CPP-STL-beginners-guide

This is my first attempt at writing a tutorial on the C++ STL. I created this with love ❤️, however as a beginner, there may be some inaccuracies. I welcome any feedback to improve it!

The C++ Standard Template Library (STL) is a powerful set of containers, algorithms, and iterators. This repository aims to provide a gentle introduction to the key components of the STL for C++ beginners, with hands-on examples and explanations. We'll cover vectors, pairs, queues, stacks, and more. While not comprehensive, it serves as a starting point to leverage templates and generic programming in your C++ projects.

The tutorials cover:

- Vectors
- Pairs
- Queues
- Stacks
- Deques
- Iterators
- Structs

With easy-to-follow examples and explanations, this repo serves as a hands-on guide to start learning the powerful STL in C++. Ideal for students and developers looking to leverage templates and generic programming in their projects.

C++ STL (Standard Template Library)

The C++ STL is a collection of template classes and functions that provide a set of generic and efficient algorithms, containers, and iterators widely used in C++ programming.

Components of STL

STL has four major components:

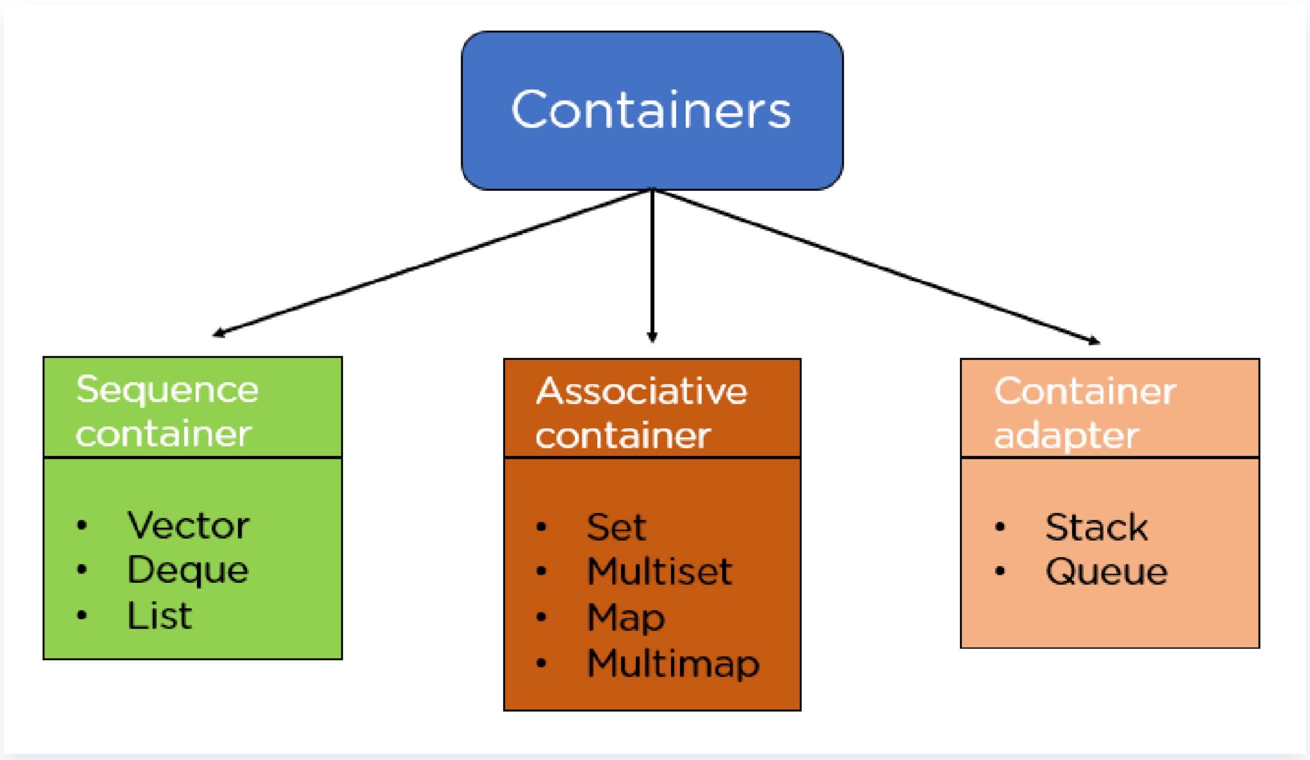
- Containers
- Iterators
- Algorithms
- Function objects

So, start with containers.

