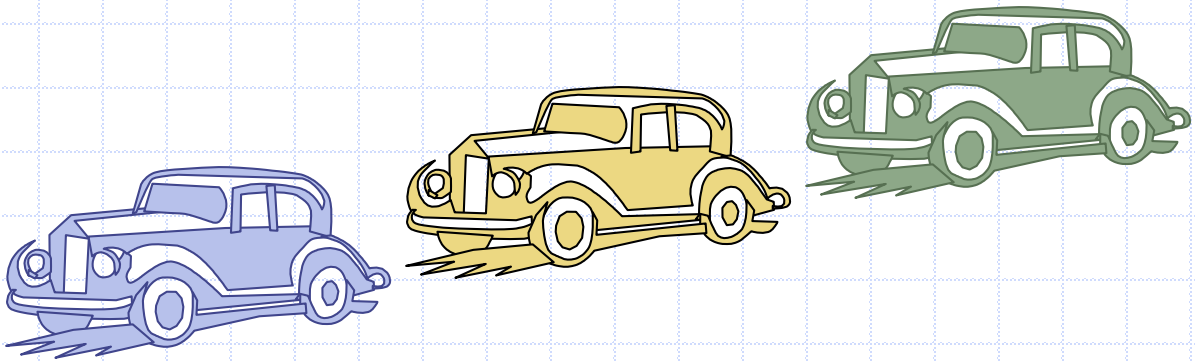
Queues



Outline and Reading

- The Queue ADT
- Implementation with a circular array
- Growable array-based queue
- Queue interface in C++

The Queue ADT

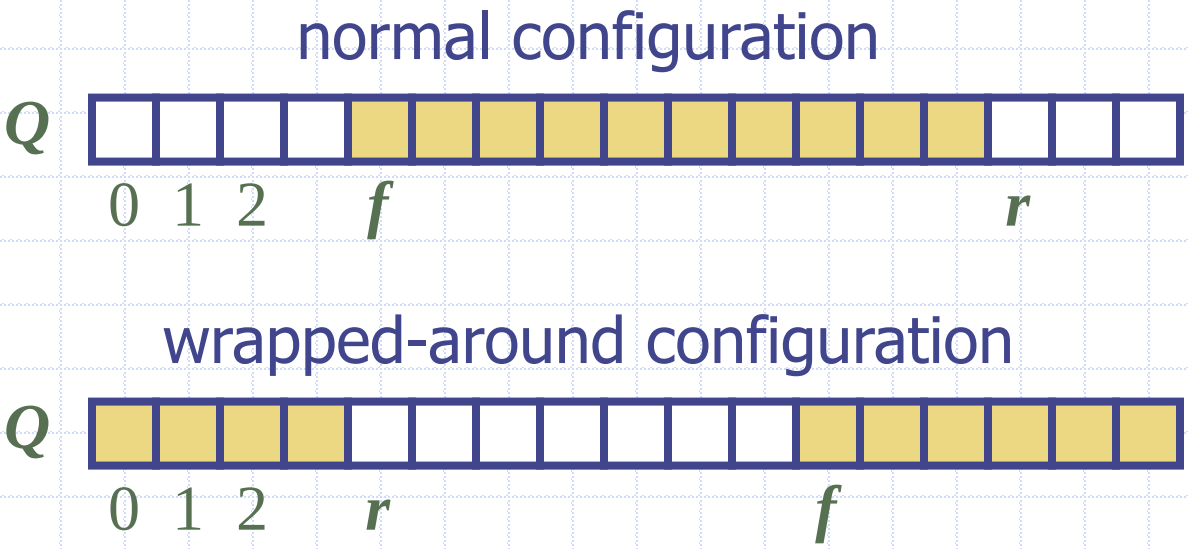
- The Queue ADT stores arbitrary objects
- Insertions and deletions follow the first-in first-out scheme
- Insertions are at the rear of the queue and removals are at the front of the queue
- Main queue operations:
  - enqueue(Object o): inserts an element o at the end of the queue
  - dequeue(): removes and returns the element at the front of the queue
- Auxiliary queue operations:
  - front(): returns the element at the front without removing it
  - size(): returns the number of elements stored
  - empty(): returns a Boolean indicating whether no elements are stored
- Exceptions
  - Attempting the execution of dequeue or front on an empty queue throws an EmptyQueueException

Applications of Queues

- Direct applications
  - Waiting lists, bureaucracy
  - Access to shared resources (e.g., printer)
  - Multiprogramming
- Indirect applications
  - Auxiliary data structure for algorithms
  - Component of other data structures

Array-based Queue

- Use an array of size N in a circular fashion
- Two variables keep track of the front and rear
  - f index of the front element
  - r index immediately past the rear element
- Array location r is kept empty

