Ve 280

Programming and Introductory Data Structures

Operator Overloading;

Stacks; Queues

Outline

- Operator overloading
- Linear List
- Stack
  - Implementation
  - Application
- Queues: Implementation

Operator Overloading
Introduction

- C++ lets us **redefine** the meaning of the operators when applied to objects of **class type**.
- This is known as **operator overloading**.
- We have already seen the overloading of the assignment operator.

- Operator overloading makes programs much easier to write and read:

```
IntSet is;
int x = is[5]; // overload [] operator
         // access the IntSet element by index
cout << is << endl; // overload << operator
            // print all the IntSet elements
```

Operator Overloading
Basics

- Overloaded operators are functions with special names: the keyword **operator** followed by the symbol (e.g., +,-, etc.) of the operator being redefined.

- Like any other function, an overloaded operator has a return type and a parameter list.

```
A operator+(const A &l, const A &r);
```

Operator Overloading

Basics

- Most overloaded operators may be defined as ordinary **nonmember** functions or as class **member** functions.

```
A operator+(const A &l, const A &r);
// returns l "+" r
A A::operator+(const A &r);
// returns *this "+" r
```

- Overloaded functions that are members of a class may appear to have **one fewer** parameter than the number of operands.
  - Operators that are member functions have an implicit `this` parameter that is bound to the **first operand**.

Operator Overloading
Basics

- An overloaded **unary** operator has **no** (explicit) parameter if it is a member function and **one** parameter if it is a nonmember function.

- An overloaded **binary** operator would have **one** parameter when defined as a member and **two** parameters when defined as a nonmember function.

Example

- Overload **operator+=** for a class of complex number.

```
class Complex {
  // OVERVIEW: a complex number class
  double real;
  double imag;
public:
  Complex(double r=0, double i=0); // Constructor
  Complex &operator += (const Complex &o);
  // MODIFIES: this
  // EFFECTS: adds this complex number with the
  // complex number o and return a reference
  // to the current object.
};
```

Example

```
Complex &Complex::operator += (const Complex &o)
{
    real += o.real;
    imag += o.imag;
    return *this;
}
```

Example

- **operator+=** is a member function.
- We can also define a nonmember function that adds two numbers.

```
Complex operator + (const Complex &o1,
     const Complex &o2)
{
  Complex rst;
  rst.real = o1.real + o2.real;
  rst.imag = o1.imag + o2.imag;
  return rst;
}
```

- However, there is a problem with this. What is it?
- Since **operator+** is a nonmember function, it cannot access the private data members.

Friend

- So, we'll need some other mechanism to make the function as a "**friend**".
- The "friend" declaration allows you to expose the **private** state of one class to another function (and only that function) explicitly.

```
class foo {
  friend void baz();
  int f;
};
void baz() { ... }
```

The function **`baz`** has access to **`f`**, which would otherwise be private to class **`foo`**.

Friend

- So, we'll need some other mechanism to make the function as a "**friend**".
- The "friend" declaration allows you to expose the **private** state of one class to another function (and only that function) explicitly.

```
class foo {
   friend void baz();
   int f;
};
void baz() { ... }
```

Note: a friend function is **NOT** a member function; it is an ordinary function.

Note: NOT `void foo::baz() { ... }`

Friend

- So, we'll need some other mechanism to make the function as a "**friend**".
- The "friend" declaration allows you to expose the **private** state of one class to another function (and only that function) explicitly.

```
class foo {
  friend void baz();
  int f;
};
void baz() { ... }
```

Note: "`friend void baz();`" goes inside `foo`. It means `foo` gives friendship to function `baz()`.

Friend

- Besides function, we can also declare a class to be friend.

```
class foo {
   friend class bar;
   int f;
};
class bar {
   ...
};
```

Then, objects of class `bar` can access private member `f` of `foo`.

Friend

```
class foo {
  friend class bar;
  friend void baz();
  int f;
};
class bar { ... };
void baz() { ... }
```

Friendship of both class and function.

- Note: Although "**friendship**" is declared inside **`foo`**, **`bar`** and **`baz()`** are not the members of **`foo`**!
- "**friend**" declaration may appear anywhere in the class.
  - It is a good idea to **group** friend declarations **together** either at the beginning or end of the class definition.