Containers

If you are dealing with many elements, then you need to use some sort of container. The container can be described as objects that are used to store the collection of data. It helps in recreating and implementing complex data structures efficiently.

Now, containers are further classified into three categories:



STL Containers

Sequence Containers

Sequence containers implement data structures that can be accessed in a sequential manner. The following sequence containers are available:

- vector
- list
- deque

Container Adaptors

Container adaptors provide a different interface for sequential containers. The following container adaptors are available:

- queue
- priority_queue
- stack

Associative Containers

Associative containers implement sorted data structures that can be quickly searched with O(log n) complexity. The following associative containers are available:

- set
- multiset
- map
- multimap

Unordered Associative Containers

Unordered associative containers implement unordered data structures that can be quickly searched. The following unordered associative containers are available (Introduced in C++11):

- unordered_set
- unordered_multiset
- unordered_map
- unordered_multimap

This tutorial covers the following topics:

The Linear Container STL includes various data structures that store elements in a linear manner. Some commonly used linear containers are:

- **Vector**: A dynamic array that can resize itself.
- **Queue**: A container that follows the First-In-First-Out (FIFO) principle.
- **Deque**: A double-ended queue that allows insertion and deletion at both ends.
- **Stack**: A container that follows the Last-In-First-Out (LIFO) principle.
- **Pair**: A simple container that holds two values togethe, can be used with other STL components.
- **Struct**: A user-defined data type that can hold multiple values. Not an STL container.

Vector :

In C++, vectors are **dynamically-sized arrays**. They offer a convenient and efficient way to store collections of elements of the same type. Imagine a flexible container that automatically adjusts its size as you add or remove elements, that's essentially what a vector is.

Declaring: There are several ways to declare a vector:

```
vector<int> v = {1, 2, 3}; // initializer list
vector<int> vect1{10, 20, 30}; // brace initialization
vector<int> v; // empty vector
vector<int> vect(n, 10); // size n, all values 10
vector<int> vect(10); // size 10
```

You can also create a vector of vectors:

```
vector<vector<data_type>> vec;
v2 = {1, 2, 3};
vec.push_back(v2);
// This creates a vector containing a single vector with the elements 1, 2, and 3.

// To create a 5x5 matrix with all elements set to 0, you can use:
vector<vector<int>> v(5, vector<int>(5, 0));
```

Accessing elements

1. Using the `at()` method:

```
vector<int> num {1, 2, 3, 4, 5};
cout << "Element at Index 0: " << num.at(0) << endl;
```

2. Using the `[]` operator:

```
cout << num[1];
```

The `at()` method is preferred over the `[]` operator because it throws an exception if you try to access an element that is out of bounds. The `[]` operator, on the other hand, will simply give you a garbage value.

```
vector<int> num {1, 2, 3};

// gives garbage value
cout << num[4];

// throws an exception
cout << num.at(4);
```

- **front()**: Returns the first element of the vector.

```
vector<int> v = {1, 2, 3};
int first_element = v.front(); // first_element = 1
```

- **back()**: Returns the last element of the vector.

```
vector<string> v = {"apple", "banana"};
string last_element = v.back(); // last_element = "banana"
```

Note: `front()` and `back()` throw an exception if the vector is empty.

Auto keyword

The `auto` keyword in C++ automatically detects and assigns a data type to the variable with which it is used. This can be helpful for making your code more concise and readable.

Here are some examples of how to use the `auto` keyword:

```
auto IntegerVar = 25;    // creates integer type variable
auto FloatVar = 26.77;  // creates float type variable
auto StringVar = "Hello";  // creates string type variable
auto CharVar = "C";    // creates char type variable
```

You can also use `auto` with references:

```
auto number1 = 10;

auto& number2 = number1; // number2 is a reference to number1
number2 = 20; // Modifies the original value of number1
```

Foreach loop

The `for` loop is a powerful tool in C++ for iterating over a sequence of elements. However, it can be a bit verbose. The `foreach` loop is a more concise way to iterate over a vector:

```
for (data_type variable_name : container_name) {
  // operations using variable_name
}
```

Here's an example of how to use the `foreach` loop to iterate over a vector of numbers:

```
vector<int> numbers = {1, 2, 3, 4, 5};

// Example 1 - modifies original vector
for (auto& num : numbers) {
  num *= 2;
}

// Example 2 - doesn't modify original vector
for (auto num : numbers) {
  // do something with num
}
```

The `foreach` loop is a great way to make your code more concise and readable. It's especially useful for working with vectors.

