15CSE201 : Data Structures and Algorithms

Queues

By Ritwik M

Based on the reference materials by Prof. Goodrich, OCW METU and Dr. Vidhya Balasubramanian

Queues

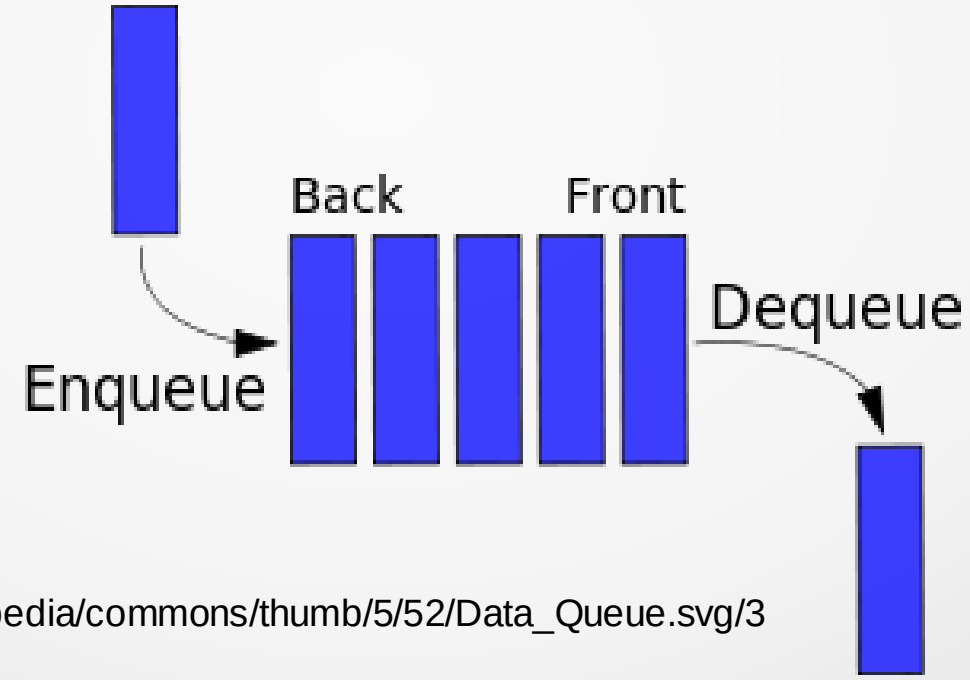
- It is a first-in-first-out abstract data type
- Applications in Real World
  - Transportation
  - Operations Research
  - Acts as buffer in many applications

Src: www.sabc.co.za

Src: www.illustrationsource.com

Queues: An Overview

- Element that is inserted first is removed first
  - Insertions at the rear of the queue and deletions at the front of the queue



http://upload.wikimedia.org/wikipedia/commons/thumb/5/52/Data_Queue.svg/300px-Data_Queue.svg.png

Queue ADT: Main Operations

- enqueue(o)
  - Inserts an object o at the end of the queue
  - Input: object; Output: None
- dequeue()
  - Removes and returns the first element in the queue
  - Input: none; Output: object
  - Error occurs if queue is empty

Other Queue Operations

- size()
  - Returns the number of objects in the queue
- isEmpty()
  - Returns a Boolean indicating if the queue is empty
- front()
  - Return first element of the queue without removing it. Error occurs if queue is empty
  - Input: None; Output: Object

Queue Exceptions

- Some operations may cause an error causing an exceptions
- Exceptions in the Queue ADT
  - QueueEmptyException
    - dequeue() and front() cannot be performed if the stack is empty
  - QueueFullException
    - Occurs when the stack has a maximum size limit ie implemented with an array
    - enqueue(o) cannot occur when the stack is full

Queue Example

Operation	Output	Queue Contents
enqueue(5)	-	(5)
enqueue(3)	-	(5,3)
enqueue(7)	-	(5,3,7)
dequeue()	5	(3,7)
size()	2	(3,7)
enqueue(4)	-	(3,7,4)
dequeue()	3	(7,4)
dequeue()	7	(4)
size()	1	(4)
dequeue()	4	()
dequeue()	“error”	()

Queue Interface (C++)

```
template <typename Object>
class Queue {
public:
    int size() const: //returns number of objects in the queue
    bool isEmpty() //returns true if queue is empty, false otherwise
    Object& front() throw(QueueEmptyException)
        //returns object in the front of the queue, throws exception if
          queue empty
    void enqueue(const Object& obj): //inserts object at front of queue
    Object dequeue() throw(QueueEmptyException)
}
```

Queue Interface (Python)

