ساختمان داده و الگوریتم ها (CE203)

جلسه نهم:
کاربردهای پشته و صف

سجاد شیرعلی شهرضا

پاییز 1401

دوشنبه، 2 آبان 1401

Based on Washington University CSE 373 (Autumn 2020 by Hunter Schafer), University of North Florida COP2220 (Chip Klostermeyer), and University of Illinois Chicago CS 201 (Spring 2014 by Bing Liu) slides

اطلاع رسانی

- بخش مرتبط کتاب برای این جلسه: 10
- امتحانک دوم (اولین امتحانک1!):
  - دوشنبه هفته آینده، 9 آبان 1401
  - در طی ساعت کلاس، سر کلاس، به صورت حضوری

کاربردهای پشته

نمونه هایی از حل مسئله با استفاده از پشته

Line Editing

- A line editor
- Place characters read into a buffer
  - May use a backspace symbol (denoted by ←) to do error correction
- Goal: Calculate the final text (corrected) and print it in reverse

Input : `abc_defgh←2klpqr←←wxyz`

Corrected Input : `abc_defg2klpwxyz`

Reversed Output : `zyxwplk2gfed_cba`

Line Editing: Solution

- Initialize a new stack
- For each character read:
  - If it is a backspace, pop out last char entered
  - If not a backspace, push the char into stack
- To print in reverse, pop out each char for output

Bracket Matching Problem

- Ensures that pairs of brackets are properly matched
- An Example:

{a,(b+f[4])*3,d+f[5]}

- Bad Examples:
  - (..)..) // too many closing brackets
  - (..(..) // too many open brackets
  - [..(..]..) // mismatched brackets

Bracket Matching Problem: Solution

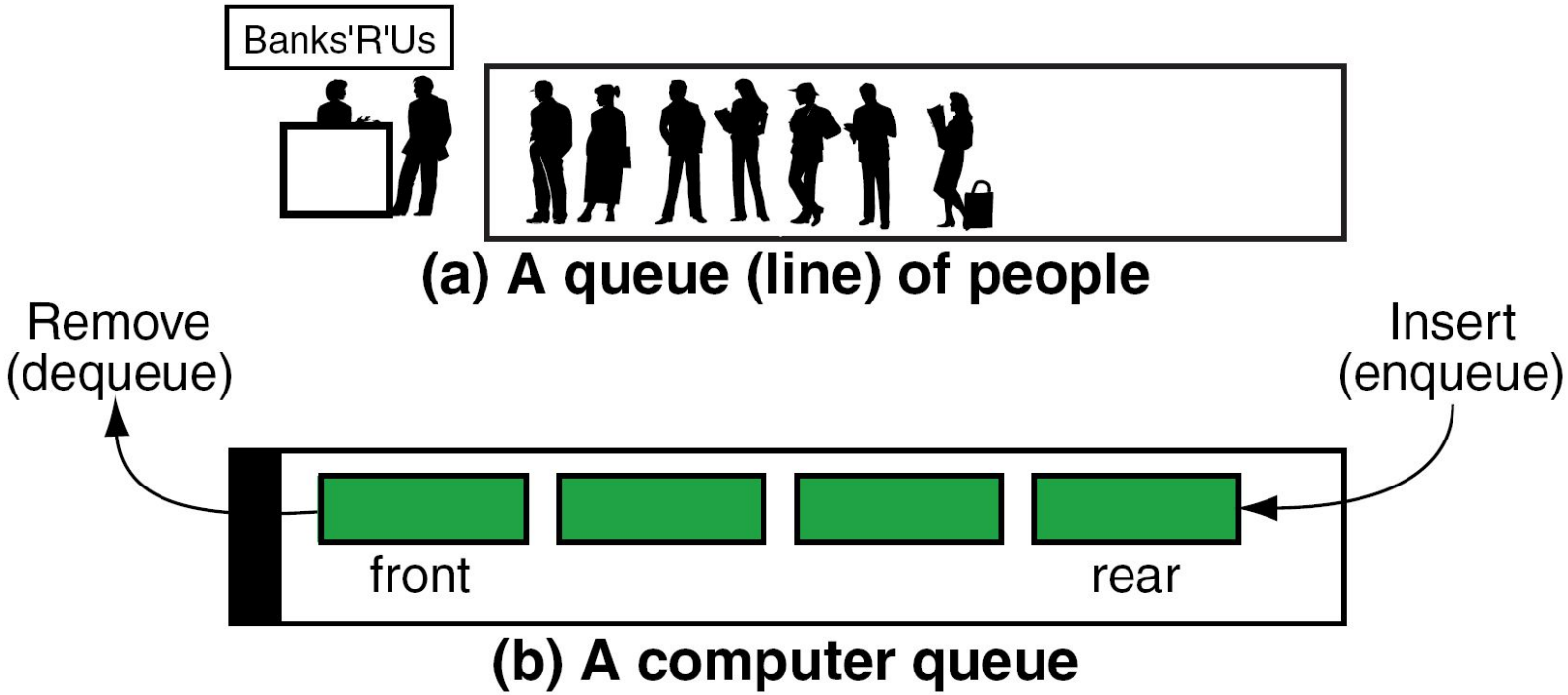
- Initialize the stack to empty
- For every char read
  - If open bracket then push onto stack
  - If close bracket, then
    - Return & remove most recent item from the stack
    - If doesn't match then flag error
  - If non-bracket, skip the char read

