Lecture 3: Stacks, Queues, and Dictionaries

CSE 373: Data Structures and Algorithms

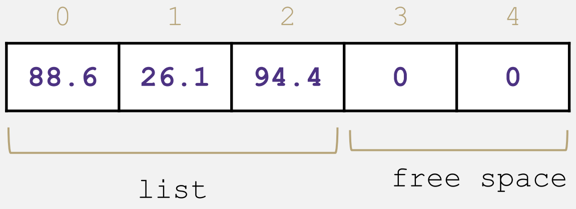
Warm Up

Q: Would you use a LinkedList or ArrayList implementation for each of these scenarios?

ArrayList
uses an Array as underlying storage

ArrayList

```
state
  data[]
  size
behavior
  get return data[index]
  set data[index] = value
  add data[size] = value,
  if out of space grow
  data
  insert shift values to
  make hole at index,
  data[index] = value, if
  out of space grow data
  delete shift following
  values forward
  size return size
```



LinkedList
uses nodes as underlying storage

LinkedList

```
state
  Node front
  size
behavior
  get loop until index,
  return node's value
  set loop until index,
  update node's value
  add create new node,
  update next of last
  node
  insert create new
  node, loop until
  index, update next
  fields
  delete loop until
  index, skip node
  size return size
```

Situation #1: Choose a data structure that implements the List ADT that will be used to store a list of songs in a playlist.

Situation #2: Choose a data structure that implements the List ADT that will be used to store the history of a bank customer's transactions.

Situation #3: Choose a data structure that implements the List ADT that will be used to store the order of students waiting to speak to a TA at a tutoring center

Instructions

Take 2 Minutes

1. www.pollev.com/cse373activity for participating in our active learning questions. For this particular question label your answer with
   - what situation #
   - ArrayList/LinkedList
   - why.
2. https://www.pollev.com/cse373studentqs to ask your own questions

Design Decisions

Situation #1: Write a data structure that implements the List ADT that will be used to store a list of songs in a playlist.

ArrayList – I want to be able to shuffle play on the playlist

Situation #2: Write a data structure that implements the List ADT that will be used to store the history of a bank customer's transactions.

ArrayList – optimize for addition to back and accessing of elements

Situation #3: Write a data structure that implements the List ADT that will be used to store the order of students waiting to speak to a TA at a tutoring center

LinkedList - optimize for removal from front

ArrayList – optimize for addition to back

List ADT tradeoffs

Last time: we used “slow” and “fast” to describe running times. Let’s be a little more precise.

Recall these basic Big-O ideas from 14X: Suppose our list has N elements

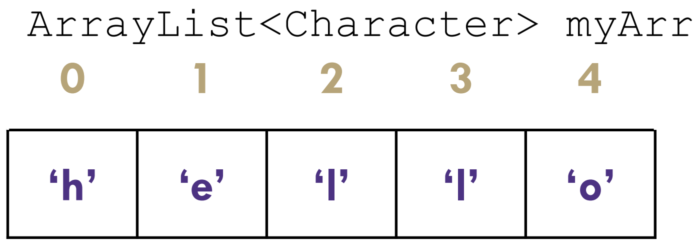
- If a method takes a constant number of steps (like 23 or 5) its running time is O(1)
- If a method takes a linear number of steps (like 4N+3) its running time is O(N)