Iterators

C++ Vector Iterators : Vector iterators are powerful tools for accessing and manipulating elements within a vector. They act like pointers, but with additional functionalities specific to vector operations.

Declaring Iterators

The syntax for declaring a vector iterator is:

```
vector<T>::iterator iteratorName;
```

Here, `T` represents the type of elements stored in the vector.

Example:

```
// Iterator for an int vector
vector<int>::iterator iter1;

// Iterator for a double vector
vector<double>::iterator iter2;
```

Initializing Iterators

There are two main ways to initialize vector iterators:

1. Using `begin()` and `end()`:

- `begin()`: Returns an iterator pointing to the first element.
- `end()`: Points to the theoretical element after the last element.

Example:

```
vector<int> num = {1, 2, 3};
vector<int>::iterator iter;

// iter points to num[0]
iter = num.begin();
cout << "num[0] = " << *iter << endl;

// iter points to num[2]
iter = num.end() - 1;
```

2. Using Reverse Iterators:

- `rbegin()`: Returns a reverse iterator pointing to the last element.
- `rend()`: Points to the theoretical element before the first element.

Example:

```
vector<int> num = {1, 2, 3};
auto iter = num.rbegin(); // iter points to num[2]

iter++; // iter points to num[1]
iter++; // iter points to num[0]

// Loop through the vector in reverse order
for (auto i = num.rbegin(); i != num.rend(); ++i) {
  cout << *i << " "; // prints 3 2 1
}
```

Looping through Vectors with Iterators

Iterators are commonly used in `for` loops to iterate through each element in a vector.

Example:

```cpp
vector<int> v = {1, 2, 3, 4, 5};

// Forward loop
for (auto i = v.begin(); i != v.end(); ++i) {
  cout << *i << " "; // prints 1 2 3 4 5
}

// Reverse loop
for (auto ir = v.rbegin(); ir != v.rend(); ++ir) {
  cout << *ir << " "; // prints 5 4 3 2 1
}
```

Using iterators provides more control and flexibility compared to traditional indexing. They offer functionalities like element insertion, deletion, and distance calculation, making them essential tools for working with vectors in C++.

Vector Functions

This section explores some essential functions used to manipulate elements within a vector

Adding Elements:

- **push_back()**: This function adds new elements to the **back** of the vector. This is the most common way to add elements as it maintains the original order and is efficient for large datasets.

```cpp
vector<int> v = {1, 2, 3};
v.push_back(4);
v.push_back(5);
// v now contains: 1, 2, 3, 4, 5
```

- **emplace_back()**: This function **constructs and adds** a new element to the back of the vector. It avoids unnecessary copies compared to `push_back()` and can be more efficient for large objects.

```cpp
vector<string> v = {"apple", "banana"};
v.emplace_back("orange");
// v now contains: "apple", "banana", "orange"
```

Let's break down the differences between `insert`, `push_back`, and `emplace_back` functions in a beginner-friendly way.

`push_back`:

- Usage:

  ```cpp
  vector<int> numbers = {1, 2, 3};
  numbers.push_back(4);
  ```

- **Explanation:** You use `push_back` when you want to add an element to the back (end) of the vector. It's like adding a new item to the end of a line.

`emplace_back`:

- Usage:

```
vector<string> names = {"Alice", "Bob"};
names.emplace_back("Charlie");
```

- **Explanation:** `emplace_back` is similar to `push_back`, but it directly constructs the element in place. It's like welcoming a new person into a group by constructing them right there instead of preparing them separately and then adding.

`insert`:

- **Purpose:** Inserts elements at a specified position in the vector.
- Usage:

```
vector<int> numbers = {1, 2, 3};
auto it = numbers.begin() + 1;
numbers.insert(it, 4);
```

- **Explanation:** `insert` is like adding elements at a specific point in the vector. It's like squeezing a new person into a group but not necessarily at the end – you decide where they fit.

Inserting books (Example):

- **Push:** This is like adding a book to the **end** of a specific section. It's quick and easy, like adding a new book to the "Science" section at the end of the other science books.
- **Emplace:** This is like building a book directly on the shelf. It's more efficient for large or complex books, like building a custom scrapbook directly on the shelf instead of bringing it from another location.