Example

- In our example of complex number class, we will declare **`operator+`** as a friend:

```
class Complex {
  // OVERVIEW: a complex number class
  double real;
  double imag;
public:
  Complex(double r=0, double i=0);
  Complex &operator += (const Complex &o);
  friend Complex operator+(const Complex &o1,
        const Complex &o2);
};
```

Its implementation is the same as before.

Overloading Operator []

- We want to access each individual element in the IntSet through **subscript operator []**, just like how we access an ordinary array.
  - For example, `is[5]` accesses the sixth element in the IntSet `is`.

- We need to overload the `operator[]`.
  - It is a binary operator: The first operand is the IntSet and the second one is the index.

Overloading Operator []

- We write two versions with bound checking

```
const int &IntSet::operator[](int i) const {
    if(i >= 0 && i < numElts) return elts[i];
    else throw BoundsError();
}
```

const version returning a const reference to int

```
int &IntSet::operator[](int i) {
    if(i >= 0 && i < numElts) return elts[i];
    else throw BoundsError();
}
```

nonconst version returning a reference to int

Overloading Operator []

- Why we need a nonconst version that returns a reference to int?
  - We need to assign to an element through subscript operation
    `is[5] = 2;`
- Why we need a const version that returns a const reference to int?
  - We may call the subscript operator with some const IntSet objects or within some const member function. Const objects/const member function can only call their const member functions.
  - Furthermore, the return type should be const reference to prevent using it as the target of assignment.

Overloading Output Operator <<

- We want to redefine the **`operator<<`** for the IntSet class, so that it prints all the elements in the set in sequence.
- Convention of the IO library
  - The **`operator<<`** should take an **`ostream&`** as its first parameter and a **const** reference to a object of the class type as its second.

    ```
    os << obj;
    ```
  - The **`operator<<`** should return a reference to its **ostream parameter**.

```
ostream &operator<<(ostream &os, const IntSet &is){
  ...
  return os;
}
```

Overloading Output Operator <<

```
ostream &operator<<(ostream &os, const IntSet &is){
  ...
  return os;
}
```

- Why should **`operator<<`** return a reference to its **ostream parameter**?
  - Because **`operator<<`** can be **chained together**:

    ```
    cout << "hello " << "world!" << endl;
    ```

  - It is equivalent to

    ```
    cout << "hello ";
    cout << "world!";
    cout << endl;
    ```

Overloading Output Operator <<

- **`operator<<`** must be a nonmember function!
  - The first operand is not of the class type.

- We can implement **`operator<<`** as follows

```
ostream &operator<<(ostream &os, const IntSet &is){
  for(int i = 0; i < is.size(); i++)
    os << is[i] << " ";
  return os;
}
```

Question: Which version of operator[] is called?

- Now we can write **`cout << is << endl;`**

Overloading Input Operator >>

- Convention of the IO library
  - The **`operator>>`** should take an **`istream&`** as its first parameter and a **nonconst** reference to a object of the class type as its second.

    ```
    os >> obj;
    ```

    Question: why nonconst?
  - The **`operator>>`** should return a reference to its **istream parameter**.

    Question: why returning reference?

```
istream &operator>>(istream &is, foo &obj){
  ...
  return is;
}
```

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Linear List ADT

- Recall the IntSet ADT
  - A collection of zero or more integers, with **no duplicates**.
  - It supports insertion and removal, but by value.

- A related ADT: linear list
  - A collection of zero or more integers; **duplicates possible.**
    - $L = (e_0, e_1, \dots, e_{N-1})$
  - It supports insertion and removal **by position**.

Linear List ADT

Insertion

```
void insert(int i, int v) // if 0 <= i <= N
// (N is the size of the list), insert v at
// position i; otherwise, throws BoundsError
// exception.
```

Example: `L1 = (1, 2, 3)`

```
L1.insert(0, 5) = (5, 1, 2, 3);
L1.insert(1, 4) = (1, 4, 2, 3);
L1.insert(3, 6) = (1, 2, 3, 6);
L1.insert(4, 0) throws BoundsError
```

Linear List ADT

Removal

```
void remove(int i) // if 0 <= i < N (N is
// the size of the list), remove the i-th
// element; otherwise, throws BoundsError
// exception.
```

Example: `L2 = (1, 2, 3)`

```
L2.remove(0) = (2, 3);
L2.remove(1) = (1, 3);
L2.remove(2) = (1, 2);
L2.remove(3) throws BoundsError
```

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Stack

- A “pile” of objects where new object is put on **top** of the pile and the top object is removed first.
  - LIFO access: last in, first out.
  - Restricted form of a **linear list**: insert and remove only at the end of the list.

