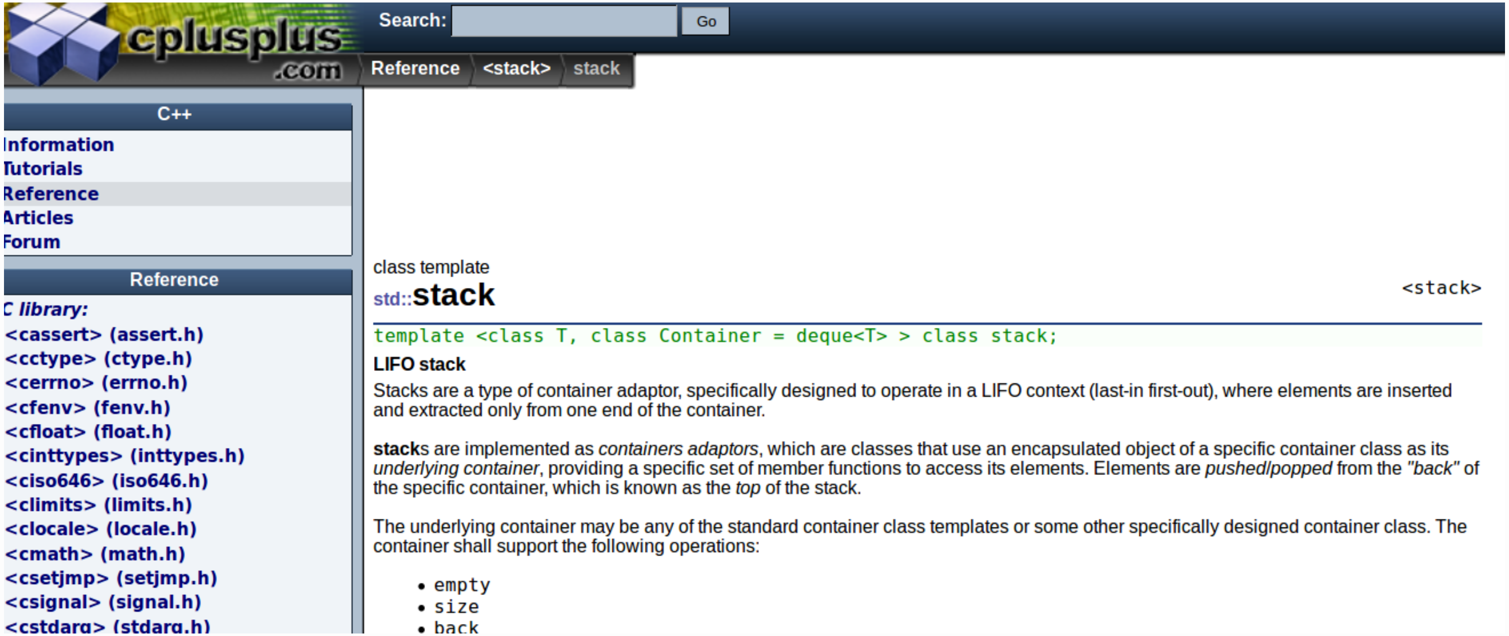
Functions:
*("T" refers to the data-type the stack stores)*

- `void push( T& item )`
- `void pop()`
- `T& top()`
- `size_type size()`
- `bool empty()`

# 4. STL Stack

Access documentation about the STL Stack at **cplusplus.com:**

http://www.cplusplus.com/reference/stack/stack/



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<csetjmp> (setjmp.h)
<csignal> (signal.h)
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class template

std::**stack**

<stack>

```
template <class T, class Container = deque<T> > class stack;
```

**LIFO stack**

Stacks are a type of container adaptor, specifically designed to operate in a LIFO context (last-in first-out), where elements are inserted and extracted only from one end of the container.

**stack**s are implemented as *containers adaptors*, which are classes that use an encapsulated object of a specific container class as its *underlying container*, providing a specific set of member functions to access its elements. Elements are *pushed/popped* from the *"back"* of the specific container, which is known as the *top* of the stack.