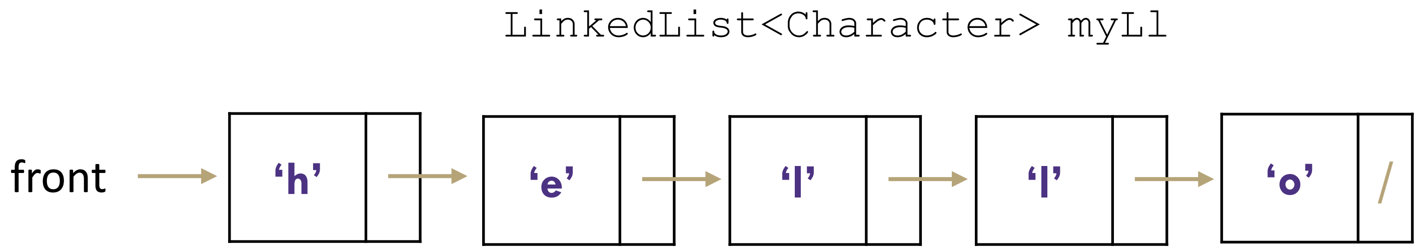
For ArrayLists and LinkedLists, what is the O() for each of these operations?

- Time needed to access N^{th} element:
- Time needed to insert at end (the array is full!)

What are the memory tradeoffs for our two implementations?

- Amount of space used overall
- Amount of space used per element





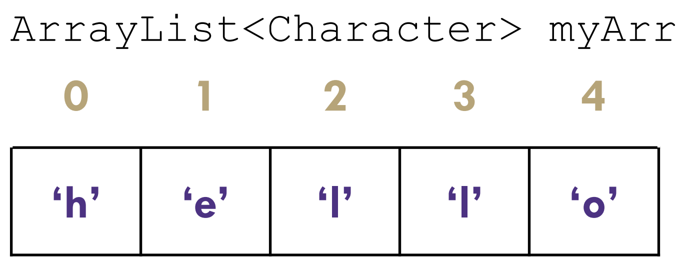
List ADT tradeoffs

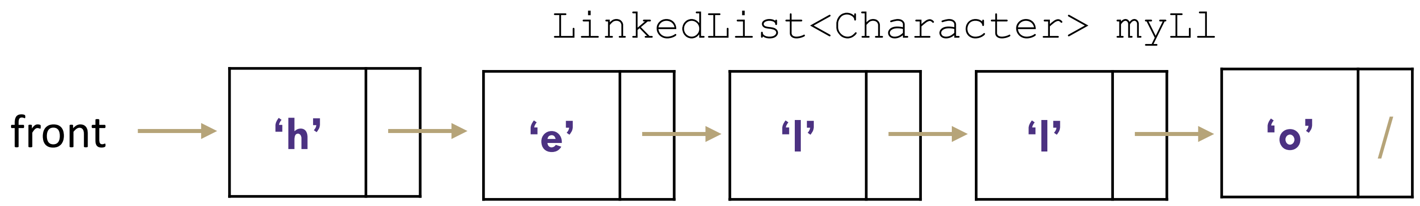
Time needed to access N^{th} element:
- ArrayList: O(1) constant time
- LinkedList: O(N) linear time

Time needed to insert at N^{th} element (the array is full!)
- ArrayList: O(N) linear time
- LinkedList: O(N) linear time

Amount of space used overall
- ArrayList: sometimes wasted space
- LinkedList: compact

Amount of space used per element
- ArrayList: minimal
- LinkedList: tiny extra





Administrivia

- reminder: P0 released on Wednesday, due next Wednesday. Lots of good setup questions on Piazza, continue to use that resource

- 4/1 Lecture is a panopto recording because we had to make some edits -- sorry for the inconvenience. If it's not published immediately in the future, it'll also be on Panopto and a little bit delayed.

- Section -- video/recording is being worked on and edited by our TAs right now, should be up soon. Handouts/Solutions/Slides always posted on the website -- the solutions/slides are up now. We'll make a Piazza announcement when the video is up.

- Student Slack -- Totally optional chatroom for y'all to join to build a community for this class (beyond piazza which is kinda rigid). You can use it to find a partner/coordinate with them, plan study sessions, or just chat with people in general! We won't be monitoring this closely, but please be kind and respectful to others. Feel free to report any incidents and we can look into it. Everyone registered should have received an invite.

