Queues (5.2)

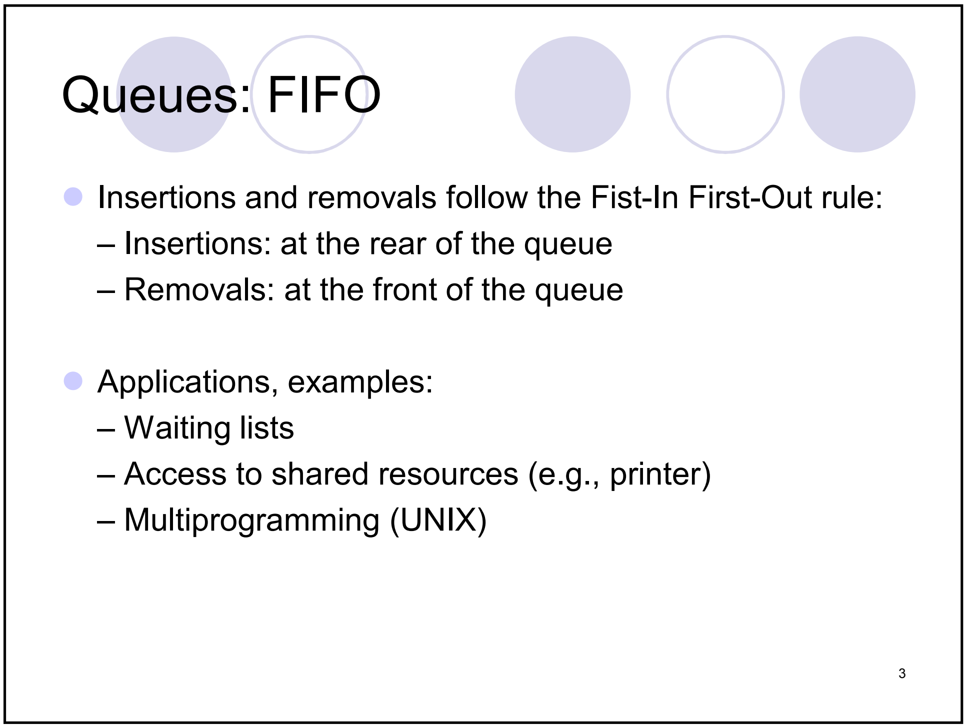
CSE 2011

Winter 2011

Announcements

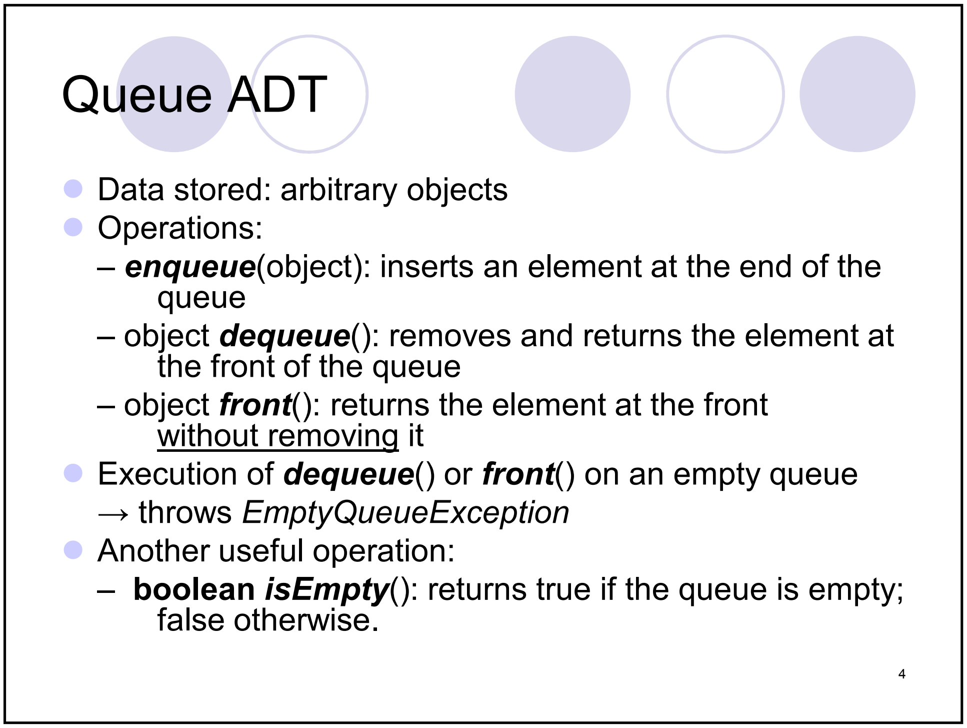
- York Programming Contest
- https://wiki.cse.yorku.ca/project/ACM/
- Link also available from the “News and Lecture Notes” page