Methods of Stack

- `size()` : number of elements in the stack.
- `isEmpty()` : checks if stack has no elements.
- `push(Object o)` : add object `o` to the top of stack.
- `pop()` : remove the top object if stack is not empty; otherwise, throw `stackEmpty`.
- `Object &top()` : return a reference to the top element.

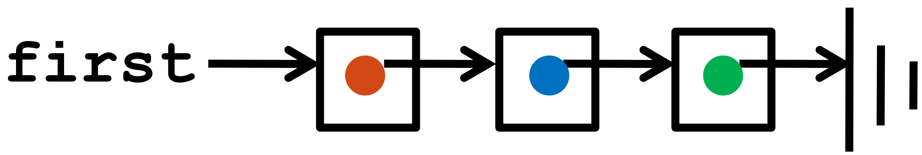
Stacks Using Arrays

`Array[MAXSIZE]:`

2	3	1	4		

- Maintain an integer **`size`** to record the size of the stack.
- **`size()`**: **`return size;`**
- **`isEmpty()`**: **`return (size == 0);`**
- **`push(Object o)`**: add object **`o`** to the end of the array and increment **`size`**. Allocate more space if necessary.
- **`pop()`**: If **`isEmpty()`**, throw **`stackEmpty;`** otherwise, decrement **`size.`**
- **`Object &top()`**: return a reference to the top element **`Array[size-1]`**

Stacks Using Linked Lists

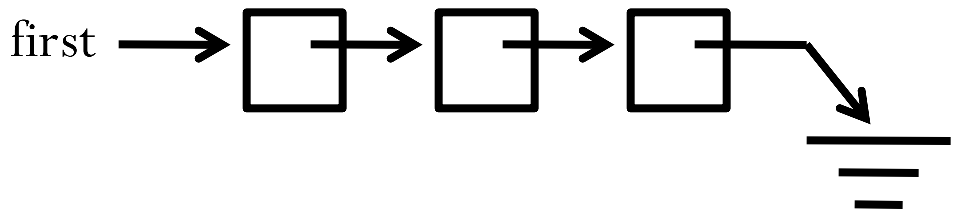


For single-ended linked list, which end is preferred to be the top? Why?

- `size()` : `LinkedList::size();`
- `isEmpty()` : `LinkedList::isEmpty();`
- `push(Object o)` : insert object at the beginning
  `LinkedList::insertFirst(Object o);`
- `pop()` : remove the first node
  `LinkedList::removeFirst();`
- `Object &top()` : return a reference to the object stored in the first node.

Recall: `LinkedList::size()`

- How to get the size of a linked list?




```
int LinkedList::size() {
  int count = 0;
  node *current = first;
  while(current){
    count++;
    current = current->next;
  }
  return count;
}
```

Array vs. Linked List: Which is Better?

- They both have advantages and disadvantages

- Linked list
  - memory-efficient: a new item just needs extra constant amount of memory
  - not time-efficient for size operation

- Array
  - time-efficient for size operation
  - not memory-efficient: need to allocate a big enough array

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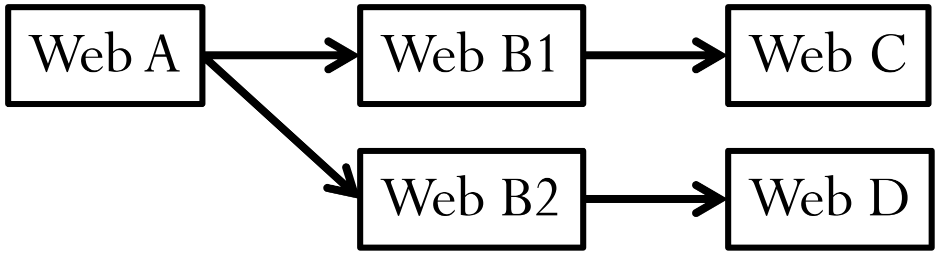
Application of Stacks