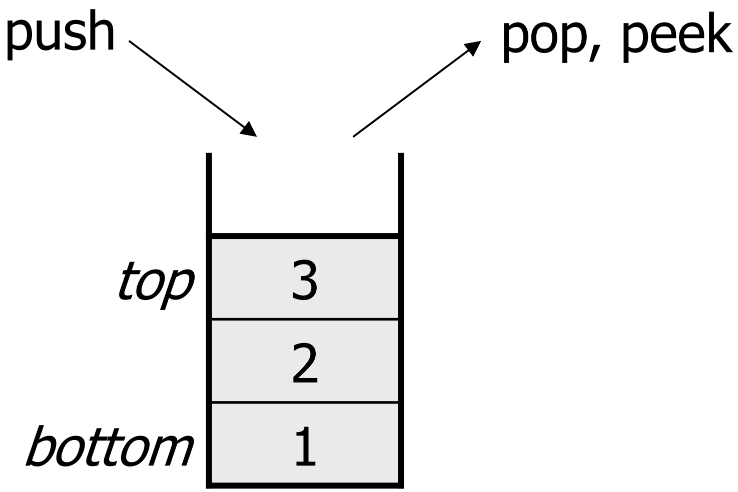
- Office Hours today, see the calendar on course website for schedule and the Zoom tab on Canvas for meeting link

Questions?

Review: What is a Stack?

stack: A collection based on the principle of adding elements and retrieving them in the opposite order.

- Last-In, First-Out ("LIFO")
- Elements are stored in order of insertion.
  - We do not think of them as having indexes.
- Client can only add/remove/examine the last element added (the "top").



Stack ADT

state

Set of ordered items
Number of items

behavior

push(item) add item to top
pop() return and remove item at top
peek() look at item at top
size() count of items
isEmpty() count of items is 0?

supported operations:

- **push(item)**: Add an element to the top of stack
- **pop()**: Remove the top element and returns it
- **peek()**: Examine the top element without removing it
- **size():** how many items are in the stack?
- **isEmpty():** true if there are 1 or more items in stack, false otherwise

Implementing a Stack with an Array

Stack ADT

state

Set of ordered items
Number of items

behavior

push(item) add item to top
pop() return and remove item at top
peek() look at item at top
size() count of items
isEmpty() count of items is 0?

ArrayStack<E>

state

```
data[]
size
```

behavior

```
push data[size] = value, if out of room grow data
pop return data[size - 1], size-1
peek return data[size - 1]
size return size
isEmpty return size == 0
```

Big O Analysis

`pop()`	O(1) Constant
`peek()`	O(1) Constant
`size()`	O(1) Constant
`isEmpty()`	O(1) Constant
`push()`	O(N) linear if you have to resize O(1) otherwise

```
push(3)
push(4)
pop()
push(5)
```

0	1	2	3
3	5		

`numberOfItems = 2`

Take 1 min to respond to activity

www.pollev.com/cse373activity
What do you think the worst possible runtime of the "push()" operation will be?

Implementing a Stack with Nodes

Stack ADT

state
Set of ordered items
Number of items

behavior
push(item) add item to top
pop() return and remove item at top
peek() look at item at top
size() count of items
isEmpty() count of items is 0?

LinkedStack<E>

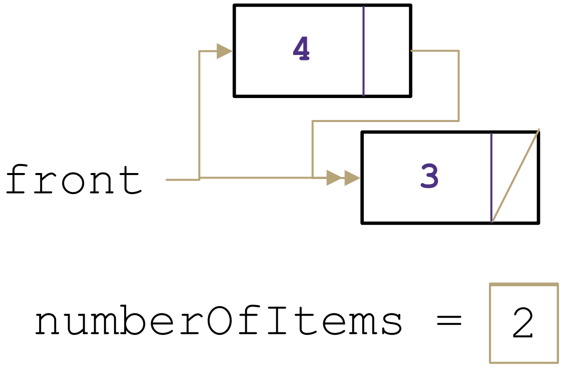
state
Node top
size

behavior
push add new node at top
pop return and remove node at top
peek return node at top
size return size
isEmpty return size == 0

Big O Analysis

pop()	O(1) Constant
peek()	O(1) Constant
size()	O(1) Constant
isEmpty()	O(1) Constant
push()	O(1) Constant

```
push(3)
push(4)
pop()
```



Take 1 min to respond to activity

www.pollev.com/cse373activity
What do you think the worst possible runtime of the "push()" operation will be?