سوال؟

صف

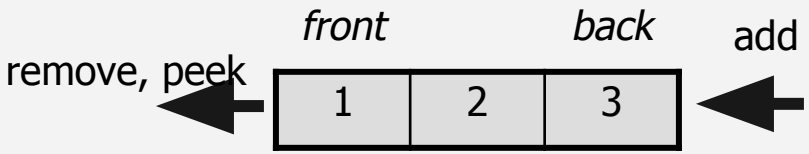
مجموعه ای از اشیاء پشت سر هم قرار گرفته

Idea


Banks'R'Us
(a) A queue (line) of people
Remove
(dequeue)
Insert
(enqueue)
front
rear
(b) A computer queue

Queue ADT

- Represents an ordered sequence of elements
- Elements can only be added from one end and removed from the other
- First-In, First-Out (FIFO)
- Elements stored in order of insertion



QUEUE ADT

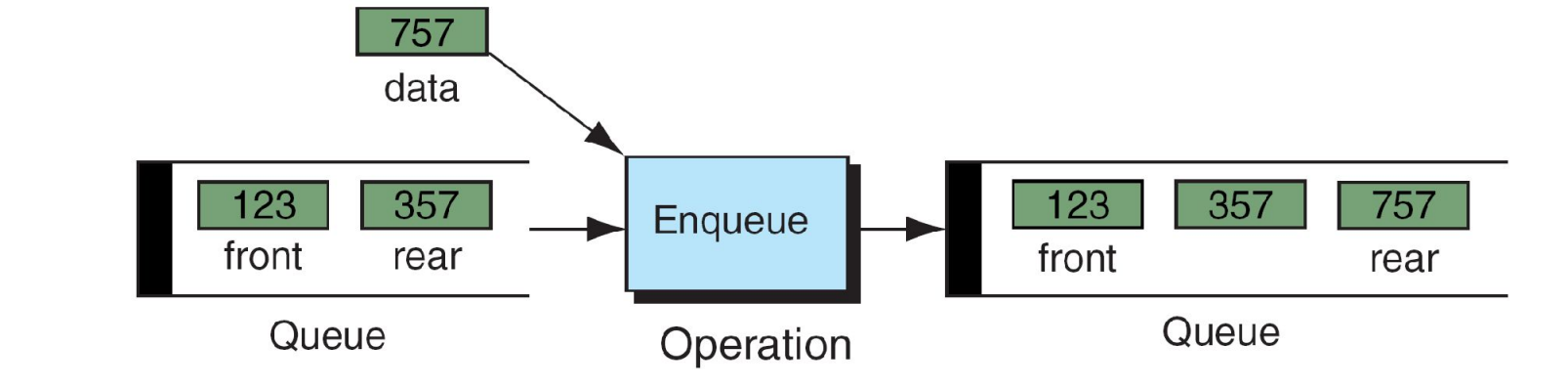
State

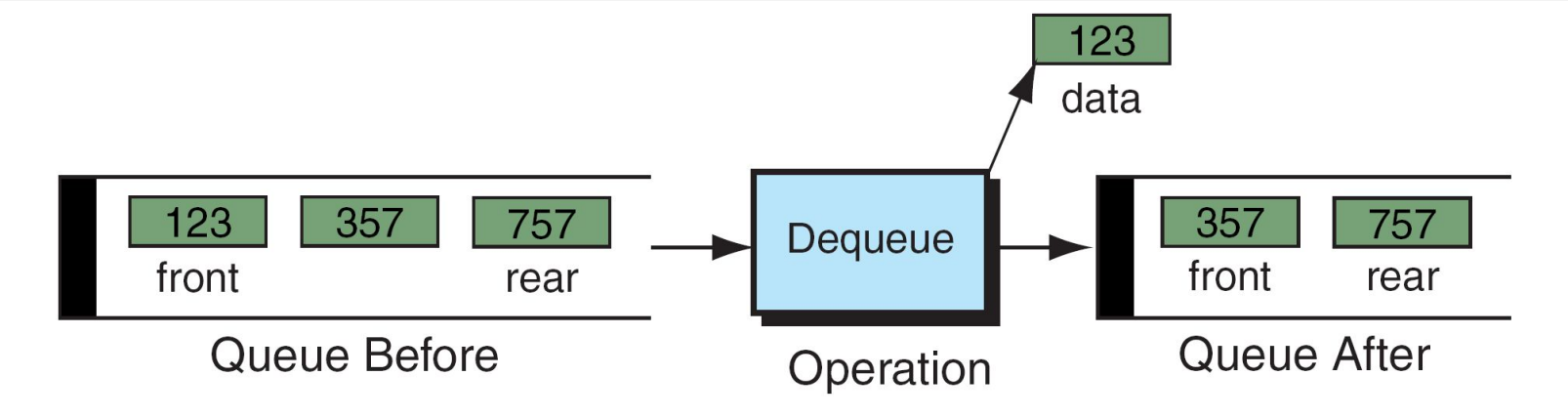
Collection of ordered items
Count of items

Behavior

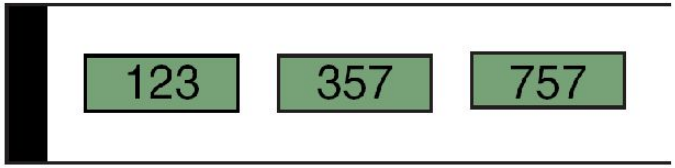
```
add(item) add item to back
remove() remove and return
item at front
peek() return item at front
size() count of items
isEmpty() count is 0?
```

