# Queues2

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Queues2

## CSC 212: Data Structures and Abstractions

08: Queues

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THINK BIG WE DO

## Solution to lab problem

```
int eval(const std::string& exp) {
    std::stack<int> operands;
    std::stack<char> operators;

    for (size_t i = 0 ; i < exp.length() ; ++i) {
        if (exp[i] == ' ' || exp[i] == '(') {
            continue;
        } else if (isdigit(exp[i])) {
            operands.push(exp[i] - '0');
        } else if (exp[i] == '+' || exp[i] == '-' || exp[i] == '*' || exp[i] == '/') {
            operators.push(exp[i]);
        } else if (exp[i] == ')') {
            int right = operands.top();
            operands.pop();
            int left = operands.top();
            operands.pop();
            char op = operators.top();
            operators.pop();
            switch (op) {
                case '+': operands.push(left + right); break;
                case '-': operands.push(left - right); break;
                case '*': operands.push(left * right); break;
                case '/': operands.push(left / right); break;
            }
        }
    }
    return operands.top();
}
```

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## Stacks

- Consider a stack implemented by a dynamic array (insertion and deletion at the end)
  - what is the computational cost?

| | |
|---|---|
| **Push** | O(1) amortized |
| **Pop** | O(1) |

- Consider a stack implemented by a dynamic array (insertion and deletion at the beginning)
  - what is the computational cost?

both operations require shifting elements

| | |
|---|---|
| **Push** | O(n) |
| **Pop** | O(n) |

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## std::stack

Defined in header <stack>

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

The std::stack class is a container adaptor that gives the programmer the functionality of a stack - specifically, a LIFO (last-in, first-out) data structure.

The class template acts as a wrapper to the underlying container - only a specific set of functions is provided. The stack pushes and pops the element from the back of the underlying container, known as the top of the stack.

**Member functions**

| | |
|---|---|
| (constructor) | constructs the stack (public member function) |
| (destructor) | destructs the stack (public member function) |
| operator= | assigns values to the container adaptor (public member function) |
| **Element access** | |
| top | accesses the top element (public member function) |
| **Capacity** | |
| empty | checks whether the container adaptor is empty (public member function) |
| size | returns the number of elements (public member function) |
| **Modifiers** | |
| push | inserts element at the top (public member function) |
| push_range (C++23) | inserts a range of elements at the top (public member function) |
| emplace (C++11) | constructs element in-place at the top (public member function) |
| pop | removes the top element (public member function) |
| swap (C++11) | swaps the contents (public member function) |

```
#include <cassert>
#include <stack>

int main()
{
    std::stack<int> stack;
    assert(stack.size() == 0);

    const int count = 8;
    for (int i = 0 ; i != count ; ++i) {
        stack.push(i);
    }
    assert(stack.size() == count);
}
```

https://en.cppreference.com/w/cpp/container/stack

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## Queues

## Queues

- First-in-first-out
  - a **queue** is a linear data structure that follows the (FIFO) principle
  - the first element added to the queue is the first one to be removed
    - analogous to a real-world queue, such as a line of people waiting for service
- Main operations
  - **Enqueue**: add an element to the end of the queue
  - **Dequeue**: remove an element from the front of the queue
- Applications
  - scheduling tasks in operating systems, managing requests in web servers, implementing breadth-first search (BFS) in graph algorithms, etc.

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## Practice

- What is the output of this code?

```
Queue<int> s1, s2;

s1.enqueue(100);
s2.enqueue(s1.dequeue());
s1.enqueue(200);
s1.enqueue(300);
s2.enqueue(s1.dequeue());
s2.enqueue(s1.dequeue());

s1.enqueue(s2.dequeue());
s1.enqueue(s2.dequeue());

while (!s1.empty()) {
    std::cout << s1.dequeue() << std::endl;
}

while (!s2.empty()) {
    std::cout << s2.dequeue() << std::endl;
}
```

| s1 | s2 |
|---|---|
| 100 | – |
| – | 100 |
| 200 | – |
| 300 | – |
| – | 200 |
| – | 300 |
| 100 | – |
| 200 | – |

s1 → 100, 200
s2 → 300

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## Practice

- Write a function that modifies a queue of elements by replacing every element with two copies of itself
  - for example: [a, b, c] becomes [a, a, b, b, c, c]