Question Break

Review: What is a Queue?

queue: Retrieves elements in the order they were added.

- First-In, First-Out ("FIFO")
- Elements are stored in order of insertion but don't have indexes.
- Client can only add to the end of the queue, and can only examine/remove the front of the queue.

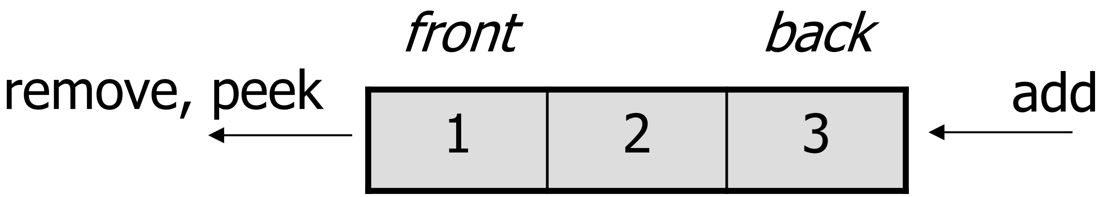
Queue ADT

state

Set of ordered items
Number 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 of items is 0?



supported operations:

- **add(item):** aka “enqueue” add an element to the back.
- **remove():** aka “dequeue” Remove the front element and return.
- **peek()**: Examine the front element without removing it.
- **size():** how many items are stored in the queue?
- **isEmpty():** if 1 or more items in the queue returns true, false otherwise

Implementing a Queue with an Array

Queue ADT

state

Set of ordered items
Number 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 of items is 0?

ArrayQueue<E>

state

```
data[]
Size
front index
back index
```

behavior

```
add - data[size] = value, if
out of room grow data
remove - return data[size -
1], size-1
peek - return data[size - 1]
size - return size
isEmpty - return size == 0
```

Big O Analysis

`remove()`	O(1) Constant
`peek()`	O(1) Constant
`size()`	O(1) Constant
`isEmpty()`	O(1) Constant
`add()`	O(N) linear if you have to resize O(1) otherwise

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

0	1	2	3	4
5	8	9		

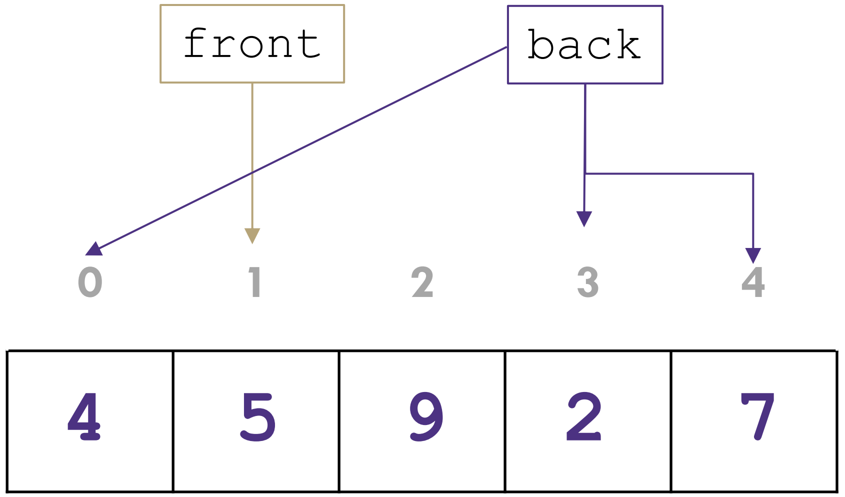
```
numberOfItems = 3
front = 1
back = 2
```