- class MyQueue():

  def enqueu(self, value): //inserts the value into the front of the queue

  def dequeue(self): //returns and removes element at front of queue if not empty, else throws exception

  def front(self): //returns the front element without removing it if the queue is not empty, else throws exception

  def size(self): //returns the number of elements currently in queue

  def isEmpty(self): //returns True if queue is empty

Exercise

- Describe the output of the following series of queue operations like a stack
  - enqueue(5),enqueue(3), dequeue(), enqueue(2), enqueue(8), dequeue(), dequeue(), isEmpty(), enqueue(9), enqueue(1), dequeue(), enqueue(7), enqueue(6), front(), dequeue(), dequeue(), enqueue(4), dequeue(), dequeue()
- Show how to implement a queue using two stacks. Analyze the running time of the queue operations.

Array based implementation of a Queue

- A Queue may be implemented by using a simple array
  - An N-element array
    - Queue is limited by the size of the array
  - Two variable to keep track of front and rear
    - Integer f denotes the index of the front element
    - Integer r denotes the position immediately past the rear element
- Strategy
  - Elements are added left to right

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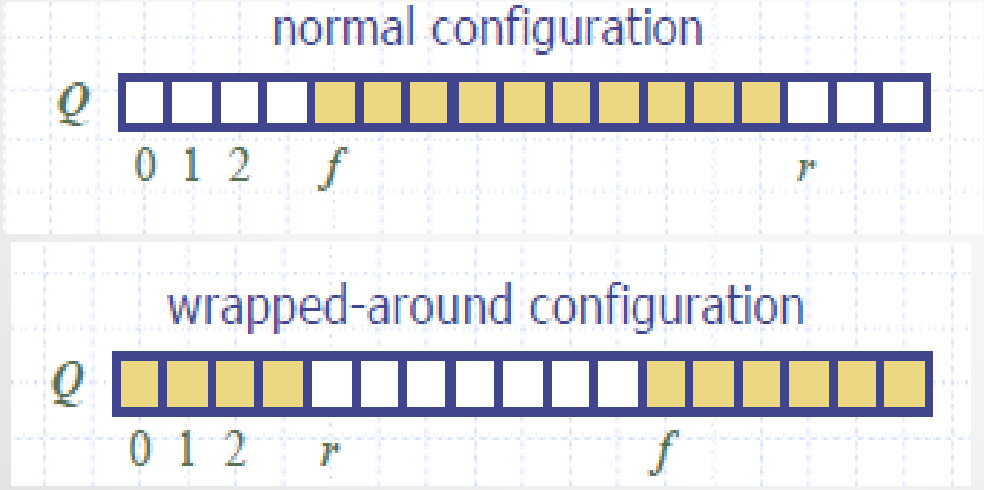
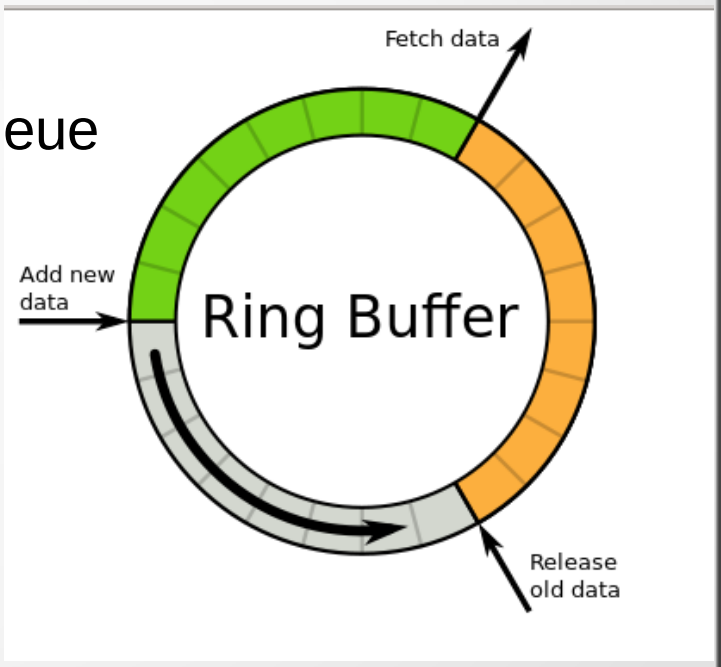
Circular Array Implementation

- After repeated enqueue and dequeue operations the rear part may reach end of queue
  - There may be place at the beginning of array
- Circular Queue
  - Allow f and r to wrap around to end of queue



Source: Goodrich



http://en.wikipedia.org/wiki/File:Ring_

Queue ADT Functions

- **Algorithm** size()

  return (*N*-*f*+*r*) mod *N*

- **Algorithm** isEmpty()

  return (*f*=*r*)