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## Implementation

- Using arrays
  - ensure **enqueue** and **dequeue** work at different ends of the array
  - array can be fixed-length or a dynamic array (additional cost)
- Considerations
  - underflow: throw an error when calling dequeue on an empty queue
  - overflow: throw an error when calling enqueue on a full queue

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## Implementation

- Array-based (standard)
  - enqueue at the end — $O(1)$ cost (amortized cost if using a dynamic array)
  - dequeue from the beginning — $O(n)$ cost
    - requires shifting elements
- Array-based (alternative)
  - enqueue at the beginning — $O(n)$ cost
    - requires shifting elements
  - dequeue from the end — $O(1)$ cost
- Circular array
  - enqueue at the end — $O(1)$ cost (amortized cost if using a dynamic array)
  - dequeue from the beginning — $O(1)$ cost
  - more efficient approach, as it eliminates the need for shifting elements
  - requires handling wrap-around at array boundaries

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## Circular array


top = (top+1) % size.

https://www.cs.usfca.edu/~galles/visualization/QueueArray.html

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```
// implements a (circular) queue using a fixed-size array
class Queue {
    private:
        // array to store queue elements
        int *array;
        // maximum number of elements queue can hold
        int length;
        // index of the first element in the queue
        int base;
        // index of the last element in the queue
        int top;

    public:

        Queue(int);
        ~Queue();

        // adds an element to the end of the queue
        void enqueue(int);
        // removes the first element from the queue
        int dequeue();
};
```

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## Practice

- Design an algorithm to:
  - load a number of audio files (songs)
  - play them in a continuous loop

```
for (i=1 to n):
    q.enqueue(load file)
while (1)
    f = q.dequeue
    play(f)
    q.enqueue(f)
```

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## Practice

- Write an algorithm to reverse the order of elements of a queue (hint: can use a separate stack)
- Write an algorithm that accepts a queue of elements and appends the queue's contents to itself in reverse order (hint: can use a separate stack)
  - for example: [a, b, c] becomes [a, b, c, c, b, a]

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## std::queue

Defined in header <queue>

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

The std::queue class template is a container adaptor that gives the functionality of a queue - specifically, a FIFO (first-in, first-out) data structure.

The class template acts as a wrapper to the underlying container - only a specific set of functions is provided. The queue pushes the elements on the back of the underlying container and pops them from the front.

**Member functions**

| | |
|---|---|
| (constructor) | constructs the queue (public member function) |
| (destructor) | destructs the queue (public member function) |
| operator= | assigns values to the container adaptor (public member function) |
| **Element access** | |
| front | access the first element (public member function) |
| back | access the last element (public member function) |
| **Capacity** | |
| empty | checks whether the container adaptor is empty (public member function) |
| size | returns the number of elements (public member function) |
| **Modifiers** | |
| push | inserts element at the end (public member function) |
| push_range (C++23) | inserts a range of elements at the end (public member function) |
| emplace (C++11) | constructs element in-place at the end (public member function) |
| pop | removes the first element (public member function) |
| swap (C++11) | swaps the contents (public member function) |

```
#include <cassert>
#include <queue>

int main()
{
    std::queue<int> queue;
    assert(queue.size() == 0);

    const int count = 8;
    for (int i = 0 ; i != count ; ++i) {
        queue.push(i);
    }
    assert(queue.size() == count);
}
```

https://en.cppreference.com/w/cpp/container/queue

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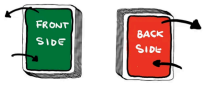
## Deques

## Deques

- Double-ended queue
  - a **deque** (pronounced "deck") is a linear data structure that allows insertion and removal of elements from both ends
  - combines the capabilities of stacks and queues
- Main operations
  - **InsertFront, InsertEnd**: add an element to the front or to the end of the queue respectively
  - **DeleteFront, DeleteEnd**: remove an element from the front or from the end of the queue respectively
- Applications
  - task scheduling, undo/redo functionality, web browser history (forward/backward), sliding window problems, palindrome checking, etc.

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## Implementation

- Using arrays
  - array can be fixed-length or a dynamic array (additional cost)
- Considerations
  - underflow: throw an error when calling "remove" on an empty queue
  - overflow: throw an error when calling "insert" on a full queue
- Circular array
  - use a circular array to allow efficient operations at both ends
  - $O(1)$ cost for all operations
    - "InsertEnd" has an amortized constant time if using a dynamic array

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## std::deque

Defined in header <deque>

