LEC 03

CSE 373

Stacks, Queues, & Maps

BEFORE WE START

Let us know in the chat:
What custom emotes should we add to the 373 Discord server?

Instructor **Hunter Schafer**

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Announcements

- Office Hours started Wednesday!
  - View office hours schedule on left panel of course website
  - Queue is run on Discord, two ways to join (separate invite links!):

1 **Create Discord Account**

- Enter your email
- Stay logged in for the quarter
- Easier to meet people and build community

OR

2 **Join Anonymously**

- Temporary display name, no other info
- Account disappears when you close window
- Use Discord as simple, anonymous queue service; get helped over Zoom

  - Use a message to enter the queue:

@TA On Duty quick question about the definition of an ADT @dubs

  - Reach out to other students while waiting!

Announcements

- Other reasons to join Discord:
  - `#search-for-partners`: find project partners, high success rate!
  - `#career-prep`: links & discussion for technical interviews, careers!
  - More? Let us know your ideas

- Project 0 (CSE 143 Review) due next Wednesday 10/07 11:59pm
- Project 1 (Deques) comes out that same day
  - Three options for projects:
    - **Choose a partner** – someone you know or meet in the class (#search-for-partners or Ed)
    - **Join the partner pool** – we'll assign you a partner
      - Will send info about this early next week!
    - **Opt to work alone** – not recommended, but available

Itempool

Pause Video when Prompted

Survey: What are you currently thinking of for partner projects?

This doesn't mean you have to commit to your answer, but we are trying to get a sense of where people are. Select which of these options best describes your thoughts.

- You already have a partner decided.
- You want to find a partner in the class on your own.
- You want to join the partner pool and have us assign you a partner.
- You want to work alone.
- Not sure yet!

Lecture Outline

- The Stack ADT
- The Queue ADT
- Design Decisions
- The Map ADT

Learning Objectives

After this lecture, you should be able to...

1. *(143 Review)* Describe the state and behavior for the Stack, Queue, and Map ADTs
2. Describe how a resizable array or linked nodes could be used to implement Stack, Queue, or Map
3. Compare the runtime of Stack, Queue, and Map operations on a resizable array vs. linked nodes, based on how they're implemented
4. Identify invariants for the data structures we've seen so far

143 Review The Stack ADT

- **Stack**: an ADT representing an ordered sequence of elements whose elements can only be added & removed from one end.
  - Last-In, First-Out (LIFO)
  - Elements stored in order of insertion
    - We don't think of them as having indices
  - Clients can only add/remove/examine the "top"

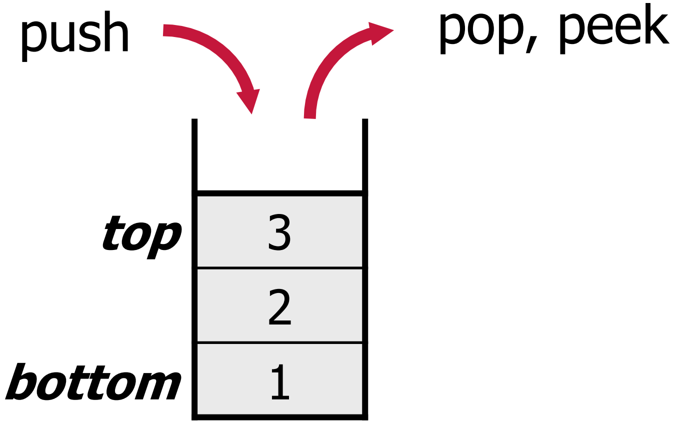
STACK ADT

State

Collection of ordered items
Count of items

Behavior

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



Implementing a Stack with Linked Nodes

STACK ADT

State
- Collection of ordered items
- Count of items

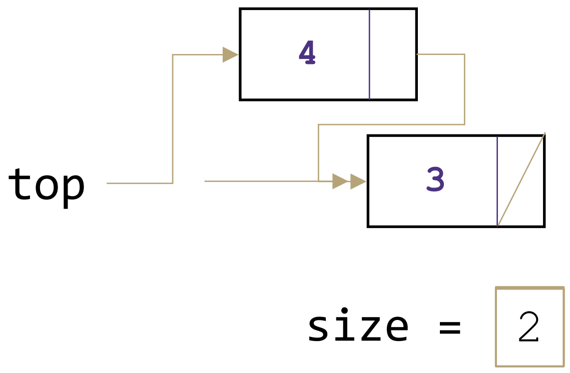
Behavior
- push(index) add item to top
- pop() return & remove item at top
- peek() return item at top
- size() count of items
- isEmpty() is count 0?