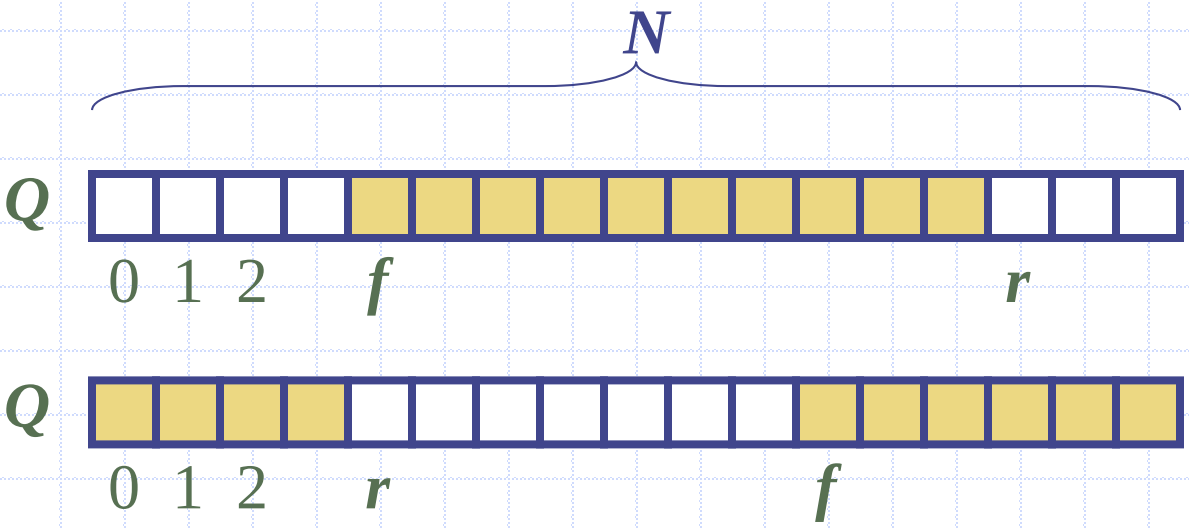


Queue Operations

- Hint: use the modulo operator

e.g. N=17, f=4, r=14
size=(17-4+14) mod 17
size=27 mod 17
size=10

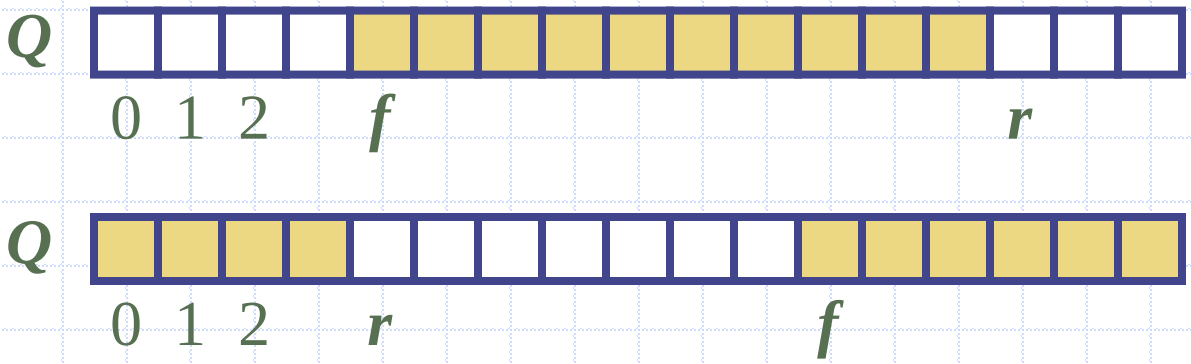
Algorithm ***size***()
  return $(N - f + r) \bmod N$
    [or = $((N+r)-f) \bmod N$]
Algorithm ***empty***()
  return $(f = r)$



Queue Operations (cont.)

- Operation enqueue throws an exception if the array is full
- This exception is implementation-dependent

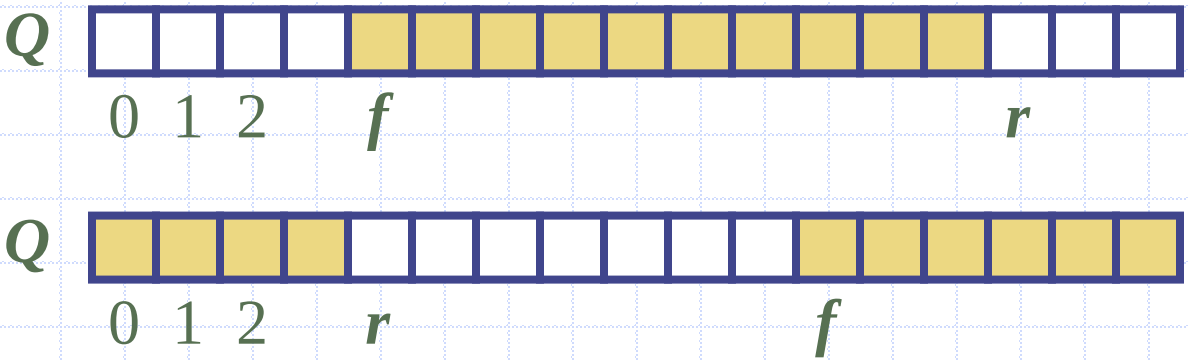
Algorithm *enqueue*(*o*)
  if *size*() = *N* – 1 **then**
    throw *FullQueueException*
  else
    Q[*r*] ← *o*
    r ← (*r* + 1) mod *N*



Queue Operations (cont.)

- Operation dequeue throws an exception if the queue is empty
- This exception is specified in the queue ADT

Algorithm *dequeue*()
  if *isEmpty*() **then**
    throw *EmptyQueueException*
  else
    $o \leftarrow Q[f]$
    $f \leftarrow (f + 1) \bmod N$
    return o



Linked-List based Queue

- Will see later…

Growable Array-based Queue

- In an enqueue operation, when the array is full, instead of throwing an exception, we can replace the array with a larger one
- Similar to what we did for an array-based stack
- The enqueue operation has amortized running time
  - $O(n)$ with the incremental strategy
  - $O(1)$ with the doubling strategy

Informal C++ Queue Interface

- Informal C++ interface for our Queue ADT
- Requires the definition of class EmptyQueueException
- A corresponding built-in STL class exists

```
template <typename Object>
class Queue {
public:
    int size();
    bool isEmpty();
    Object& front()
        throw(EmptyQueueException);
    void enqueue(Object o);
    Object dequeue()
        throw(EmptyQueueException);
};
```