Operations

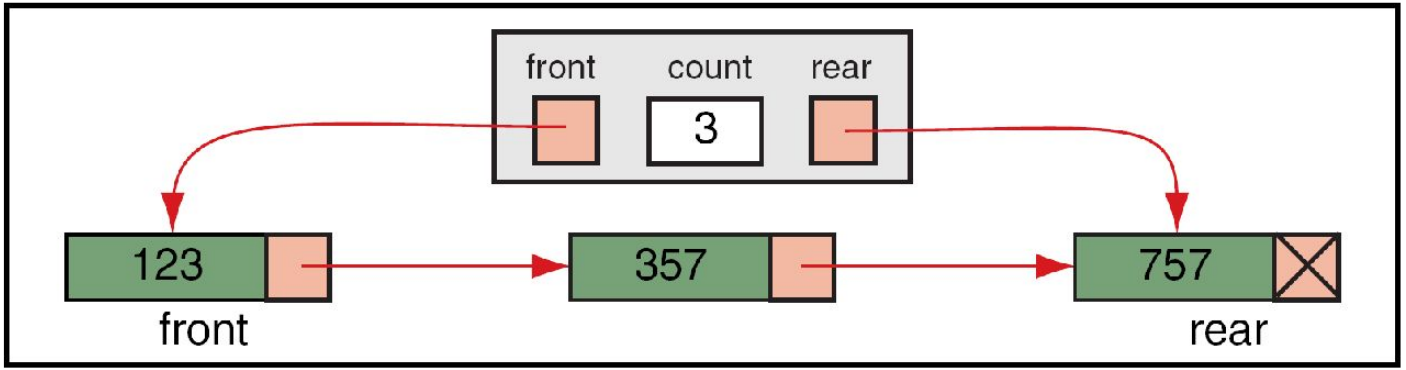

757
data
123
357
front
rear
Queue
Enqueue
Operation
123
357
757
front
rear
Queue


123
data
123
357
757
front
rear
Queue Before
Dequeue
Operation
357
757
front
rear
Queue After

Linked-list Implementation



(a) Conceptual queue



(b) Physical queue

Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

LinkedQueue<E>

State

Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
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isEmpty() count is 0?

LinkedQueue<E>

State

Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

size = 0

front →

back →

Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

LinkedQueue<E>

State

Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

size = 0

add(5)

front →

back →

Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
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size() count of items
isEmpty() count is 0?

LinkedQueue<E>

State

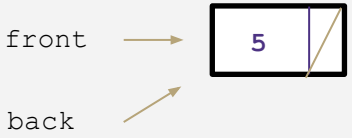
Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

size = 1

add(5)



Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
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isEmpty() count is 0?

LinkedQueue<E>

State

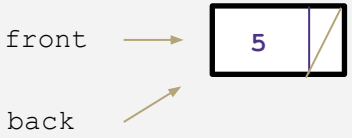
Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

size = 1

add(5)
add(8)



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QUEUE ADT

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isEmpty() count is 0?

LinkedQueue<E>

State

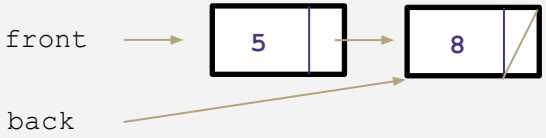
Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

size = 2

add(5)
add(8)



Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

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LinkedQueue<E>

State

Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

size = 2

add(5)
add(8)
remove()

Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
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add(5)
add(8)
remove()

Implementing a Queue with Linked Nodes

QUEUE ADT

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LinkedQueue<E>

State

Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

Big-Oh Analysis

remove()

peek()

size()

isEmpty()

add()

size = 1

add(5)
add(8)
remove()

Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
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isEmpty() count is 0?

LinkedQueue<E>

State

Node front
Node back
size

Behavior

add – add node to back
remove – return and remove node at front
peek – return node at front
size – return size
isEmpty – return size == 0

Big-Oh Analysis

remove()	O(1) Constant
peek()	
size()	
isEmpty()	
add()	

size = 1

add(5)
add(8)
remove()

Implementing a Queue with Linked Nodes

QUEUE ADT

State

Collection of ordered items
Count of items

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Big-Oh Analysis

remove()	O(1) Constant
peek()	O(1) Constant
size()	
isEmpty()	
add()	

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add(5)
add(8)
remove()

Implementing a Queue with Linked Nodes

QUEUE ADT

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remove()	O(1) Constant
peek()	O(1) Constant
size()	O(1) Constant
isEmpty()	
add()	

size = 1

add(5)
add(8)
remove()

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isEmpty()	O(1) Constant
add()	

size = 1

add(5)
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remove()

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Big-Oh Analysis

remove()	O(1) Constant
peek()	O(1) Constant
size()	O(1) Constant
isEmpty()	O(1) Constant
add()	O(1) Constant