LinkedStack<E>

State
- Node top
- size

Behavior
- push add new node at top
- pop return & remove node at top
- peek return node at top
- size return size
- isEmpty return size == 0

push(3)
push(4)
pop()



Big-Oh Analysis

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

Itempool

Pause Video when Prompted

STACK ADT

State

Collection of ordered items
Count of items

Behavior

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

LinkedStack<E>

State

Node top
size

Behavior

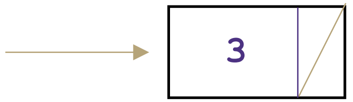
push add new node at top
pop return & remove node at top
peek return node at top
size return size
isEmpty return size == 0

Big-Oh 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()

top



size = 1

What do you think the worst possible runtime of push() could be?

Implementing a Stack with an Array

STACK ADT

State
- Collection of ordered items
- Count of items

Behavior
- push(index) add item to top
- pop() return & remove item at top
- peek() return item at top
- size() count of items
- isEmpty() is count 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-Oh Analysis

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

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

0	1	2	3
3	5		

size = 2

Itempool

Pause Video when Prompted

STACK ADT

State

Collection of ordered items
Count of items

Behavior

`push(index)` add item to top
`pop()` return & remove item at top
`peek()` return item at top
`size()` count of items
`isEmpty()` is count 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-Oh 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)
```

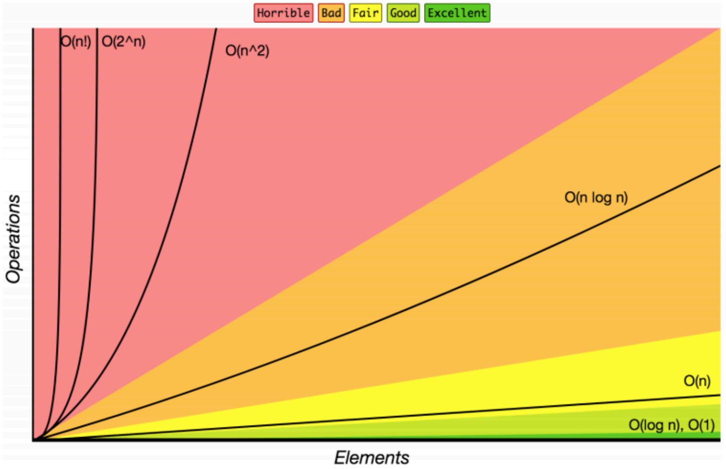
0	1	2	3
3	5		

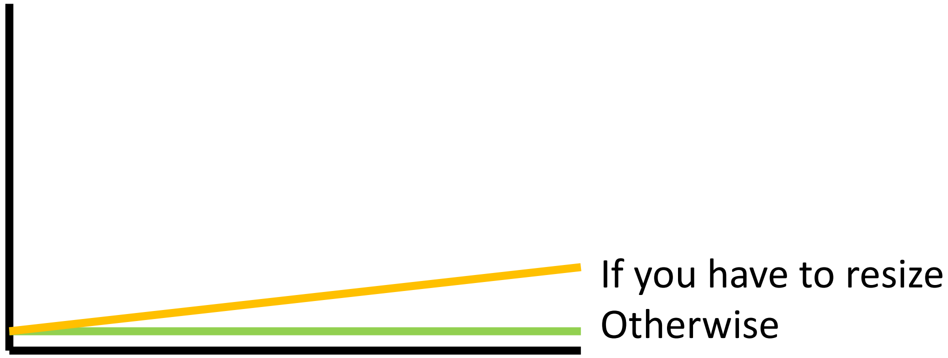
size = 2

What do you think the worst possible runtime of push( ) could be?

Preview Why Not Decide on One?

- Big-Oh analysis of `push()`: **O(n) linear** if you have to resize, **O(1) constant** otherwise
- Two insights to keep in mind:
  1. Behavior is *completely* different in these two cases. Almost better not to try and analyze them both together.
  2. Big-Oh is a *tool* to describe runtime. Having to decide just one or the other would make it a less useful tool – not a complete description.





Lecture Outline

- The Stack ADT
- **The Queue ADT**
- Design Decisions
- The Map ADT

143 Review The Queue ADT

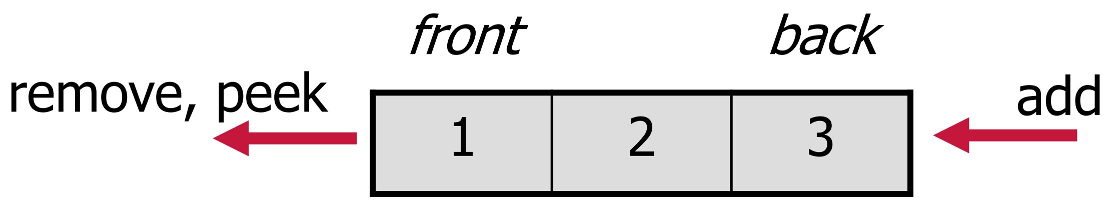
- **Queue**: an ADT representing an ordered sequence of elements whose elements can only be added from one end and removed from the other.
  - First-In, First-Out (FIFO)
  - Elements stored in order of insertion
    - We don't think of them as having indices
  - Clients can only add to the "end", and can only examine/remove at the "front"

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?
```