Take 1 min to respond to activity

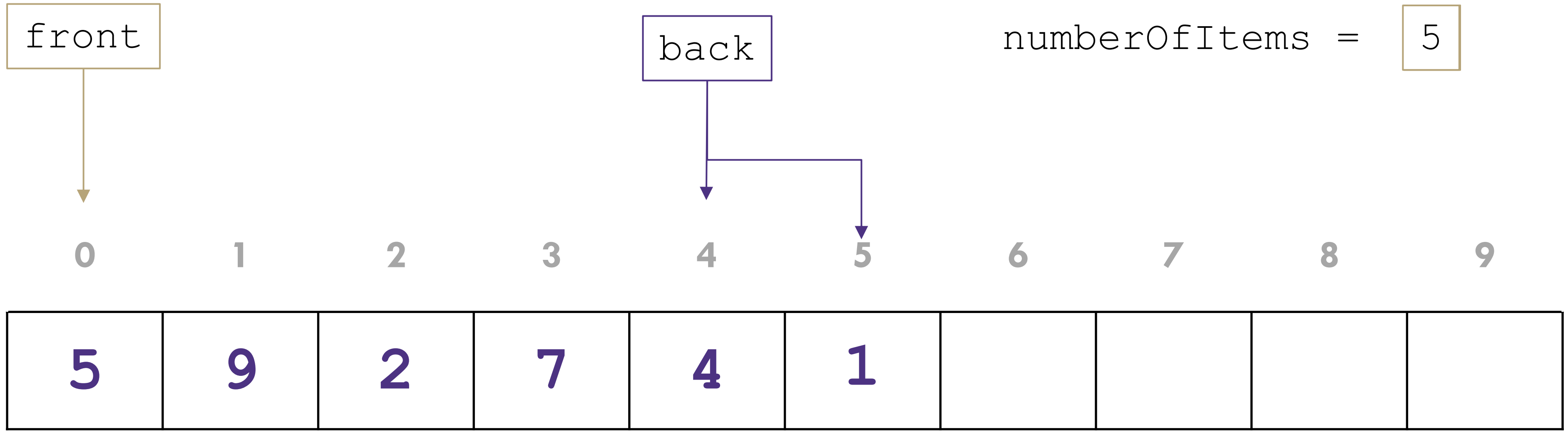
www.pollev.com/cse373activity
What do you think the worst possible runtime of the "add()" operation will be?

Implementing a Queue with an Array
> Wrapping Around

add(7)
add(4)
add(1)



numberOfItems = 5



Implementing a Queue with Nodes

Queue ADT

state

Set of ordered items
Number 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 of items is 0?

LinkedQueue<E>

state

```
Node front
Node back
size
```

behavior

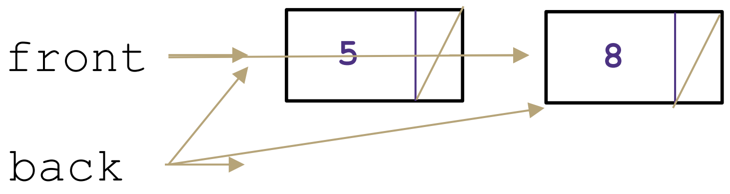
```
add - add node to back
remove - return and remove node at front
peek - return node at front
size - return size
isEmpty - return size == 0
```

Big O Analysis

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

`numberOfItems = 2`

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



Take 1 min to respond to activity

www.pollev.com/cse373activity
What do you think the worst case runtime of the "add()" operation will be?

Questions?

Design Decisions

Take 5 Minutes

Discuss in your Breakouts: For each scenario select the appropriate ADT and implementation to best optimize for the given scenario.