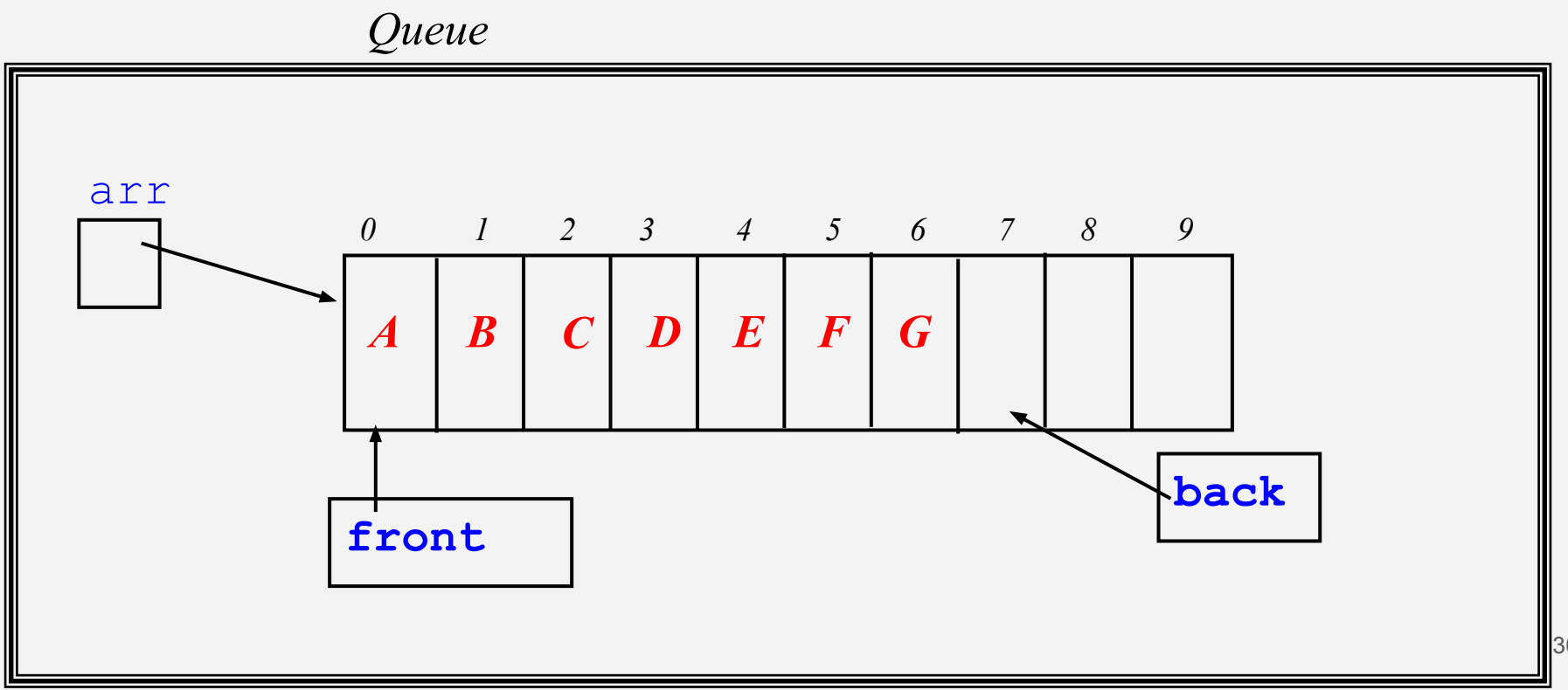
size = 1

```
add(5)
add(8)
remove()
```

سوال؟

پیاده سازی صف با آرایه

Idea



Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
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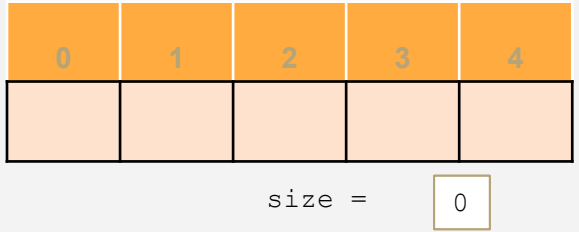

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
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size() count of items
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ArrayQueueV1<E>

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data[]
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peek – return node at 0
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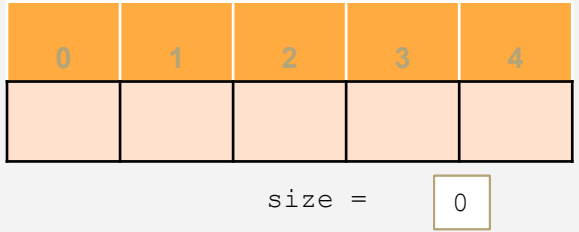
add(5)



Implementing a Queue with an Array

QUEUE ADT

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Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

add(5)

0	1	2	3	4
5				

size = 1

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

```
add(5)
add(8)
```

0	1	2	3	4
5				

size = 1

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

add(5)
add(8)

0	1	2	3	4
5	8			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

```
add(5)
add(8)
add(9)
```

0	1	2	3	4
5	8			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

```
add(5)
add(8)
add(9)
```

0	1	2	3	4
5	8	9		

size = 3

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

```
add(5)
add(8)
add(9)
remove()
```

0	1	2	3	4
5	8	9		

size = 3

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

```
add(5)
add(8)
add(9)
remove()
```

0	1	2	3	4
8	9			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

Big-Oh Analysis

peek()

size()

isEmpty()

add()

remove()

add(5)
add(8)
add(9)
remove()

0	1	2	3	4
8	9			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

Big-Oh Analysis

peek()	O(1) Constant
size()	
isEmpty()	
add()	
remove()	

add(5)
add(8)
add(9)
remove()

0	1	2	3	4
8	9			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

Big-Oh Analysis

peek()	O(1) Constant
size()	O(1) Constant
isEmpty()	
add()	
remove()	

add(5)
add(8)
add(9)
remove()

0	1	2	3	4
8	9			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

Big-Oh Analysis

peek()	O(1) Constant
size()	O(1) Constant
isEmpty()	O(1) Constant
add()	
remove()	

add(5)
add(8)
add(9)
remove()

0	1	2	3	4
8	9			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
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add(item) add item to back
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ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
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isEmpty – return size == 0

Big-Oh Analysis

peek()	O(1) Constant
size()	O(1) Constant
isEmpty()	O(1) Constant
add()	What are different cases?
remove()	

```
add(5)
add(8)
add(9)
remove()
```