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
```

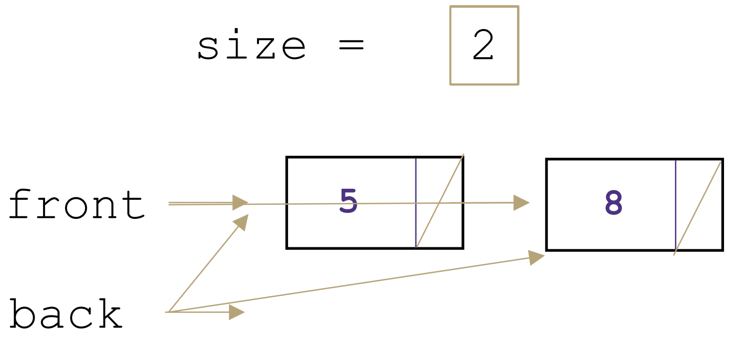
Behavior

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

Big-Oh Analysis

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

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



Implementing a Queue with an Array (v1)

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

0	1	2	3	4
5	8	9		

size = 3

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

Big-Oh Analysis

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

Itempool

Pause Video when Prompted

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()	O(n) Linear if you have to resize, O(1) otherwise
remove()	O(n) Linear

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

0	1	2	3	4
8	9			

size = 2

What do you think the worst possible runtime of add() & remove() could be?

Consider Data Structure Invariants

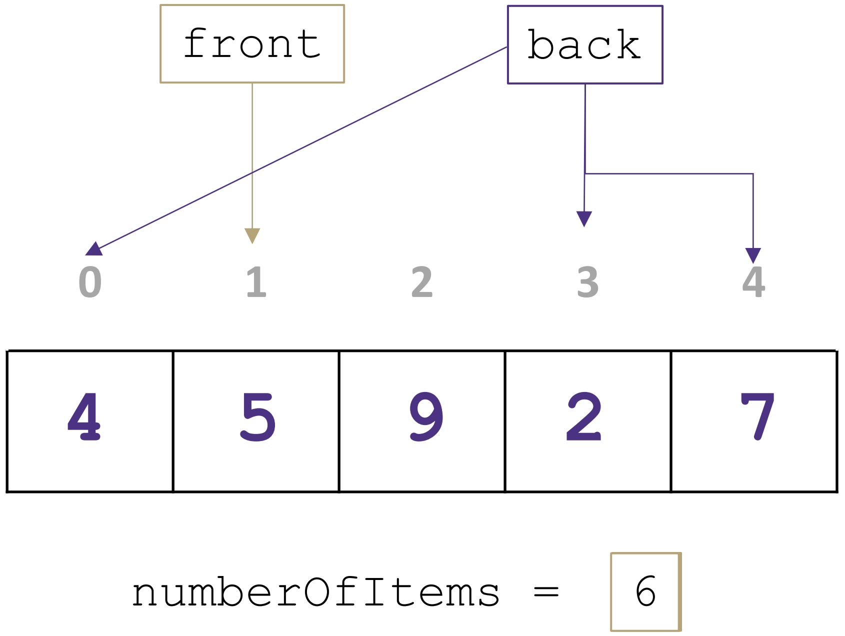
- **Invariant**: a property of a data structure that is always true between operations