In summary, `push_back` is for adding to the end, `emplace_back` is for constructing and adding to the end.

- **insert(position, value)**: This function inserts a new element at a specified **position** within the vector. The existing elements at and after the position are shifted to make room for the new element.

```
vector<int> v = {1, 2, 3};
v.insert(v.begin() + 1, 10); // Insert 10 at index 1
// v now contains: 1, 10, 2, 3
```

- **insert(position, n, value)**: This function inserts **n copies** of a specific value at a specified position.

```
vector<char> v = {'a', 'b', 'c'};
v.insert(v.begin() + 1, 2, 'x'); // Insert 2 'x' at index 1
// v now contains: 'a', 'x', 'x', 'b', 'c'
```

- **insert(position, begin, end)**: This function inserts a **range of elements** from another container (begin and end iterators) at a specified position.

```
vector<int> v1 = {1, 2, 3};
vector<int> v2 = {4, 5, 6};
v1.insert(v1.begin() + 2, v2.begin(), v2.end());
// v1 now contains: 1, 2, 4, 5, 6, 3
```

Removing Elements:

- **pop_back()**: This function removes the element from the **back** of the vector. This is efficient for large datasets as it doesn't need to shift elements.

```
vector<string> v = {"apple", "banana", "orange"};
v.pop_back();
// v now contains: "apple", "banana"
```

- **erase(position)**: This function removes the element at a specified **position** from the vector. The remaining elements are shifted down to fill the gap.

```
vector<int> v = {1, 2, 3, 4};
v.erase(v.begin() + 2); // Erase element at index 2
// v now contains: 1, 2, 4

vector<string> fruits = {"apple", "banana", "orange"};
fruits.erase(fruits.end() - 1); // Remove the last element ("orange")

// Fruits now contains: {"apple", "banana"}
```

- **erase(begin, end)**: This function removes a **range of elements** from a specified position (begin and end iterators) within the vector.

```
vector<char> v = {'a', 'b', 'c', 'd', 'e'};
v.erase(v.begin() + 1, v.begin() + 3); // Erase elements from index 1 to 2
(exclusive)
// v now contains: 'a', 'd', 'e'
```

Complexity of `erase`

The time complexity of `erase` depends on the operation:

- **Single element:** O(n), where n is the number of elements after the erased element. This is because remaining elements need to be shifted to fill the gap.
- **Range of elements:** O(n + m), where n is the number of elements after the erased range and m is the number of erased elements.
- **Erasing the last element:** O(1), as no shifting is necessary.

Other Operations:

- **swap()**: This function exchanges the contents of two vectors of the same type. This is useful when swapping large datasets as it avoids copying elements.

```
vector<int> v1 = {1, 2, 3};
vector<int> v2 = {4, 5, 6};
v1.swap(v2);
```

Vector Operations: Size, Capacity, and More

This section explores additional functions for managing vector size and accessing elements.

Size and Capacity:

- **size()**: Returns the number of elements currently present in the vector.

```
vector<int> v = {1, 2, 3};
int size = v.size(); // size = 3
```

- **capacity()**: Returns the size of the memory currently allocated to the vector. This may be larger than the actual number of elements.
    - allocated : مخصص

```
vector<int> v;
v.push_back(1); // capacity might be increased
size_t capacity = v.capacity(); // capacity might be > 1
```

Resizing and Shrinking:

- **resize(n)**: Changes the size of the vector to n. If n is smaller than the current size, elements are removed. If it's larger, new elements are added with their default values.

```
vector<int> v = {1, 2, 3};
v.resize(5); // v becomes {1, 2, 3, 0, 0}
```

- **resize(n, value)**: Similar to `resize(n)`, but assigns the specified value to all new elements added.

```
vector<string> v = {"apple", "banana"};
v.resize(5, "orange"); // v becomes {"apple", "banana", "orange", "orange",
"orange"}
```

- **shrink_to_fit()**: Reduces the capacity of the vector to match its size.

```
vector<int> v(100); // allocated space for 100 elements
v.push_back(1); // only 1 element added
v.shrink_to_fit(); // capacity reduced to 1
```

- **reserve(n)**: Requests that the vector capacity be at least enough to hold n elements. This avoids reallocation when adding elements.

```
vector<char> v;
v.reserve(100); // ensures space for at least 100 elements
```

- **empty()**: Checks if the vector contains any elements.

```
vector<int> v;
bool is_empty = v.empty(); // is_empty is true
```