- Midterm test: tentative date
- March 1, 13:00-14:20 (80 minutes)



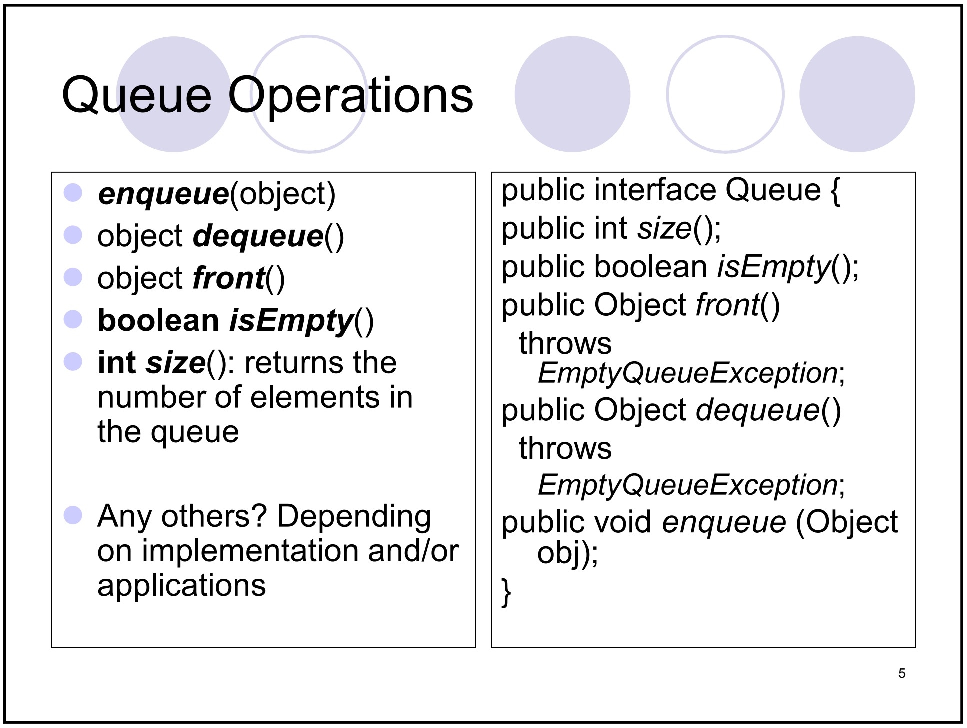
Queues: FIFO

- Insertions and removals follow the Fist-In First-Out rule:
  - Insertions: at the rear of the queue
  - Removals: at the front of the queue
- Applications, examples:
  - Waiting lists
  - Access to shared resources (e.g., printer)
  - Multiprogramming (UNIX)



Queue ADT

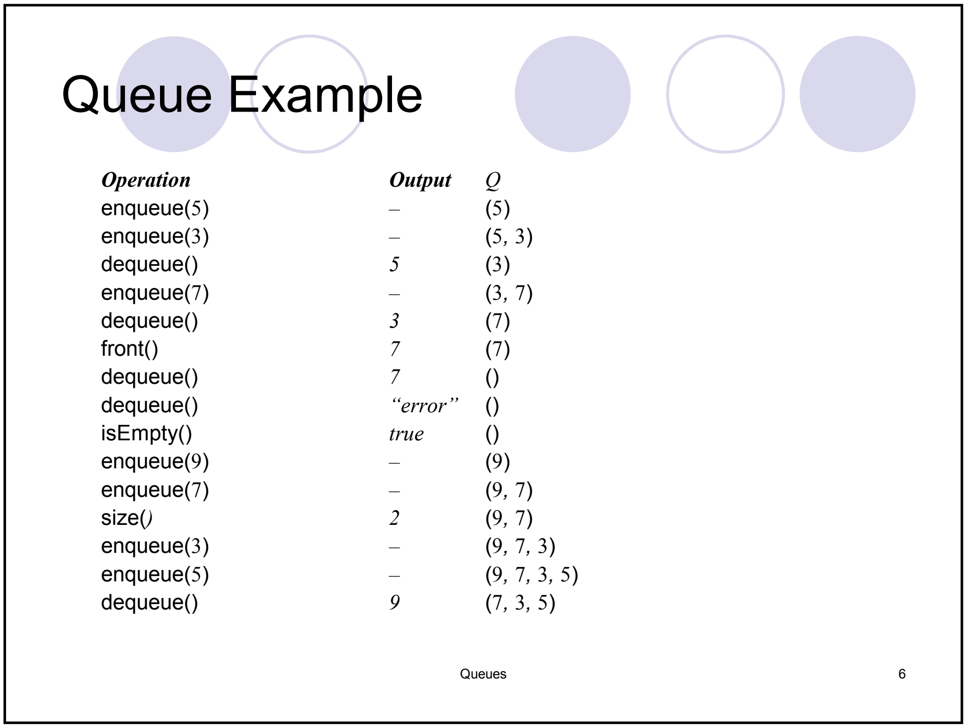
- Data stored: arbitrary objects
- Operations:
  - ***enqueue***(object): inserts an element at the end of the queue
  - object ***dequeue***(): removes and returns the element at the front of the queue
  - object ***front***(): returns the element at the front without removing it
- Execution of ***dequeue***() or ***front***() on an empty queue → throws *EmptyQueueException*
- Another useful operation:
  - **boolean *isEmpty***(): returns true if the queue is empty; false otherwise.