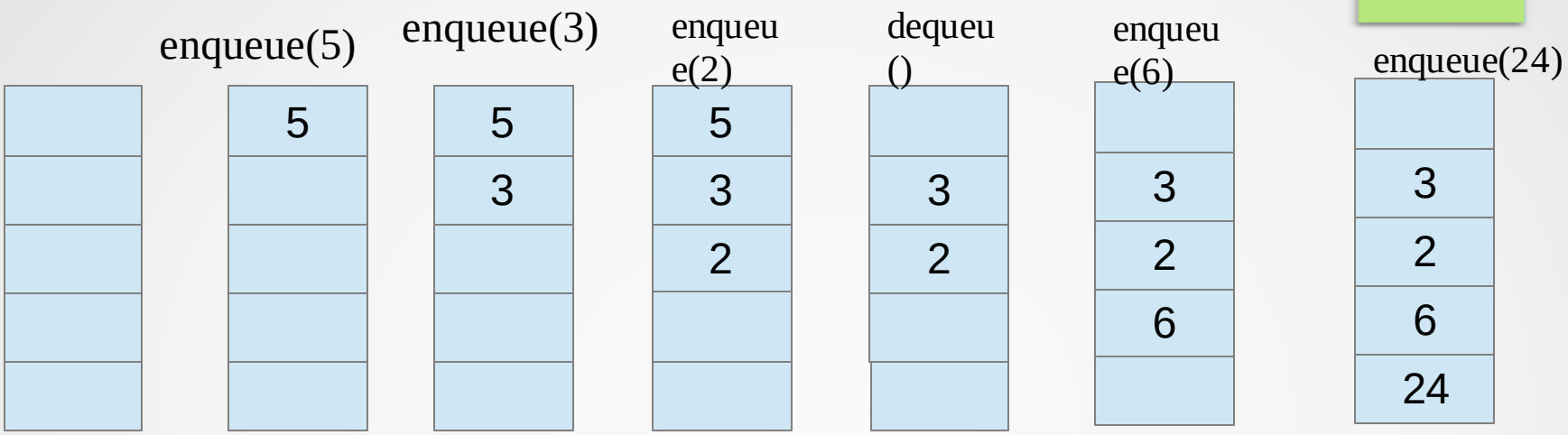
- **Algorithm** front()

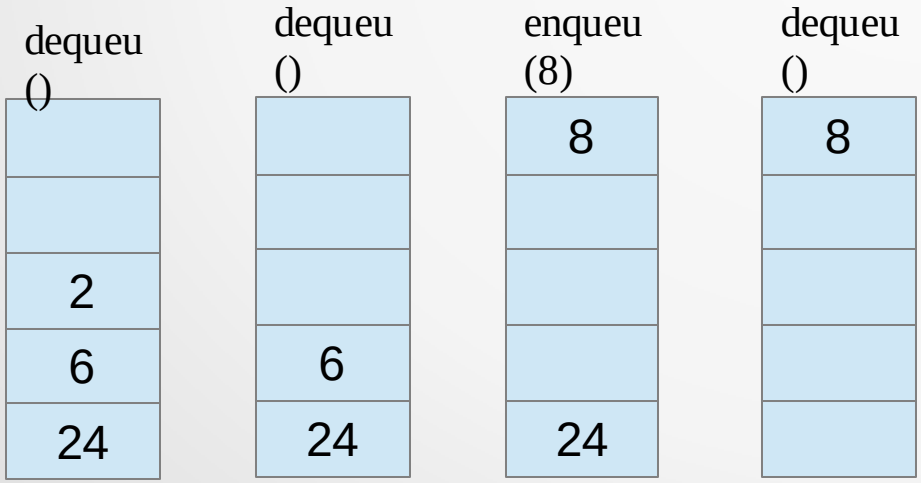
  if isEmpty() **then**

  throw a QueueEmptyException

  return *Q*[*f*]

Circular Queue: Example





- enqueu(24)
  - $r \leftarrow (r+1) \bmod N$
  - *= (4+1) mod 5 =0*
- *dequeu() (fig 11)*
  - $f \leftarrow (f+1) \bmod N$
  - *= (4+1) mod 5 =0*
- *size() (after fig 10)*
  - $(N-f+r) \bmod N$
  - *= (5-4+1)mod 5= 2*

Difficulties of Circular Queue

- Full / Empty Buffer Distinction
- Solution:
  - Always keep one slot open.
  - Use a fill count to distinguish the two cases.
  - Use an extra mirroring bit to distinguish the two cases.
  - Use read and write counts to get the fill count from.
  - Use absolute indices.
  - Record last operation.