0	1	2	3	4
8	9			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
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ArrayQueueV1<E>

State

data[]
size

Behavior

add – data[size] = value, if out of room grow
remove – return/remove at 0, shift everything
peek – return node at 0
size – return size
isEmpty – return size == 0

Big-Oh Analysis

peek()	O(1) Constant
size()	O(1) Constant
isEmpty()	O(1) Constant
add()	O(n) Linear: if we need to resize O(1) Constant: otherwise
remove()	

```
add(5)
add(8)
add(9)
remove()
```

0	1	2	3	4
8	9			

size = 2

Implementing a Queue with an Array

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
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سوال؟

Data Structure Invariants

- Invariant: a property of a data structure that is always true between operations
  - True when finishing any operation
  - It can be counted on to be true when starting an operation

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Data Structure Invariants

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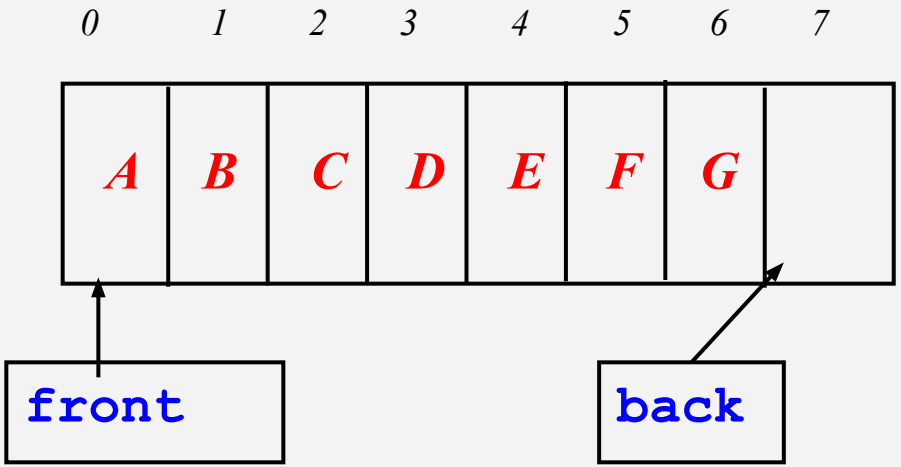
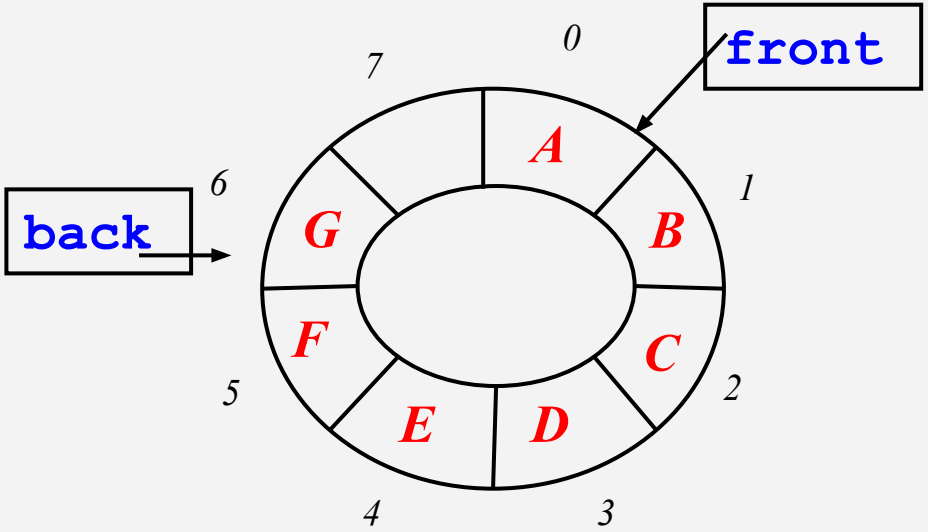
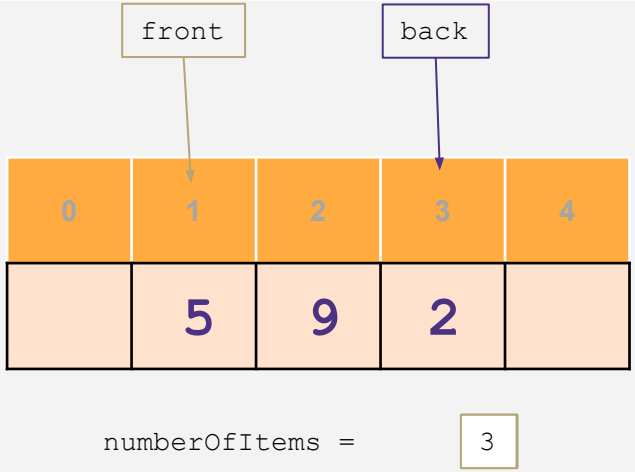
- ArrayQueue is basically an ArrayList
- What invariants does ArrayList have for its data array?
  - The i-th item in the list is stored in data[i]
- Notice: serving this invariant is what slows down the operation.
- Could we choose a different invariant?