Queue Operations

- ***enqueue***(object)
- object ***dequeue***()
- object ***front***()
- **boolean *isEmpty***()
- **int *size***(): returns the number of elements in the queue
- Any others? Depending on implementation and/or applications

```
public interface Queue {
public int size();
public boolean isEmpty();
public Object front()
  throws
    EmptyQueueException;
public Object dequeue()
  throws
    EmptyQueueException;
public void enqueue (Object
    obj);
}
```



Queue Example

Operation	***Output***	*Q*
enqueue(5)	–	(5)
enqueue(3)	–	(5, 3)
dequeue()	*5*	(3)
enqueue(7)	–	(3, 7)
dequeue()	*3*	(7)
front()	*7*	(7)
dequeue()	*7*	()
dequeue()	*"error"*	()
isEmpty()	*true*	()
enqueue(9)	–	(9)
enqueue(7)	–	(9, 7)
size()	*2*	(9, 7)
enqueue(3)	–	(9, 7, 3)
enqueue(5)	–	(9, 7, 3, 5)
dequeue()	*9*	(7, 3, 5)

Array-based Implementation

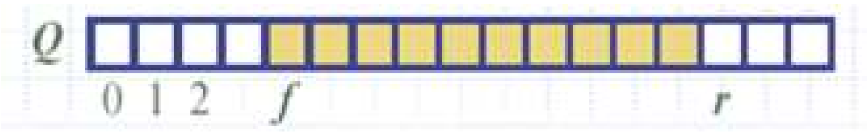
- An array *Q* of maximum size *N*
- We need to decide where the front and rear are.
- How to enqueue, dequeue?
- Running time of enqueue?
- Running time of dequeue?

Array-based Implementation (2)

- An array *Q* of maximum size *N*
- Need to keep track the front and rear of the queue:

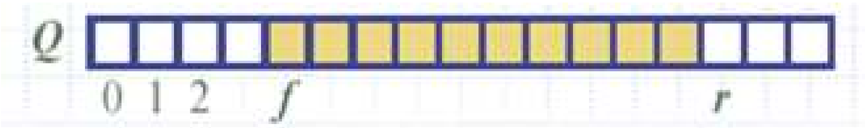
  f: index of the front object

  r: index immediately past the rear element
- Note: *Q*[*r*] is empty (does not store any object)



Array-based Implementation (3)

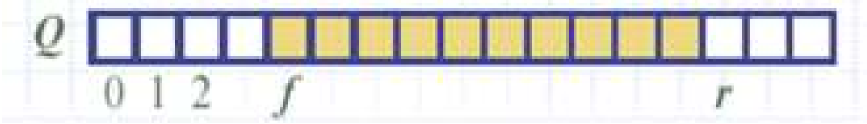
- Front element: *Q*[*f*]
- Rear element: *Q*[*r* – *1*]
- Queue is empty: *f* = *r*
- Queue size*: r* – *f*
- How to dequeue?
- How to enqueue?