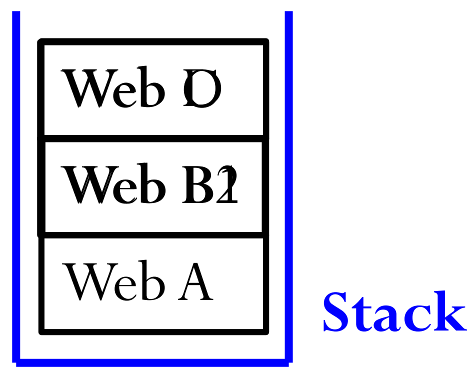
- Function calls in C++
- Web browser's "back" feature
- Parentheses Matching

Web Browser's "back" Feature



Visiting order

- Web A
- Web B1
- Web C
- Back (to Web B1)
- Back (to Web A)
- Web B2
- Web D



Parentheses Matching

- Output pairs (u,v) such that the left parenthesis at position u is matched with the right parenthesis at v.

```
( ( a + b ) * c + d - e ) / ( f + g )
0 1 2 3 4 5 6 7 8 9 10  12  14  16  18
```

  - Output is: (1, 5); (0, 12); (14, 18);

```
( a + b ) ) * ( ( c + d )
0 1 2 3 4 5 6 7 8 9 10  12
```

  - Output is

    (0, 4);

    Right parenthesis at 5 has no matching left parenthesis;

    (8, 12);

    Left parenthesis at 7 has no matching right parenthesis

How to Realize Parentheses Matching?

```
( ( a + b ) * c + d - e ) / ( f + g )
0 1 2 3 4 5 6 7 8 9 10  12  14  16  18
```

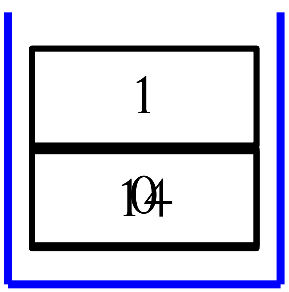
- Scan expression from left to right.
- When a **left** parenthesis is encountered, push its position to the stack.
- When a **right** parenthesis is encountered, pop the top position from the stack, which is the position of the **matching left** parenthesis.
  - If the stack is empty, the **right** parenthesis is not matched.
- If string is scanned over but the stack is not empty, there are not-matched **left** parentheses.

Parentheses Matching

`( ( a + b ) * c + d - e ) / ( f + g )`

`0 1 2 3 4 5 6 7 8 9 10  12  14  16  18`

Stack



(1, 5) (0, 12) (14, 18)

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Queues

- A "line" of items in which the **first** item inserted into the queue is the **first** one out.
  - Restricted form of a linear list: insert at **one end** and remove from **the other**.
  - FIFO access: first in, first out.

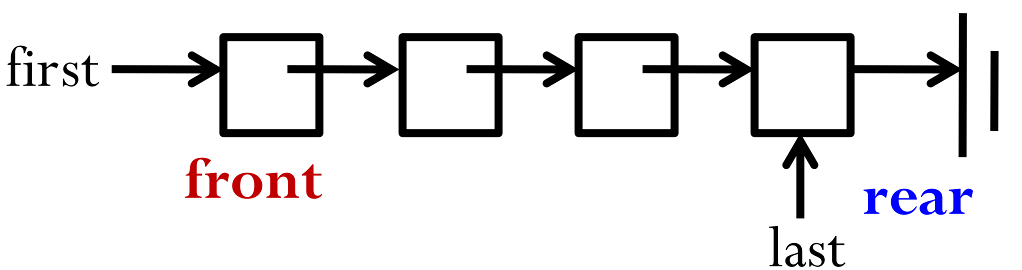
Methods of Queue

- **`size()`** : number of elements in the queue.
- **`isEmpty()`** : check if queue has no elements.
- **`enqueue(Object o)`** : add object **`o`** to the **rear** of the queue.
- **`dequeue()`** : remove the **front** object of the queue if not empty; otherwise, throw **`queueEmpty`**.
- **`Object &front()`** : return a reference to the front element of the queue.
- **`Object &rear()`** : return a reference to the rear element of the queue.