Complexity Analysis

- Time Complexity
  - size – $O(1)$
  - isEmpty – $O(1)$
  - front – $O(1)$
  - enqueue – $O(1)$
  - dequeue – $O(1)$
- Space Complexity
  - $O(N)$

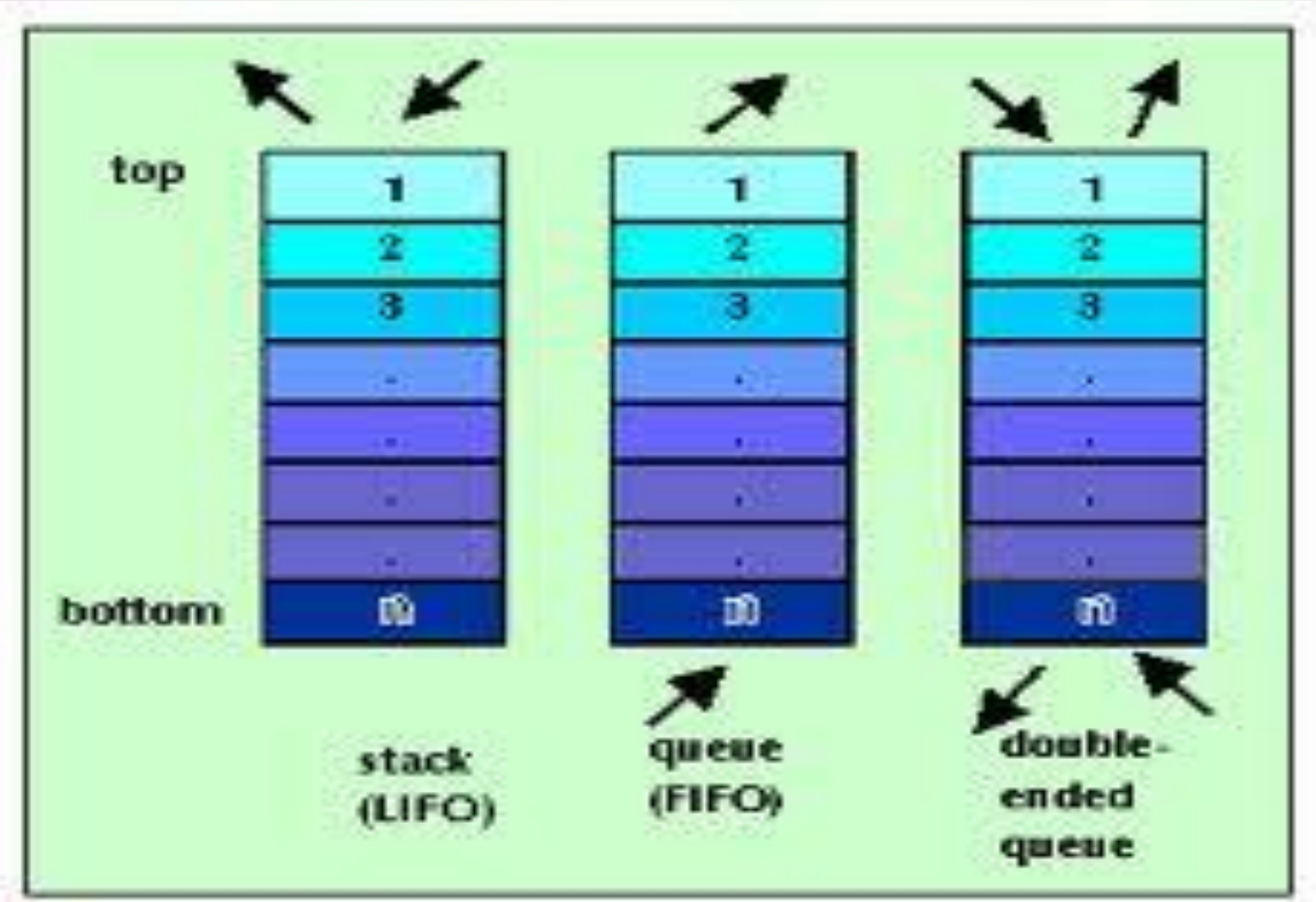
Growable Array-based Queue

- 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

Exercises

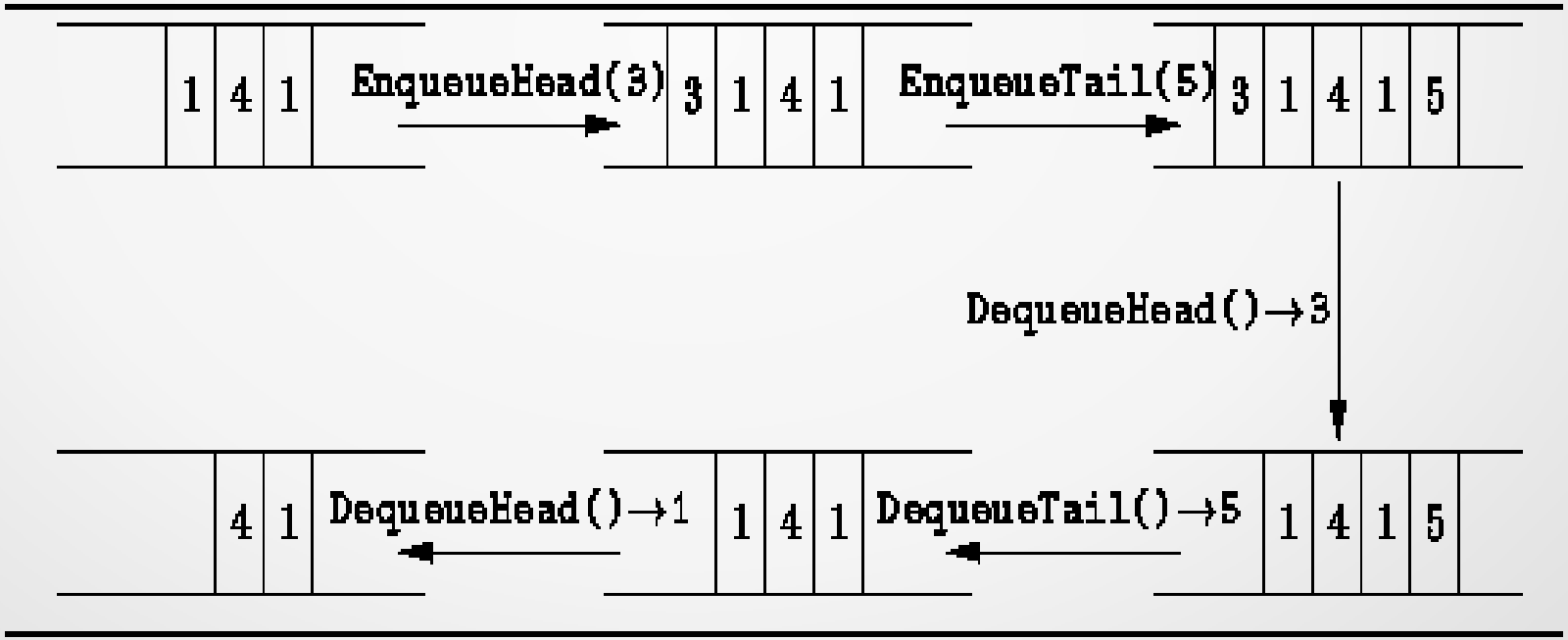
- Reverse the order of elements in a stack S using one additional queue
- Using additional non-array variables, order all elements on a queue using
  - Two additional queues
  - One additional queue
- Is it possible to keep 2 stacks in a single array, if one grows from position one of the array, and the other grows from the last position. Write a procedure PUSH(x,s) that pushes element x onto stack S, where S is one or the other of these two stacks. Include all necessary error checks.

Double-Ended Queue



Double-Ended Queues

- It is a queue like data structure that supports insertion and deletion at both ends
  - Front and rear of the queue
- Also known as deque(pronounced "*deck*")



Deque Abstract Data Type

- insertFirst(*o*)
  - Insert a new object *o* at the beginning of D
  - Input: Object; Output: None
- insertLast(*o*)
  - Insert a new object *o* at the end of D
  - Input: Object; Output: None
- RemoveFirst()
  - Remove the first object of D. Error occurs if D is empty
  - Input: None; Output: None
- RemoveLast()
  - Remove the last object of D. Error occurs if D is empty
  - Input: None; Output: None

Additional Deque functions

- first()
  - Return first object of D; error occurs if D is empty
  - Input: None; Output: Object
- last()
  - Return last object of D; error occurs if D is empty
  - Input: None; Output: Object
- size()
  - Returns the number of objects in D
- isEmpty()
  - Returns a Boolean indicating if D is empty

Implementation

- Can use a dynamic array
  - uses a variant of a dynamic array that can grow from both ends, sometimes called array deques
  - Can also use circular arrays
- Dynamic Arrays
  - Works like regular arrays
  - No limit on size
    - array is discarded and replaced by a bigger array whenever necessary
    - Can use either linear or doubling strategy