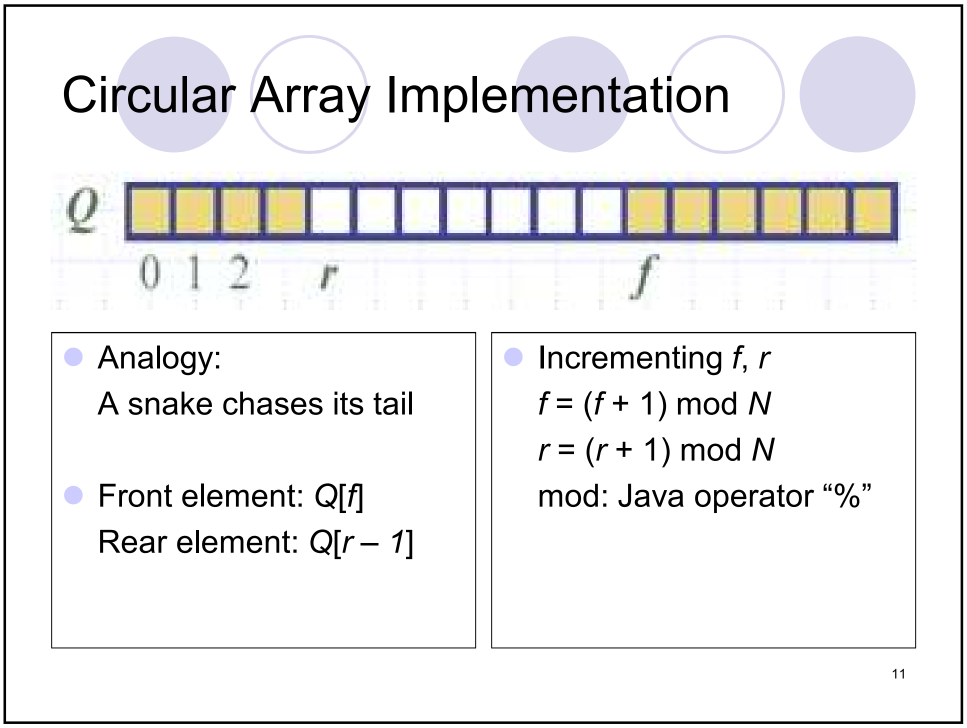
Dequeue() and Enqueue()

```
Algorithm dequeue():
if (isEmpty())
 throw QueueEmptyException;
temp = Q[f];
f = f + 1;
return temp;
```

```
Algorithm enqueue(object):
if (r == N)
  throw QueueFullException;
Q[r] = object;
r = r + 1;
```



What if *r* == *N* and Q[0…3] cells are empty?



Circular Array Implementation

- Analogy:
  A snake chases its tail
- Front element: *Q*[*f*]
  Rear element: *Q*[*r* – *1*]

- Incrementing *f*, *r*
  f = (*f* + 1) mod *N*
  r = (*r* + 1) mod *N*
  mod: Java operator "%"

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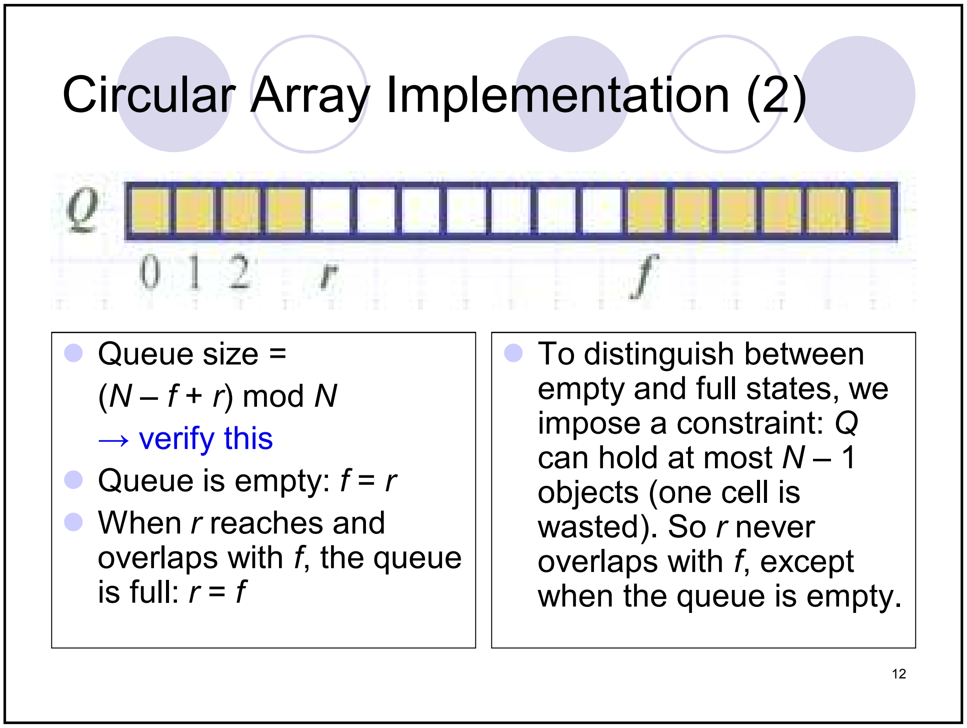