Situation: You are writing a program to schedule jobs sent to a laser printer. The laser printer should process these jobs in the order in which the requests were received. There are busy and slow times for requests that can have large differences in the volume of jobs sent to the printer. Which ADT and what implementation would you use to store the jobs sent to the printer?

ADT options:
- List
- Stack
- Queue

Implementation options:
- array
- linked nodes

Breakout Instructions

1. Instructor will trigger breakout rooms

2. Accept the invite that pops up

3. Work with your partners to answer the question on slide 16

4. TAs will be coming in and out. Fill out this form to request a TA's assistance: https://forms.gle/b9NiC1s11FKBcpm89

5. Instructor will end the breakouts in 5 minutes

For detailed instructions on how breakouts work: https://docs.google.com/presentation/d/15HiAPu6yYz2WWbkonRejBtUcq_FFhmoWFyT2l25G06o/edit#slide=id.g8289eae46a_0_694

Design Decisions

Take 5 Minutes

Discuss in your Breakouts: For each scenario select the appropriate ADT and implementation to best optimize for the given scenario.

Situation: You are writing a program to schedule jobs sent to a laser printer. The laser printer should process these jobs in the order in which the requests were received. There are busy and slow times for requests that can have large differences in the volume of jobs sent to the printer. Which ADT and what implementation would you use to store the jobs sent to the printer?

ADT options:

- List
- Stack
- Queue

Implementation options:

- array
- linked nodes

Dictionaries

Dictionaries (aka Maps)

Every Programmer's Best Friend

You'll probably use one in almost every programming project.

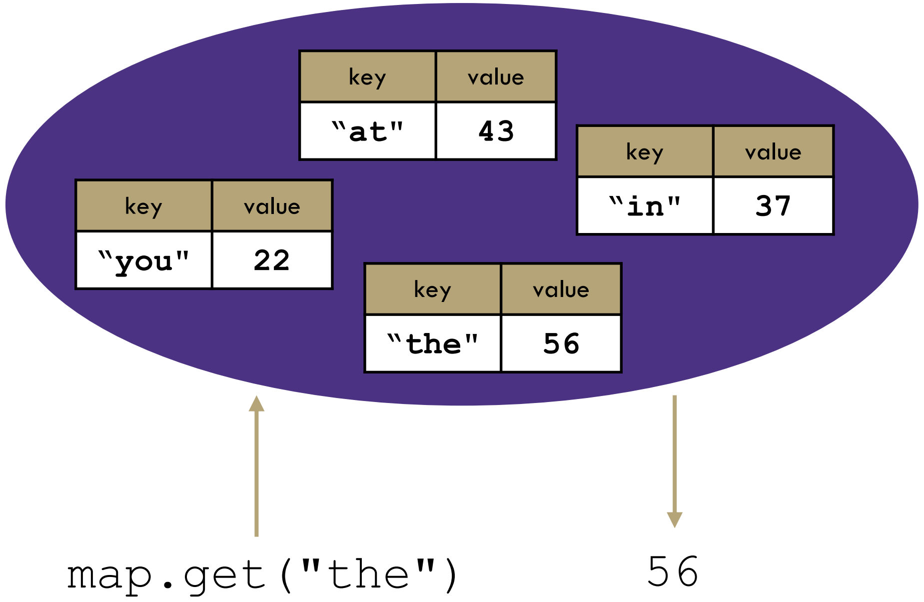
- Because it's hard to make a big project without needing one sooner or later.

```
// two types of Map implementations supposedly covered in CSE 143
Map<String, Integer> map1 = new HashMap<>();
Map<String, String> map2 =  new TreeMap<>();
```

Review: Maps

map: Holds a set of distinct *keys* and a collection of *values*, where each key is associated with one value.