Modifying Elements:

- **assign(n, value)**: Replaces all elements in the vector with the specified value.

```
vector<int> v = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };

v.assign(10, 0);
deb(v); // v = {0,0,0,0,0,0,0,0,0,0}
deb(v.capacity());

v.assign(20, 0); // creates a vector of size 20 and assigns 0 to all elements
deb(v); // v = {0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0}
deb(v.capacity());

v.assign(5, 10); // creates a vector of size 5 and assigns 10 to all elements
deb(v); // v = {10,10,10,10,10}
deb(v.capacity()); // capacity remains same (not lowered)
```

Additional Points:

- `clear()` removes all elements from the vector, but **doesn't change its capacity**.
- `front()` and `back()` are not iterators and **should not be used for loop iterations**.

By understanding these functions, you can effectively manage the size and content of your vectors, leading to efficient and optimized code.

Advantages of Vector

- Vectors have contiguous memory allocation, which means that elements are stored in contiguous memory locations. This makes accessing elements faster compared to other containers like lists and deques. (Note that accessing elements in a vector using the [] operator is faster than using the at() function, as the at() function performs a range check.) (list and deque are not contiguous, they are linked list)
- Vectors have a dynamic size, which means that they can be resized during runtime.

- Vectors support random access, which means that elements can be accessed in constant time using an index.

Disadvantages of Vector

- Inserting or deleting elements in the middle of a vector can be expensive, as all the elements after the insertion or deletion point have to be shifted.
- Vectors have a fixed capacity, which means that if the number of elements exceeds the capacity, the vector has to be reallocated and all the elements have to be copied to the new memory location. This can be expensive in terms of time and memory.
  for example, if the capacity of a vector is 10 and we try to insert the 11th element, the vector will be reallocated to a new memory location with a capacity of 20 and all the 10 elements will be copied to the new memory location.

Pair

A pair in C++ is a container that holds two heterogeneous values (can be different data types). Pairs provide a convenient way to store a simple key-value pair or return two values from a function.

The pair is a simple container that can be used with other STL components, such as associative containers and container adaptors, but it is not part of the STL itself.

Declaring Pairs

To use pairs, include the utility header:

```cpp
#include <utility>
```

Pairs can be declared in several ways:

```cpp
pair<type1, type2> myPair;

pair<int, string> p1;

pair<char, int> p2('a', 5);

auto p3 = make_pair(true, 3.14);

pair<int, vector<int>> p4;
p4.first = 1;
p4.second = { 1, 2, 3 };
```

Accessing Elements

The elements can be accessed using `.first` and `.second`:

```
pair<int, string> p = {1, "abc"};

int x = p.first;  // x = 1
string y = p.second; // y = "abc"
```

Modifying Elements

Elements can be modified using `.first` and `.second`:

```
p.first = 2;
p.second = "def";
```

Relational Operators

Pairs support comparison operators like `==`, `!=`, `<=`, `>=` to compare the elements lexicographically:

```
pair<int, int>p1 = {1, 2};
pair<int, int>p2 = {2, 1};

p1 == p2 // false
p1 != p2 // true
p1 >= p2 // false
```

swap()

The `swap()` function can be used to swap the contents of two pairs efficiently:

```
p1.swap(p2);
// p1 = {2, 1}
// p2 = {1, 2}
```

Usage in Containers

Using STL containers, inside each other allows you to create complex data structures that provide flexibility **and** convenience.

Pairs can be used as elements in other STL containers like vector:

```cpp
vector<pair<int, string>> v;
v.push_back({1, "abc"});
v.push_back({2, "def"});

vector<pair<int, string>> students;
students.push_back({ 1, "Ahmed" });
students.push_back({ 2, "Mohamed" });
students.push_back({ 3, "Ali" });
students.push_back({ 4, "Mahmoud" });
for (auto& x : students) {
        cout << x.first << " " << x.second << el;
}
```

This allows creating complex data structures easily.

Overall, pairs provide a simple way to handle two elements together in situations where using a custom class would be overhead.

Queue

The queue is a linear data structure that follows the **First-In-First-Out (FIFO)** principle.

Elements are inserted at the back (enqueue operation) and removed from the front (dequeue operation).