Circular Array Implementation (2)

- Queue size =
  (*N* – *f* + *r*) mod *N*
  → verify this
- Queue is empty: *f* = *r*
- When *r* reaches and overlaps with *f*, the queue is full: *r* = *f*

- To distinguish between empty and full states, we impose a constraint: *Q* can hold at most *N* – 1 objects (one cell is wasted). So *r* never overlaps with *f*, except when the queue is empty.

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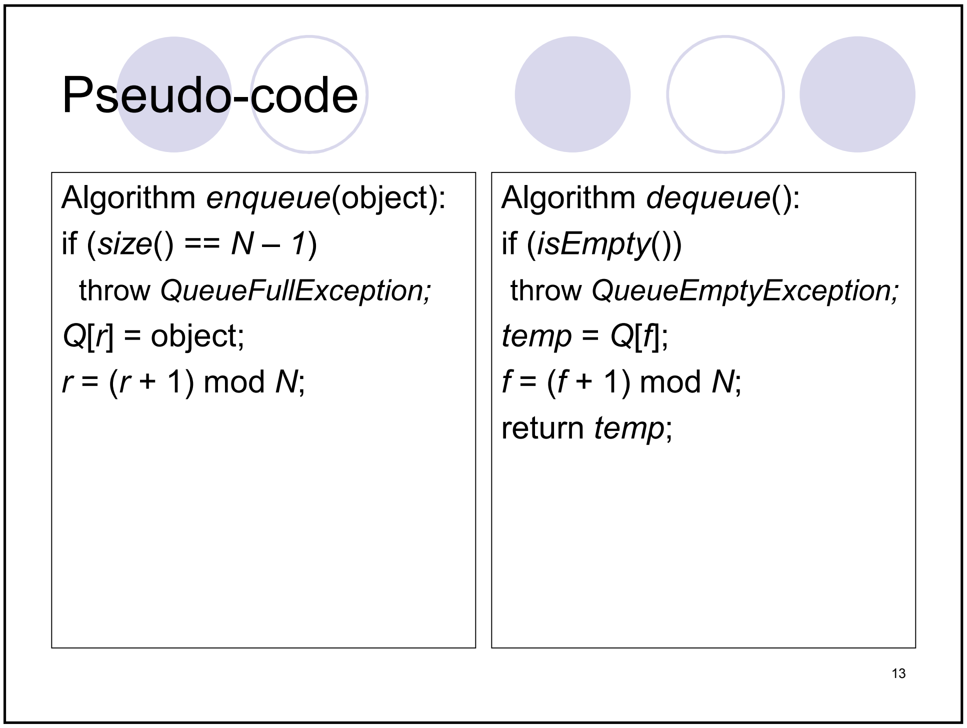
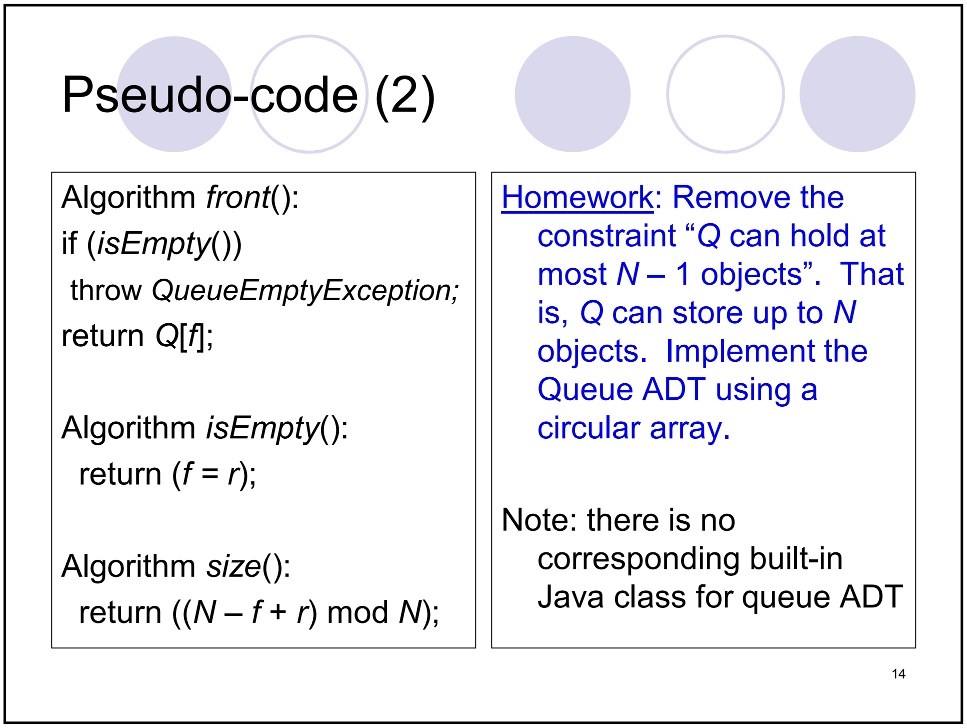