  - true when finishing any operation, so it can be counted on to be true when starting an operation.

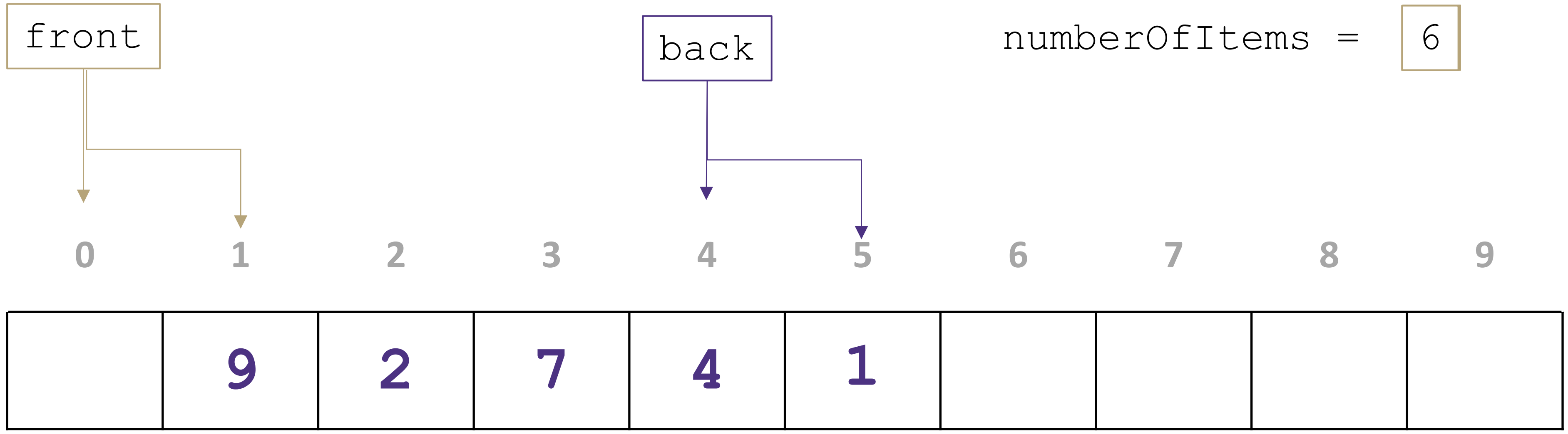
- ArrayQueueV1 is basically an `ArrayList`. What invariants does `ArrayList` have for its `data` array?
  - The i-th item in the list is stored in data[i]
    - Notice: serving this invariant is what slows down the operation. Could we choose a different invariant?

Implementing a Queue with an Array

Wrapping Around with "front" and "back" indices

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





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>

State

`data[], front,`
`size, back`

Behavior

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

Big-Oh Analysis

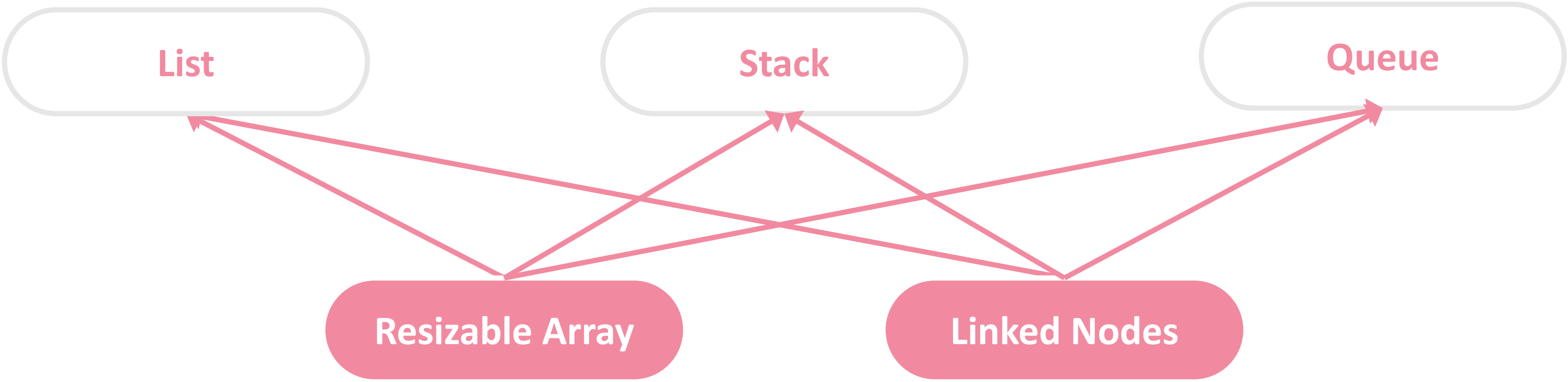
`peek()`	O(1) Constant
`size()`	O(1) Constant
`isEmpty()`	O(1) Constant
`add()`	O(n) Linear if you have to resize, O(1) otherwise
`remove()`	O(1) Constant

Lecture Outline

- The Stack ADT