Declaration

To use queues, include the queue header:

```cpp
 #include <queue>
```

Queues can be declared as:

```cpp
queue<int> q; // empty queue of ints

queue<string> q2({"apple", "banana", "orange"});

// WRONG
queue<int> q2 = {1,2,3,4,5}; // wrong way
```

Enqueue (Inserting Elements)

New elements are added using `push()` or `emplace()` :

```
q.push(1); // Insert 1 to back

q.emplace(2); // Construct and insert element
```

- `push()` copies the element to the back.
- `emplace()` constructs the element in-place at the back.

Dequeue (Removing Elements)

Front elements can be removed using `pop()` :

```
q.pop(); // Remove front element
```

Front and Back

- `front()` - Access first element.
- `back()` - Access last element.

```
q.front();
q.back();
```

Note: Calling `front()` or `back()` on an empty queue leads to undefined behavior.

Size and Empty

- `size()` - Get current size.
- `empty()` - Check if queue is empty.

```
int num = q.size();

if(q.empty()) {
  // queue is empty
}
```

Iterating Over Queue

```
while(!q.empty()) {
  auto x = q.front();
  q.pop();

  // process element x
}

// you can't access the second element of the queue directly, you have to pop the
first element to access the second element
```

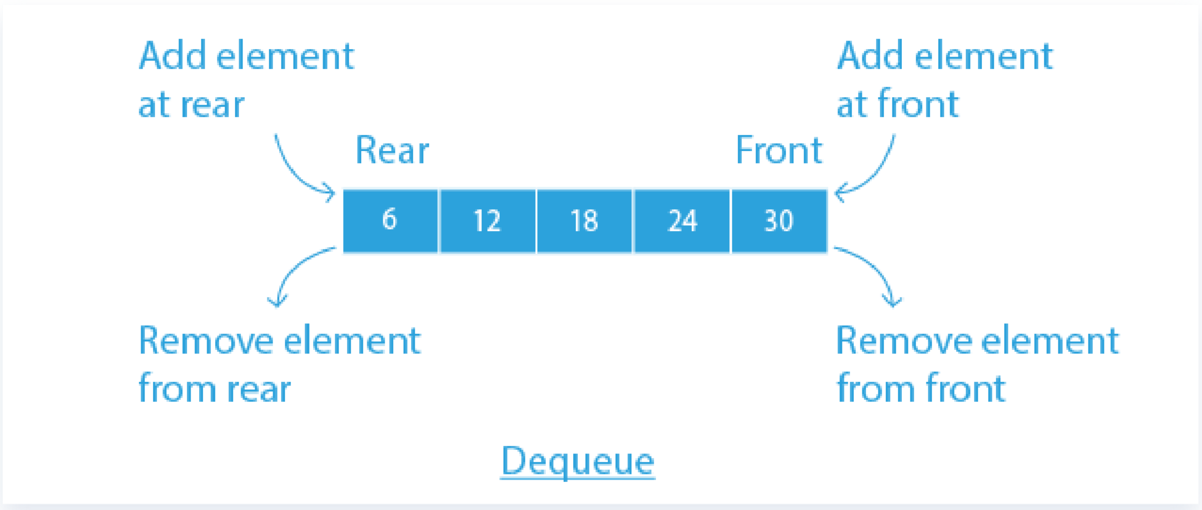
Copy and compare

```
queue<int> q;
q.push(1);
q.push(2);
q.push(3);

queue<int>q2;
// copy the queue
q2 = q;

// check if two queues are equal or not :
cout << (q == q2) << el;
```

This allows processing elements while removing them.

The queue provides a convenient FIFO data structure useful in many algorithms and applications. It saves effort over manually handling insertion and removal of elements.

Deque



The deque (double-ended queue) is a linear container that allows fast insertion and deletion at both the beginning and the end. It overcomes limitations of vectors and queues in this aspect.

Declaration

```
#include <deque>

deque<int> dq; // Empty deque of ints
deque<int> dq2 = { 1, 2, 3, 4, 5 };
```

Inserting Elements

- push_front(x) - Insert x at the beginning

- **push_back(x)** - Insert x at the end
- **emplace_front(x)** - Construct and insert x at the beginning
- **emplace_back(x)** - Construct and insert x at the end

```
dq.push_front(5);
dq.emplace_back(10);
```

Removing Elements

- **pop_front()** - Remove first element
- **pop_back()** - Remove last element

```
dq.pop_front();
dq.pop_back();
```