- a.k.a. "dictionary"



Dictionary ADT
state Set of items & keys Count of items **behavior** put(key, item) add item to collection indexed with key get(key) return item associated with key containsKey(key) return if key already in use remove(key) remove item and associated key size() return count of items

supported operations:

- **put**(*key, value*): Adds a given item into collection with associated key,
  - **if the map previously had a mapping for the given key, old value is replaced.**
- **get**(*key*): Retrieves the value mapped to the key
- **containsKey**(key): returns true if key is already associated with value in map, false otherwise
- **remove**(*key*): Removes the given key and its mapped value

Aug → 37.3

KEYS	VALUES
Jan	327.2
Feb	368.2
Mar	197.6
Apr	178.4
May	100.0
Jun	69.9
Jul	32.3
Aug	37.3
Sep	19.0
Oct	37.0
Nov	73.2
Dec	110.9
Annual	1551.0

2 Minutes

Implementing a Dictionary with an Array

Dictionary ADT

state

Set of items & keys
Count of items

behavior

put(key, item) add item to collection indexed with key
get(key) return item associated with key
containsKey(key) return if key already in use
remove(key) remove item and associated key
size() return count of items

ArrayDictionary<K, V>

state

`Pair<K, V>[] data`

behavior

`put` find key, overwrite value if there. Otherwise create new pair, add to next available spot, grow array if necessary
`get` scan all pairs looking for given key, return associated item if found
`containsKey` scan all pairs, return if key is found
`remove` scan all pairs, replace pair to be removed with last pair in collection
`size` return count of items in dictionary

```
containsKey('c')
get('d')
put('b', 97)
put('e', 20)
```

0	1	2	3	4
('a', 1)	('b' 97)	('c', 3)	('d', 4)	('e', 20)

Big O Analysis – (if key is the last one looked at / not in the dictionary)

put()	O(N) linear
get()	O(N) linear
containsKey()	O(N) linear
remove()	O(N) linear
size()	O(1) constant

Big O Analysis – (if the key is the first one looked at)

put()	O(1) constant
get()	O(1) constant
containsKey()	O(1) constant
remove()	O(1) constant
size()	O(1) constant

2 Minutes

Implementing a Dictionary with Nodes

Dictionary ADT

state

Set of items & keys
Count of items

behavior

put(key, item) add item to collection indexed with key
get(key) return item associated with key
containsKey(key) return if key already in use
remove(key) remove item and associated key
size() return count of items

LinkedDictionary<K, V>

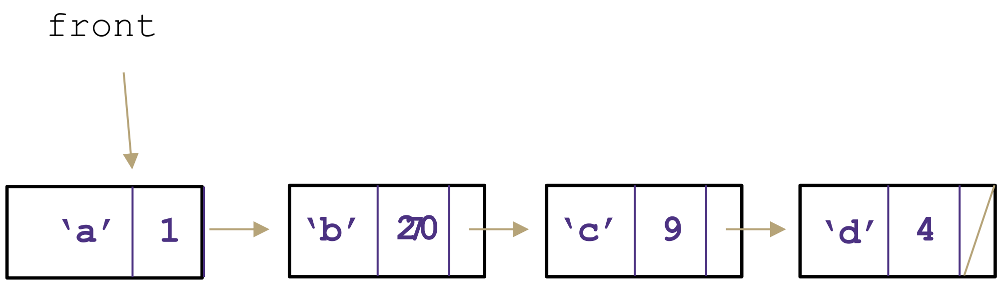
state

front
size

behavior

put if key is unused, create new with pair, add to front of list, else replace with new value
get scan all pairs looking for given key, return associated item if found
containsKey scan all pairs, return if key is found
remove scan all pairs, skip pair to be removed
size return count of items in dictionary

```
containsKey('c')
get('d')
put('b', 20)
```



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get()	O(N) linear
containsKey()	O(N) linear
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size()	O(1) constant

Big O Analysis – (if the key is the first one looked at)

put()	O(1) constant
get()	O(1) constant
containsKey()	O(1) constant
remove()	O(1) constant
size()	O(1) constant