The underlying container may be any of the standard container class templates or some other specifically designed container class. The container shall support the following operations:

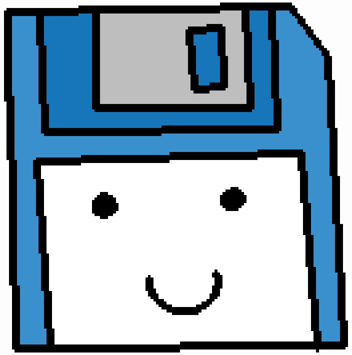
- `empty`
- `size`
- `back`

## Notes

Functions:
*("T" refers to the data-type the stack stores)*

- `void push( T& item )`
- `void pop()`
- `T& top()`
- `size_type size()`
- `bool empty()`

Example Time!



# 4. STL Stack

## Using a STL Stack...

```
cin >> text;

stack<char> letters;

for ( unsigned int i = 0; i < text.size(); i++ )
{
    cout << "Letter " << i << " = " << text[i] << endl;
    letters.push( text[i] );
}

cout << endl << "Pop off stack: " << endl;

while ( !letters.empty() )
{
    cout << letters.top();
    letters.pop();
}
```

Declaring a stack of characters

Pushing characters onto the stack

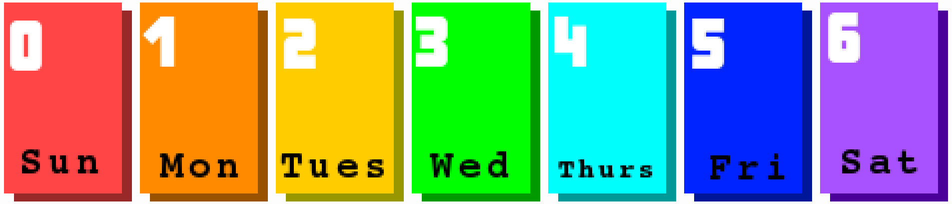
Checking if the stack is empty

Accessing the top-most item

Removing the top-most item

# 5. STL Map

When we're using a plain-old array, we have a series of elements in order, starting at 0, going until (size – 1).




**7 items in the array**
**=**
**Index 0 through 6 is valid**

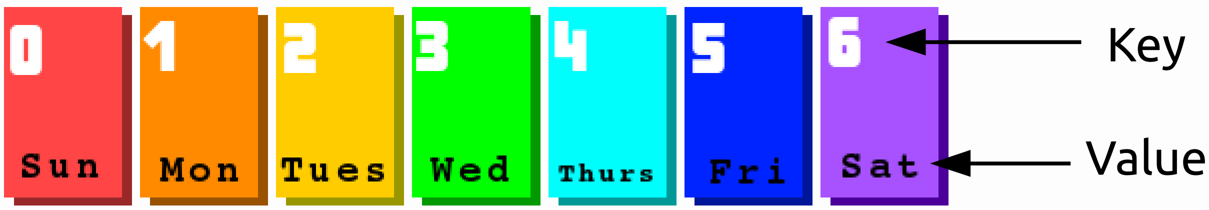
**Notes**

A map is also known as a dictionary or hash table.

A map contains key-value pairs.

# 5. STL Map

A value of 0, 1, 2, 3, 4, 5, or 6, which specifies an element's position, is known as an index, but we can also think of it like a "key",
which helps us locate the value we want




**Notes**

A map is also known as a dictionary or hash table.

A map contains key-value pairs.

# 5. STL Map

But with a data structure like a map, our keys don’t have to just be integers, and they don’t have to be array indices.

The **key** can be **any data type**, and it can point to a **value** of any data type as well.

**Notes**

A map is also known as a dictionary or hash table.

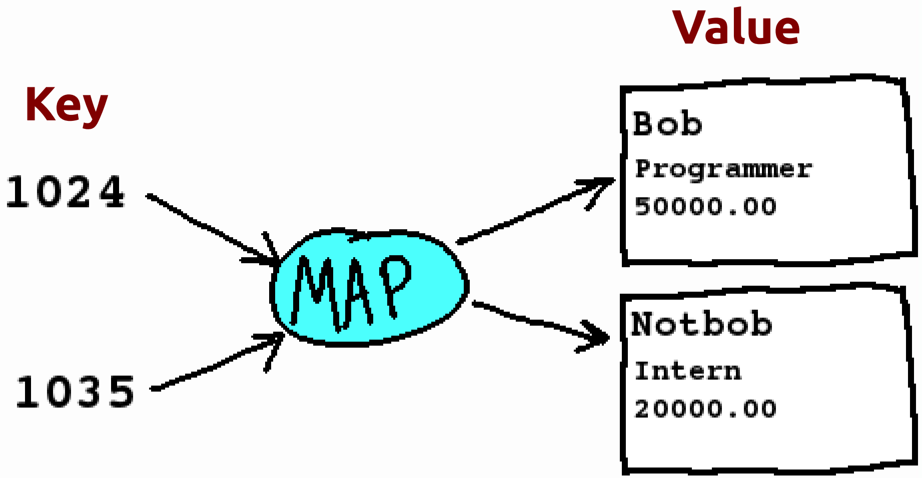
A map contains key-value pairs.