Access

- **front()** - Access first element
- **back()** - Access last element

```
dq.front();
dq.back();
cout << dq[2] << el;
```

Size, Empty

- **size()** - Number of elements
- **empty()** - Check if deque is empty

```
int num = dq.size();

if(dq.empty()) {
  // deque is empty
}
```

Iterating Over Deque

```
for(auto x : dq) {
  // process element x
}
for (int i = 0; i < dq.size(); ++i) {
    cout << dq[i] << " ";
}
```

Difference between Deque and Vector

- **Insertion and Deletion**: Deque allows fast insertion and deletion at both the beginning and the end, while vector only allows efficient insertion and deletion at the end. This makes deque more suitable for scenarios where elements need to be added or removed frequently from both ends.
- **Memory Allocation**: Deque uses a sequence of individually allocated fixed-size arrays, while vector uses a single dynamically allocated array. This means that deque can grow more efficiently than vector when elements are added or removed frequently.
- **Random Access**: Both deque and vector support random access to elements using the `[]` operator. However, deque may have slightly slower random access compared to vector due to its internal data structure.

Additional Functions

In addition to the functions mentioned in the code snippet, here are some additional functions available in the deque container:

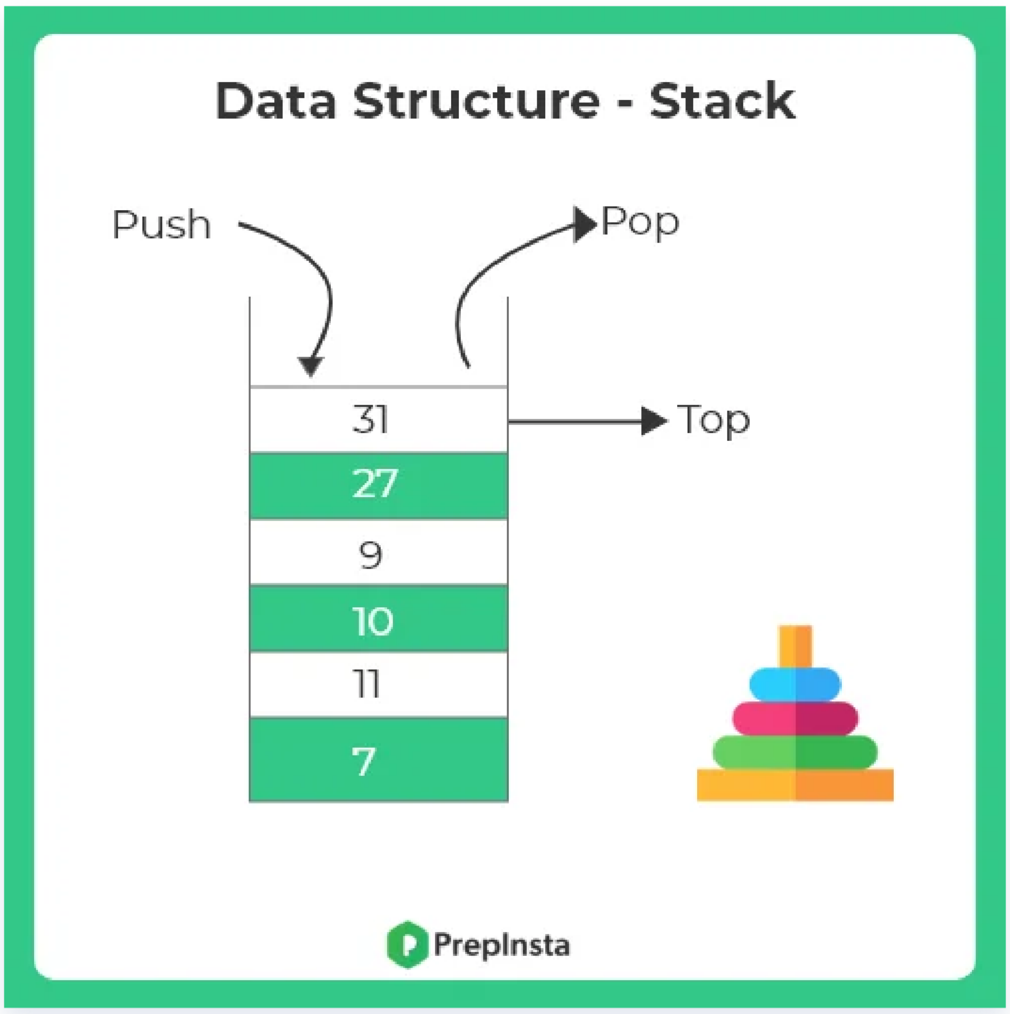
- **insert(pos, x)**: Inserts element x at the specified position pos.
- **erase(pos)**: Removes the element at the specified position pos.
- **clear()**: Removes all elements from the deque.
- **resize(n)**: Resizes the deque to contain n elements.
- **swap(dq2)**: Swaps the contents of two deques.