Circular Array



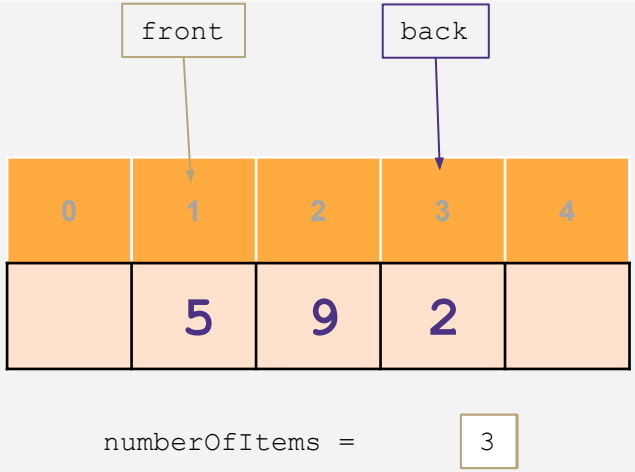


Wrapping Around with “front” and “back” indices



Wrapping Around with “front” and “back” indices

add(7)



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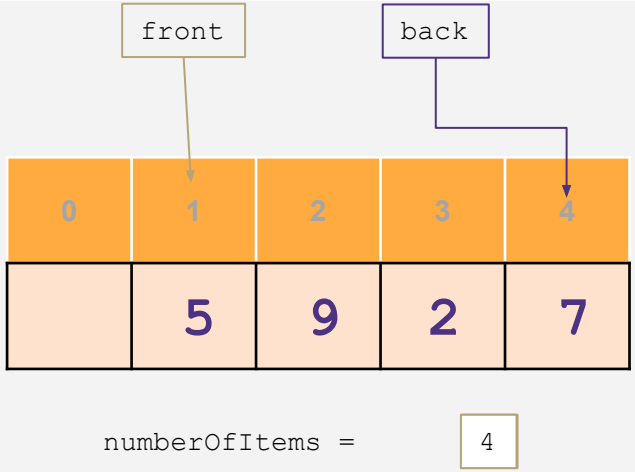
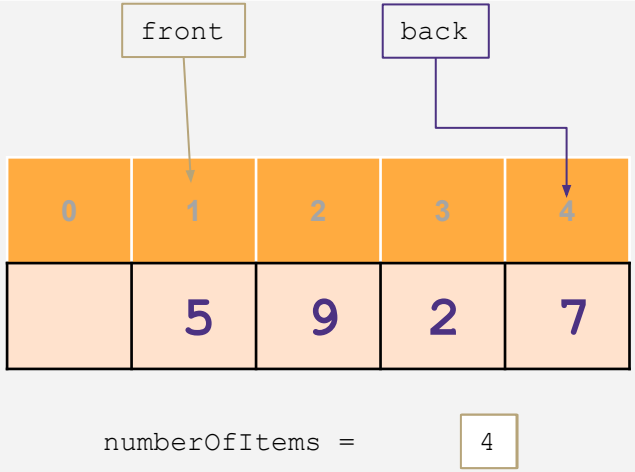


Wrapping Around with “front” and “back” indices

add(7)
add(4)



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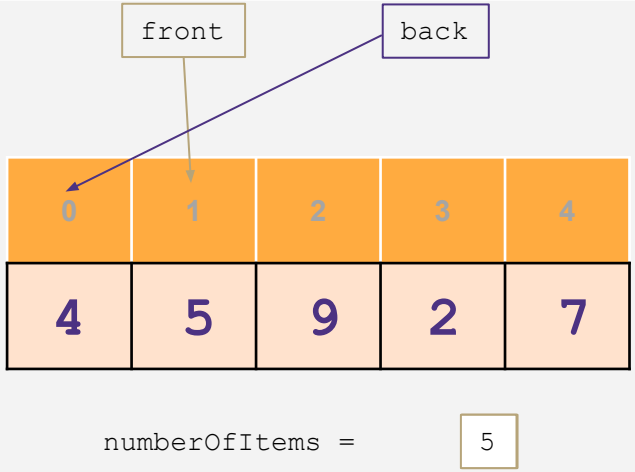

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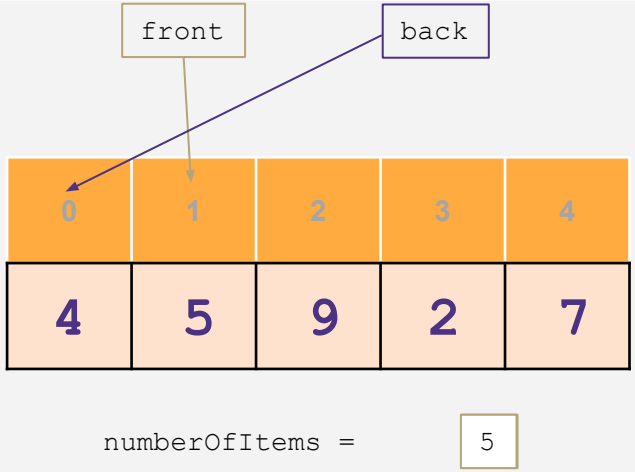

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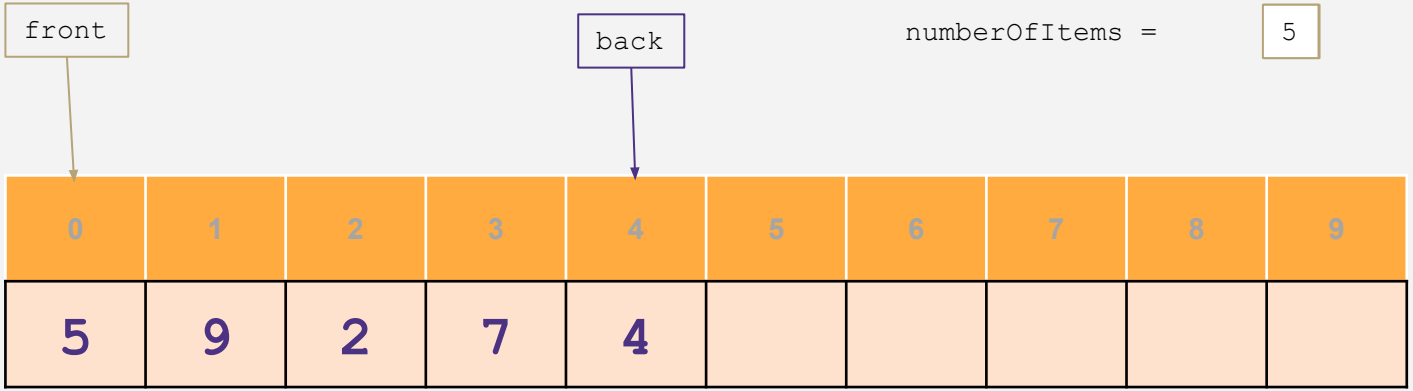
4	5	9	2	7