# 5. STL Map

For example, think of an employee ID, that points to an employee object in a program…

```
class Employee
{
    public:
    // ...

    private:
    string name;
    string jobTitle;
    float salary;
};
```




### Notes

A map is also known as a dictionary or hash table.

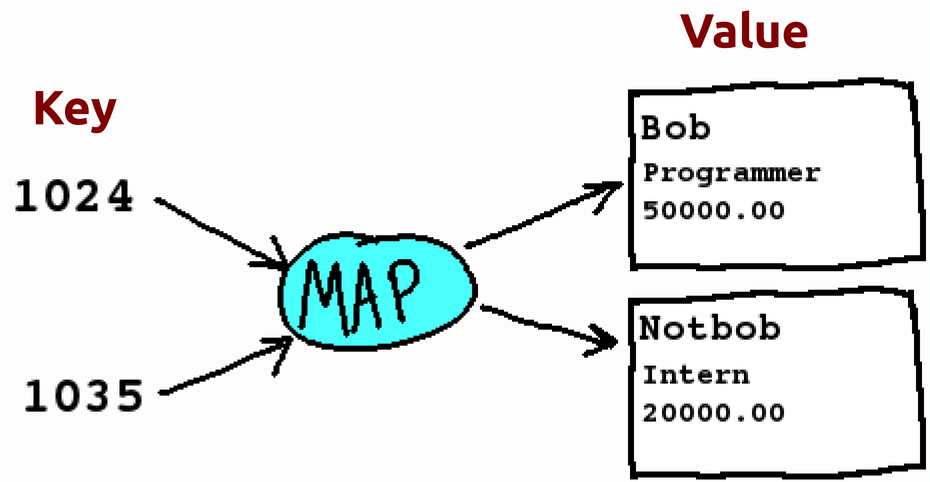
A map contains key-value pairs.

# 5. STL Map

Maps are built in a special way so that we can access elements by key, and it will access it quickly – search algorithm not required.

```
class Employee
{
    public:
    // ...

    private:
    string name;
    string jobTitle;
    float salary;
};
```




## Notes

A map is also known as a dictionary or hash table.

A map contains key-value pairs.