Queues Using Linked Lists

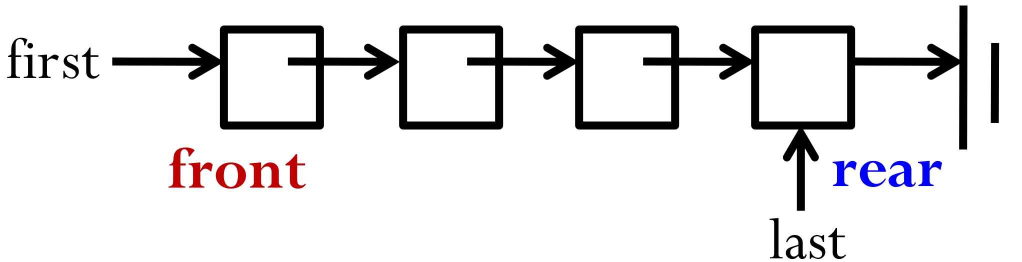
- Which type of linked list should we choose?
  - We need fast **`enqueue`** and **`dequeue`** operations.

- Double-ended singly-linked list is sufficient!



- **`enqueue(Object o):`** append object at the end
  `LinkedList::insertLast(Object o);`
- **`dequeue():`** remove the first node
  `LinkedList::removeFirst();`

Queues Using Linked Lists



- **`size()`**: **`LinkedList::size();`**
- **`isEmpty()`**: **`LinkedList::isEmpty();`**
- **`Object &front()`**: return a reference to the object stored in the first node.
- **`Object &rear()`**: return a reference to the object stored in the last node.

Queues Using Arrays

`Array[MAXSIZE]:`

2	3	1	4			

front   rear

- If we stick to the requirement that the n elements of a queue are the **beginning** n elements of the array,
  - How many operations for **`enqueue`**?
    - I.e., independent of n (number of elements) or proportional to n?
  - How many operations ofr **`dequeue`**?

- A better way is to let the elements "**drift**" within the array.

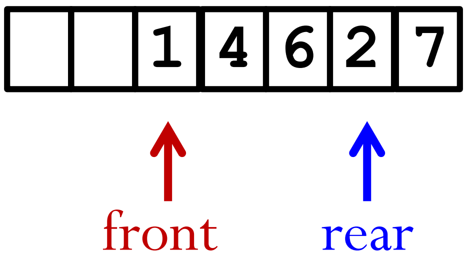
enqueue(6);

dequeue();

dequeue();