These functions provide more flexibility and control over the deque container.

The deque provides flexibility of vectors and queues together while enabling fast inserts and deletes at both ends. This makes it useful in algorithms requiring dynamic collections.

Stack

The stack is a linear data structure that follows the **Last-In-First-Out (LIFO)** principle. The last element inserted is the first one to be removed.



Declaration

Include the stack header to use stacks:

```
#include <stack>
```

Stacks can be declared as:

```
stack<int> s; // Empty stack of ints
```

Push (Inserting Elements)

New elements are added using `push()` :

```
s.push(5); // Insert 5 to stack top
```

`emplace()` can also be used to construct and insert:

```
s.emplace(10); // Construct 10 and push
```

Pop (Removing Elements)

Top elements can be removed using `pop()` :

```
s.pop(); // Remove element from top
```

Top

`top()` allows accessing the top element without removing:

```
int x = s.top(); // Access top element
```

Size and Empty

- `size()` - Current number of elements
- `empty()` - Check if stack is empty

```
int num = s.size();

if(s.empty()) {
  // stack is empty
}
```

The stack provides a convenient LIFO implementation for algorithms that require element access in reverse order. It handles insertion and removal from one end automatically

Reversing a String

```
string reverseString(string str) {

  stack<char> letters;

  for(char ch : str) {
    letters.push(ch);
  }

  string result;

  while(!letters.empty()) {
    result += letters.top();
    letters.pop();
  }

  return result;
}

string name = "John";
string rev = reverseString(name); // rev = "nhoJ"
```

Pushes characters onto stack, then pops them back off to build reversed string.

Checking Balanced Parentheses

```cpp
bool isBalanced(string exp) {

  stack<char> parentheses;

  for(char ch : exp) {
    if(ch == '(' || ch == '[') {
      parentheses.push(ch);
    }
    else if(ch == ')' || ch == ']') {
      if(parentheses.empty()) {
        return false;
      }

      if(ch == ')' && parentheses.top() != '(') {
        return false;
      }

      if(ch == ']' && parentheses.top() != '[') {
        return false;
      }

      parentheses.pop();
    }
  }

  return parentheses.empty();
}

string statement = "[code](inside)parenthesis";

if(isBalanced(statement)) {
  // balanced
}
else {
  // not balanced
}
```

Struct

A struct in C++ is a user-defined data type that allows grouping together data items of different types. It can contain members that can be accessed through dot notation.

Declaring Structs

```cpp
struct Student {
  string name;
  int age;
  int id;
  // Default Constructor
  Student() {
    name = "";
    age = 0;
    id = 0;
  }

  // Parameterized Constructor
  Student(string n, int a, int i) {
    name = n;
    age = a;
    id = i;
  }
  void  print() {
      cout << "Name : " << name << endl;
      cout << "Age : " << age << endl;
      cout << "ID : " << id << endl;
   }
};

// Usage
Student s1; // invokes default constructor, members initialized

Student s2("Ahmed", 20, 1); // invokes parameterized constructor
```

This declares a Student struct.

Creating Struct Objects

```
Student s1("Ahmed", 20, 1);

Student s2; // Default constructor
s2.name = "Sarah";
```

Access members using dot `.` operator.

Structs in Containers

Structs can also be used inside other containers:

```
vector<Student> database;

database.push_back(Student("Ahmed", 20, 1));

for(auto s : database) {
  // access struct members
}

  pair<Student, int> p;
    Student s2;
    s2.name = "Mohamed";
    s2.age = 21;
    s2.id = 456;
    p.first = s2;
    p.second = 100;
    cout << p.first.name << endl;
    cout << p.second << endl;
```

Struct vs Class

- Members and base classes in structs are public by default while private in classes.
- Structs can't inherit other structs/classes (no hierarchy) while classes can.

Good for simple data holders without encapsulation needs.

Overall, structs allow customizing and reusing complex data types conveniently.