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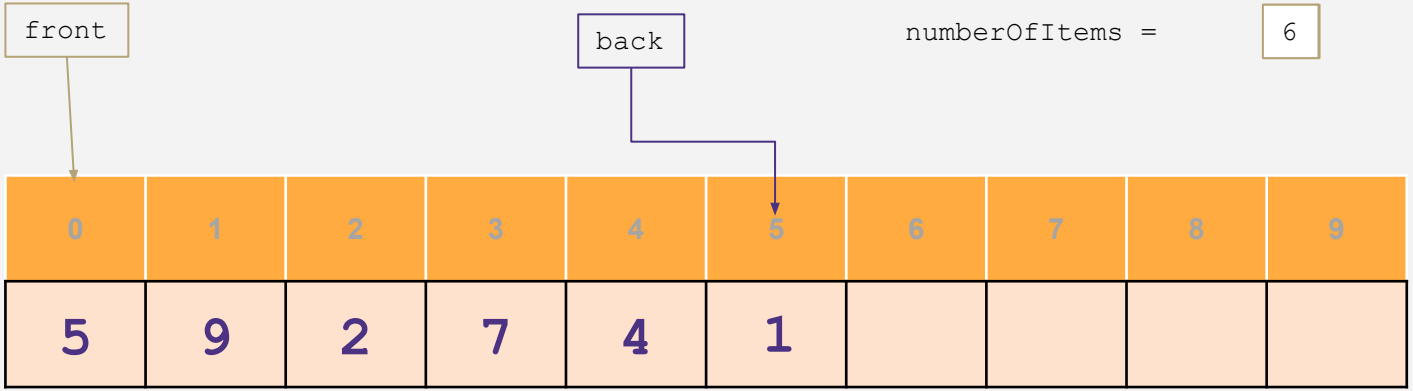

Wrapping Around with “front” and “back” indices

add(7)
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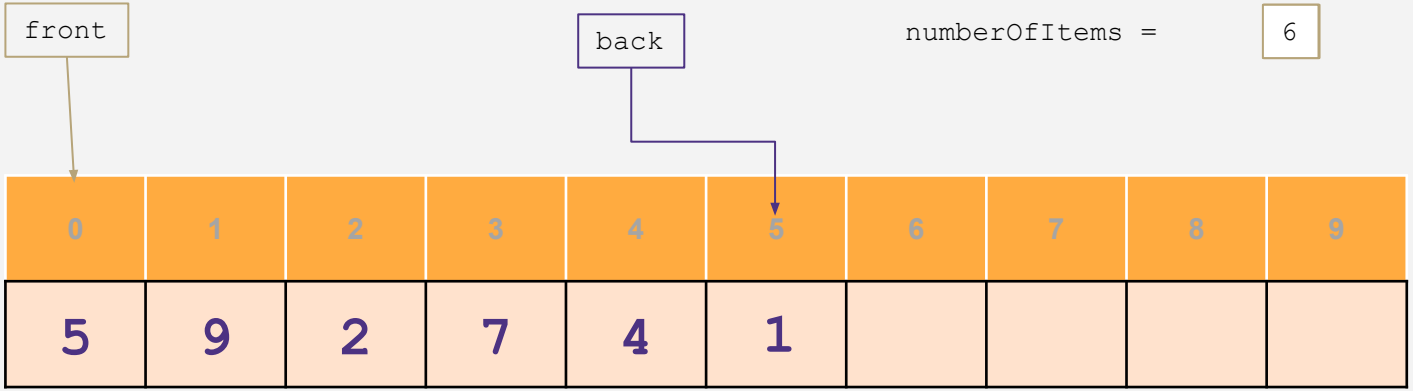
remove()



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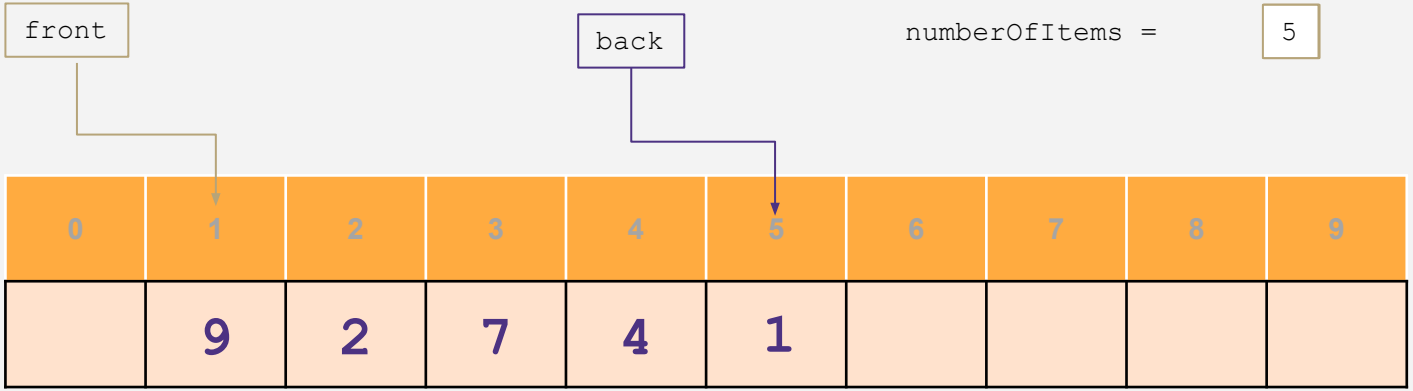