2	3	1	4	6		

Queues Using Arrays

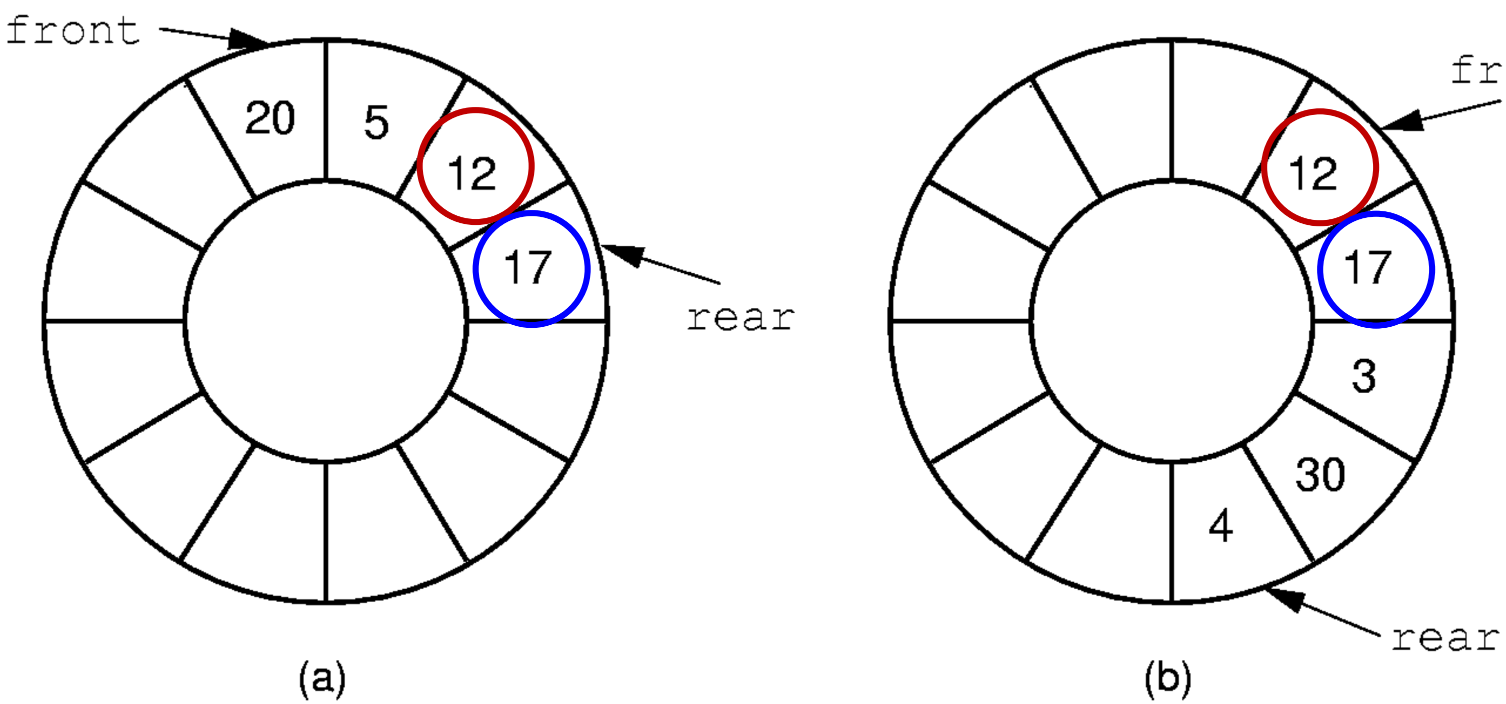


- We maintain two integers to indicate the front and the rear of the queue.

- However, as items are added and removed, the queue "drifts" toward the end.
  - Eventually, there will be no space to the right of the queue, even though there is space in the array.

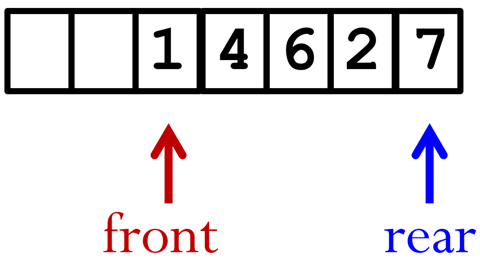
Queues Using Arrays

- To solve the problem of memory waste, we use a **circular array**.

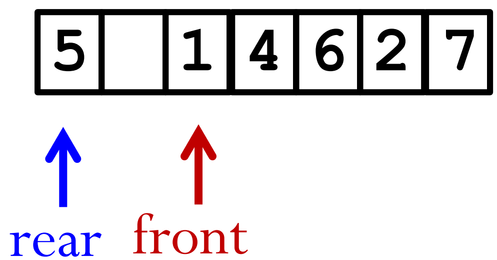


Circular Arrays

- We can implement a circular array using a plain linear array:
  - When front/rear equals the **last** index (i.e., MAXSIZE-1), increment of front/rear gives the **first** index (i.e., 0).



`enqueue(5)`



Circular Arrays

- To realize the “circular” increment, we can use modulo operation:

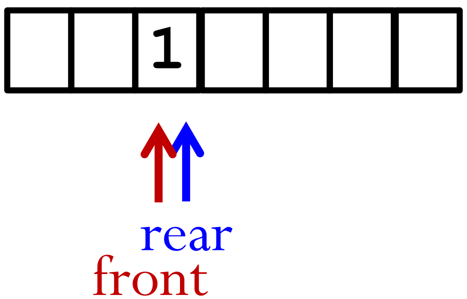
```
front = (front+1) % MAXSIZE;

rear = (rear+1) % MAXSIZE;
```

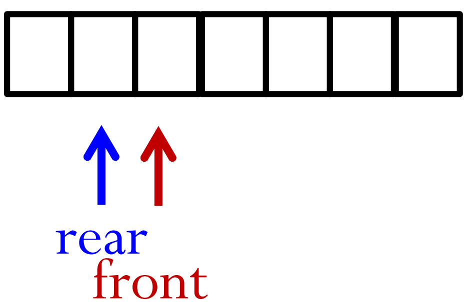
If **`front(or rear) == MAXSIZE-1`**, the statement sets **`front(or rear)`** to 0.