# 5. STL Map

## Some handy map functions are…

- **operator[]**
  Access an element of the map, using a key

- **empty**
  Returns whether the map is empty or not

- **size**
  Get the amount of elements in the map

### Notes

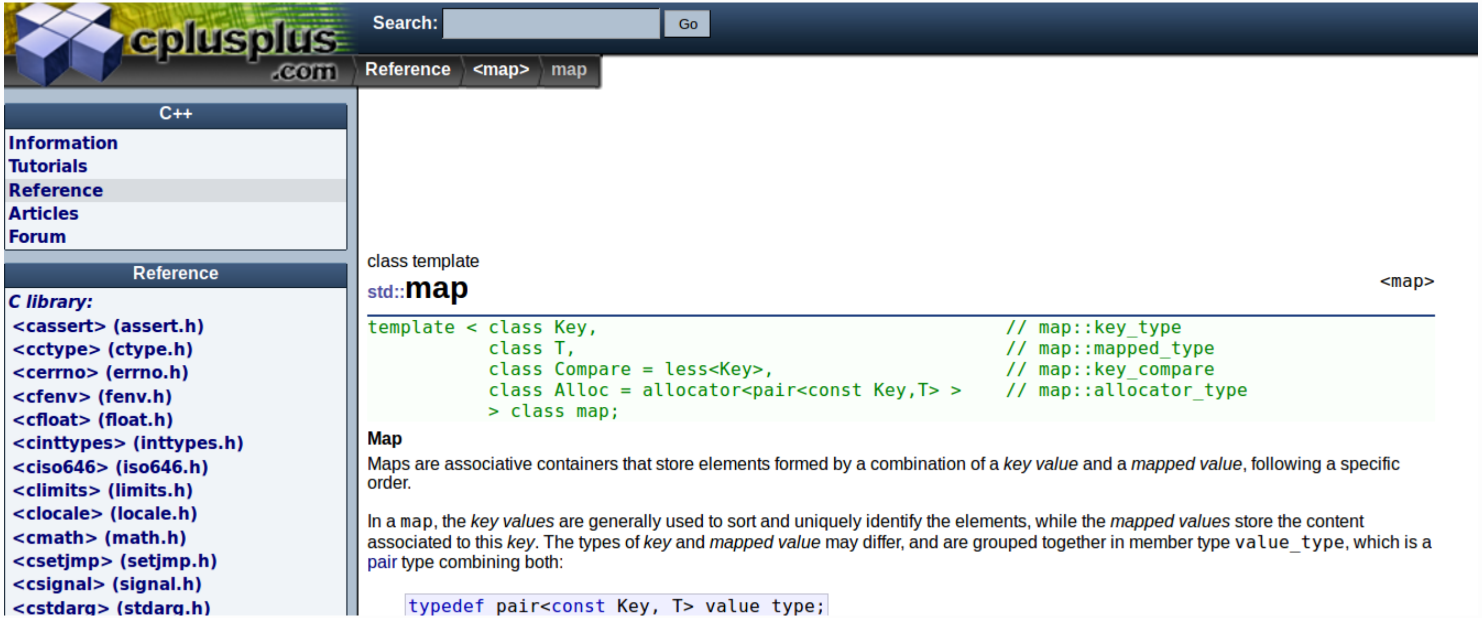
Functions:
*("T1" and "T2" refer to the key and value data-types)*

- `T2& operator[] ( const T1& key )`
- `size_type size()`
- `bool empty()`

# 5. STL Map

Access documentation about the STL Map at **cplusplus.com:**

http://www.cplusplus.com/reference/map/map/



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<cmath> (math.h)
<csetjmp> (setjmp.h)
<csignal> (signal.h)
<cstdarg> (stdarg.h)

class template
std::**map** <map>

```
template < class Key,                                     // map::key_type
           class T,                                       // map::mapped_type
           class Compare = less<Key>,                     // map::key_compare
           class Alloc = allocator<pair<const Key,T> >    // map::allocator_type
           > class map;
```

**Map**

Maps are associative containers that store elements formed by a combination of a *key value* and a *mapped value*, following a specific order.

In a `map`, the *key values* are generally used to sort and uniquely identify the elements, while the *mapped values* store the content associated to this *key*. The types of *key* and *mapped value* may differ, and are grouped together in member type `value_type`, which is a pair type combining both:

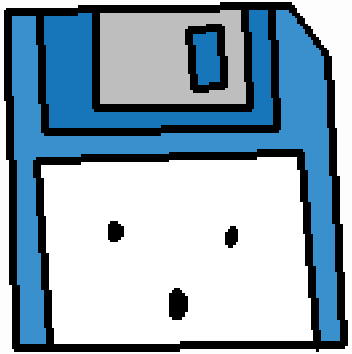
```
typedef pair<const Key, T> value_type;
```

## Notes

Functions:
*("T1" and "T2" refer to the key and value data-types)*

- `T2& operator[] ( const T1& key )`
- `size_type size()`
- `bool empty()`

# Example Time!



# 5. STL Map

Using a STL Map…

```
map<string, int> employees;
employees["Harry"] = 1024;
employees["Ron"] = 256;
employees["Hermione"] = 512;

string key;
cout << "Enter an employee name: ";
cin >> key;

cout << "That employee ID is "
     << employees[ key ] << endl;
```

Declare a map, with string keys and int values

Adding key-value pairs

Accessing a value, given some key

# Conclusion

We will eventually implement each of these structures ourselves to learn how these work, but sometimes it can be handy to view new concepts from the outside→in to begin with.

Data structures are all about writing structures (i.e., classes) to store data. Structures need a way to add data, access data, and remove data. We will be writing lots of add, access, and remove functions this semester!