Implementing a Queue with an Array (v2)

QUEUE ADT

State

Collection of ordered items
Count of items

Behavior

add(item) add item to back
remove() remove and return item at front
peek() return item at front
size() count of items
isEmpty() count is 0?

ArrayQueueV2<E>

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data[], front,
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ADTs & Data Structures

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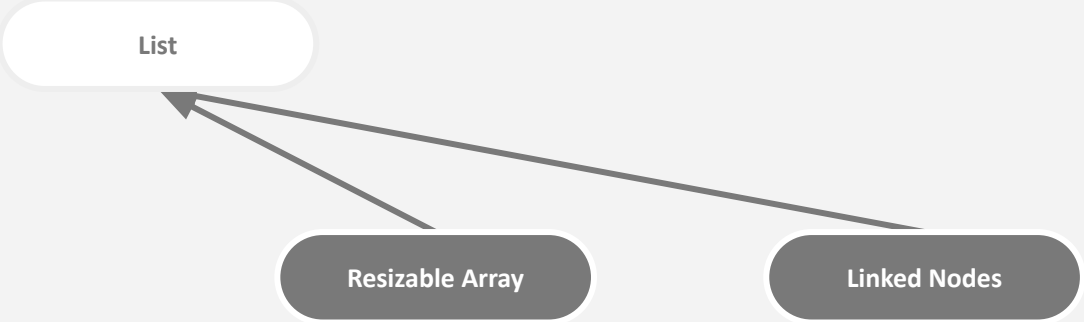

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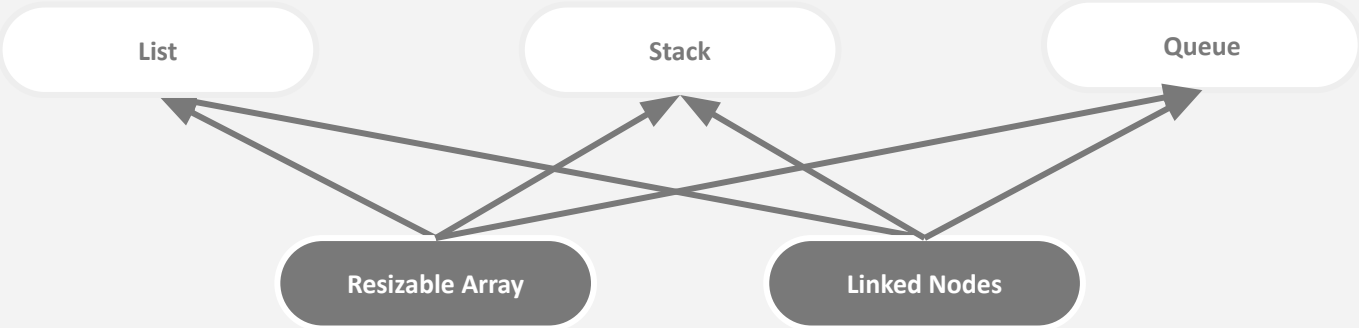
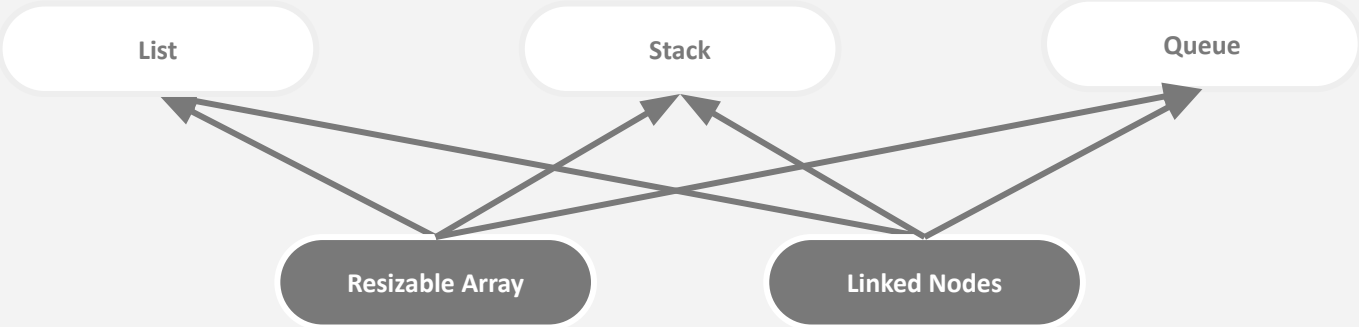
- Data structure can implement multiple ADTs



ADTs & Data Structures

- ADT can be implemented by multiple data structures
- Data structure can implement multiple ADTs
  - But the ADT decides how it can be used
    - An ArrayList used as a List should support get()
    - An ArrayList used as a Stack should not support get()



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