Boundary Conditions

- Suppose that **`front`** points to the **first** element in the queue and that **`rear`** points to the **last** element in the queue.
- What will a queue with one element look like?

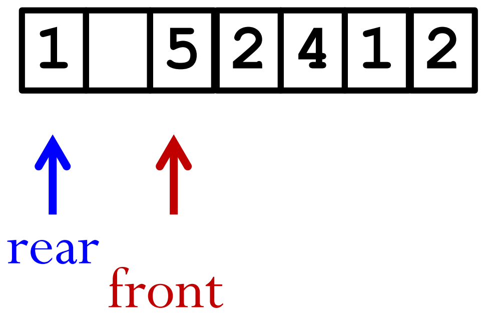


- What will an empty queue look like?

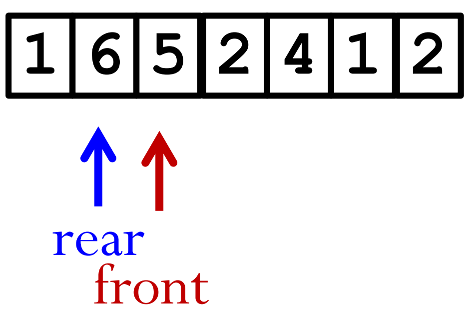


Boundary Conditions

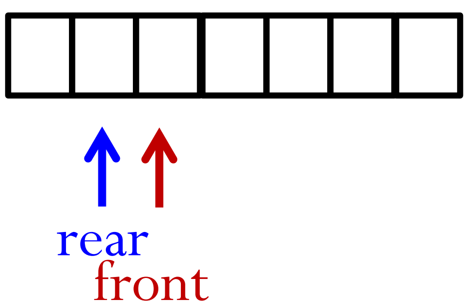
- What will a queue with one empty slot look like?



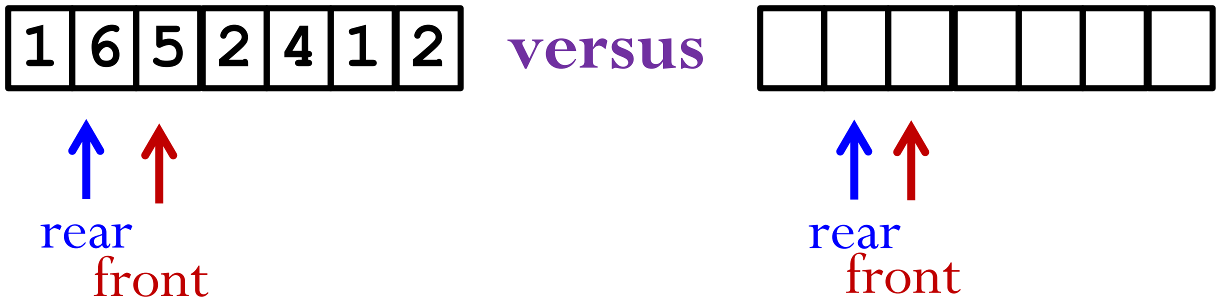
- What will a full queue look like?



versus an empty queue



Boundary Conditions



- To distinguish between the full array and the empty array, we need a flag indicating **`empty`** or **`full`**, or a **`count`** on the number of elements in the queue.

Queues Using Arrays

- **`enqueue(Object o)`**: increment **`rear`**, wrapping to the beginning of the array if the end of the array is reached; if **`rear`** becomes **`front`**, reallocate arrays.

- **`dequeue()`**: increment **`front`**, wrapping to the beginning of the array if the end of the array is reached; if empty, throw **`queueEmpty`**.

- **`isEmpty(): return (count == 0);`**

- **`size(): return count;`**

Reference

- **C++ Primer (4th Edision)**, by *Stanley Lippman, Josee Lajoie, and Barbara Moo*, Addison Wesley Publishing (2005)
  - Chapter 12.5 Friends
  - Chapter 14 Overloaded Operations and Conversions