```
template<
    class T,
    class Allocator = std::allocator<T>
> class deque;                                          (1)

namespace pmr {
    template< class T >
    using deque = std::deque<T, std::pmr::polymorphic_allocator<T>>;   (2)  (since C++17)
}
```

`std::deque` (double-ended queue) is an indexed sequence container that allows fast insertion and deletion at both its beginning and its end. In addition, insertion and deletion at either end of a deque never invalidates pointers or references to the rest of the elements.

As opposed to `std::vector`, the elements of a deque are not stored contiguously: typical implementations use a sequence of individually allocated fixed-size arrays, with additional bookkeeping, which means indexed access to deque must perform two pointer dereferences, compared to vector's indexed access which performs only one.

The storage of a deque is automatically expanded and contracted as needed. Expansion of a deque is cheaper than the expansion of a `std::vector` because it does not involve copying of the existing elements to a new memory location. On the other hand, deques typically have large minimal memory cost; a deque holding just one element has to allocate its full internal array (e.g. 8 times the object size on 64-bit libstdc++; 16 times the object size or 4096 bytes, whichever is larger, on 64-bit libc++).

The complexity (efficiency) of common operations on deques is as follows:

- Random access - constant $O(1)$.
- Insertion or removal of elements at the end or beginning - constant $O(1)$.
- Insertion or removal of elements - linear $O(n)$.

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**Member functions**

| | |
|---|---|
| (constructor) | constructs the deque (public member function) |
| (destructor) | destructs the deque (public member function) |
| operator= | assigns values to the container (public member function) |
| assign | assigns values to the container (public member function) |
| assign_range (C++23) | assigns a range of values to the container (public member function) |
| get_allocator | returns the associated allocator (public member function) |

**Element access**

| | |
|---|---|
| at | access specified element with bounds checking (public member function) |
| operator[] | access specified element (public member function) |
| front | access the first element (public member function) |
| back | access the last element (public member function) |

**Iterators**

| | |
|---|---|
| begin<br>cbegin (C++11) | returns an iterator to the beginning (public member function) |
| end<br>cend (C++11) | returns an iterator to the end (public member function) |
| rbegin<br>crbegin (C++11) | returns a reverse iterator to the beginning (public member function) |
| rend<br>crend (C++11) | returns a reverse iterator to the end (public member function) |

**Capacity**

| | |
|---|---|
| empty | checks whether the container is empty (public member function) |
| size | returns the number of elements (public member function) |
| max_size | returns the maximum possible number of elements (public member function) |
| shrink_to_fit (DR*) | reduces memory usage by freeing unused memory (public member function) |

**Modifiers**

| | |
|---|---|
| clear | clears the contents (public member function) |
| insert | inserts elements (public member function) |
| insert_range (C++23) | inserts a range of elements (public member function) |
| emplace (C++11) | constructs element in-place (public member function) |
| erase | erases elements (public member function) |
| push_back | adds an element to the end (public member function) |
| emplace_back (C++11) | constructs an element in-place at the end (public member function) |
| append_range (C++23) | adds a range of elements to the end (public member function) |
| pop_back | removes the last element (public member function) |
| push_front | inserts an element to the beginning (public member function) |
| emplace_front (C++11) | constructs an element in-place at the beginning (public member function) |
| prepend_range (C++23) | adds a range of elements to the beginning (public member function) |
| pop_front | removes the first element (public member function) |
| resize | changes the number of elements stored (public member function) |
| swap | swaps the contents (public member function) |

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