Pseudo-code

```
Algorithm enqueue(object):
if (size() == N – 1)
  throw QueueFullException;
Q[r] = object;
r = (r + 1) mod N;
```

```
Algorithm dequeue():
if (isEmpty())
  throw QueueEmptyException;
temp = Q[f];
f = (f + 1) mod N;
return temp;
```



Pseudo-code (2)

```
Algorithm front():
if (isEmpty())
  throw QueueEmptyException;
return Q[f];

Algorithm isEmpty():
  return (f = r);

Algorithm size():
  return ((N – f + r) mod N);
```

Homework: Remove the constraint “*Q* can hold at most *N* – 1 objects”. That is, *Q* can store up to *N* objects. Implement the Queue ADT using a circular array.

Note: there is no corresponding built-in Java class for queue ADT

Analysis of Circular Array Implementation

Performance

- Each operation runs in *O*(1) time

Limitation

- The maximum size *N* of the queue is fixed
- How to determine *N*?
- Alternatives?
  - Extendable arrays
  - Linked lists (singly or doubly linked???)

Singly or Doubly Linked?

- Singly linked list

```
public static class Node
   {
      private Object data;
      private Node  next;
   }
```

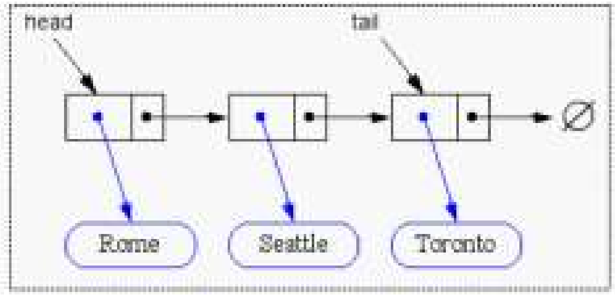
- Needs less space.
- Simpler code in some cases.
- Insertion at tail takes O(n).

- Doubly linked list

```
public static class DNode
   {
      private Object data;
      private Node  prev;
      private Node next;
   }
```

- Better running time in many cases (discussed before).

Implementing a Queue with a Singly Linked List



- Head of the list = front of the queue (enqueue)
- Tail of the list = rear of the queue (dequeue)
- *Is this efficient?*

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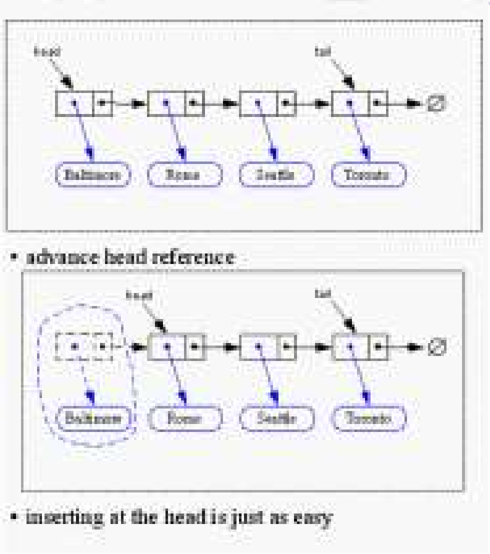
dequeue(): Removing at the Head



- advance head reference
- inserting at the head is just as easy

Running time = ?

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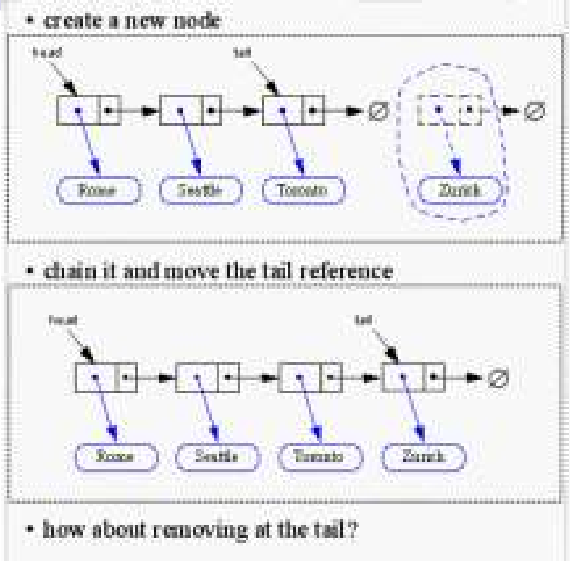
enqueue(): Inserting at the Tail



- create a new node

- chain it and move the tail reference

- how about removing at the tail?

Running time = ?

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Method *enqueue*() in Java

```
public void enqueue(Object obj) {
    Node node = new Node();
    node.setElement(obj);
    node.setNext(null);   // node will be new tail node
    if (size == 0)
      head = node;          // special case of a previously empty queue
    else
      tail.setNext(node);  // add node at the tail of the list
    tail = node;             // update the reference to the tail node
    size++;
}
```

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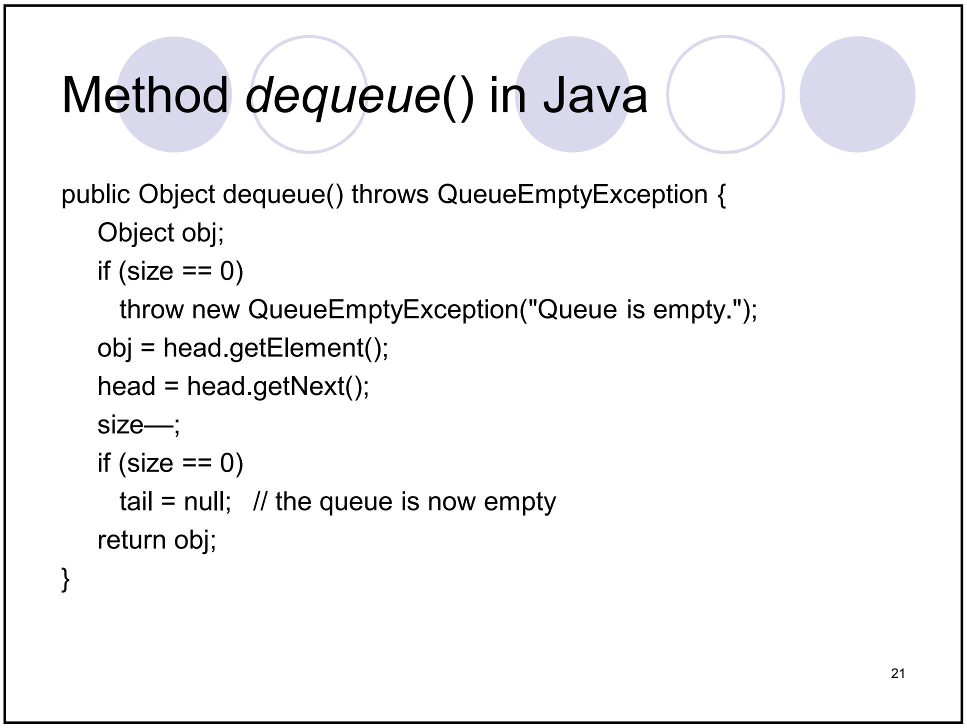
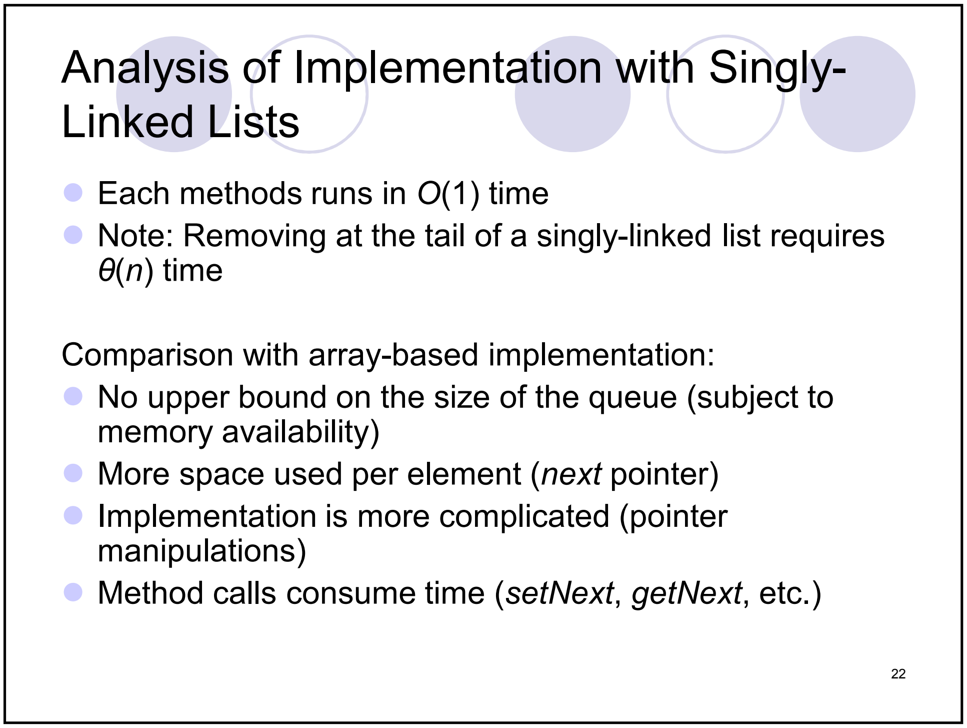


Method *dequeue*() in Java

```
public Object dequeue() throws QueueEmptyException {
    Object obj;
    if (size == 0)
      throw new QueueEmptyException("Queue is empty.");
    obj = head.getElement();
    head = head.getNext();
    size—;
    if (size == 0)
      tail = null;   // the queue is now empty
    return obj;
}
```

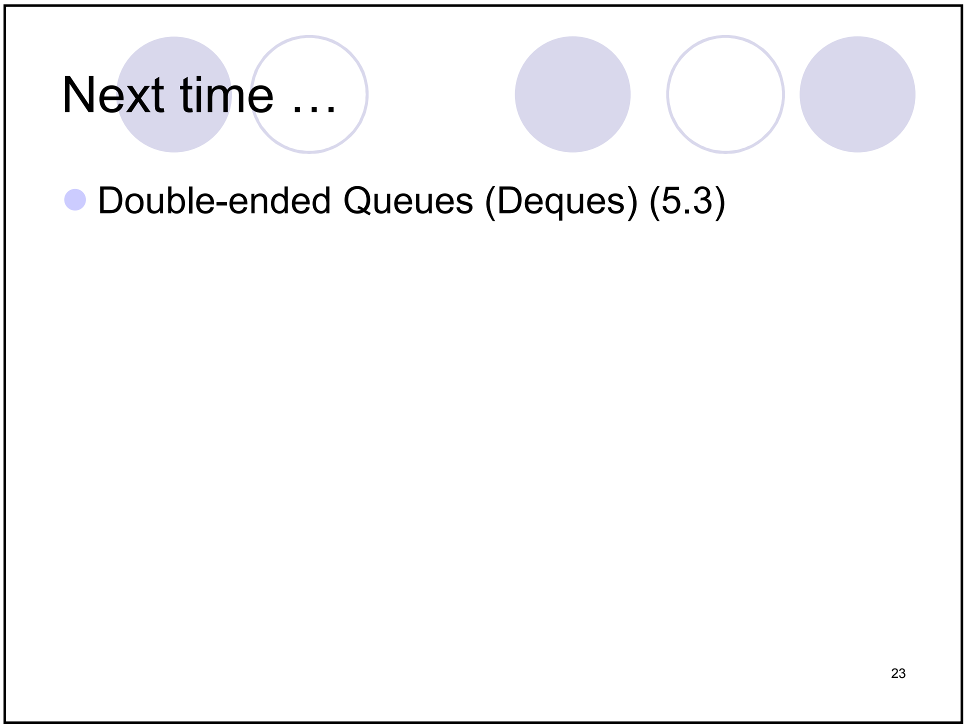


Analysis of Implementation with Singly-Linked Lists

- Each methods runs in $O(1)$ time
- Note: Removing at the tail of a singly-linked list requires $\theta(n)$ time

Comparison with array-based implementation:

- No upper bound on the size of the queue (subject to memory availability)
- More space used per element (*next* pointer)
- Implementation is more complicated (pointer manipulations)
- Method calls consume time (*setNext*, *getNext*, etc.)



Next time …

- Double-ended Queues (Deques) (5.3)