- The Queue ADT
- **Design Decisions**
- **The Map ADT**

ADTs & Data Structures

- We’ve now seen that just like an ADT can be implemented by multiple data structures, a data structure can implement multiple ADTs



- But the ADT decides how it can be used
  - An ArrayList used as a List should support `get()`, but when used as a Stack should not

143 Review The Map ADT

- **Map**: an ADT representing a set of distinct keys and a collection of values, where each key is associated with one value.
  - Also known as a **dictionary**
  - If a key is already associated with something, calling put(key, value) replaces the old value
- A programmer's best friend ☺
  - It's hard to work on a big project without needing one sooner or later
  - CSE 143 introduced:
    - `Map<String, Integer> map1 = new HashMap<>();`
    - `Map<String, String> map2 =  new TreeMap<>();`

MAP ADT

State

Set of keys, Collection of values
Count of keys

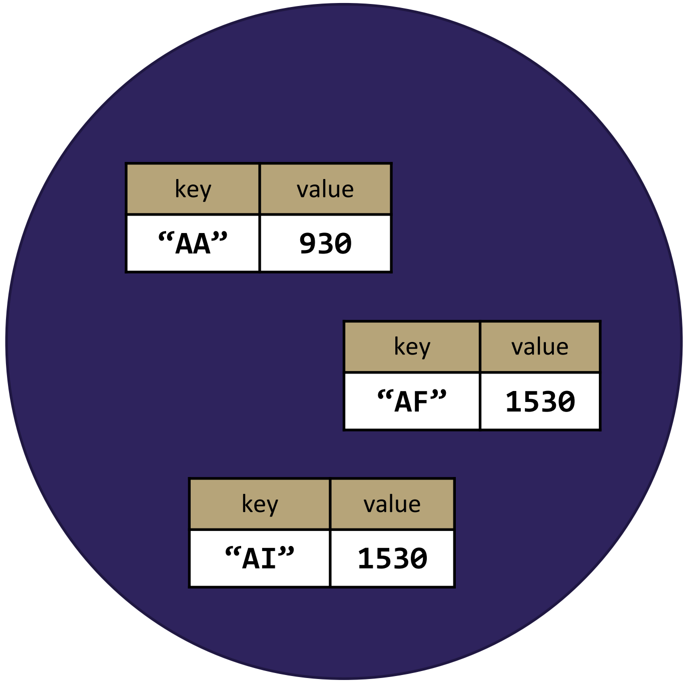
Behavior

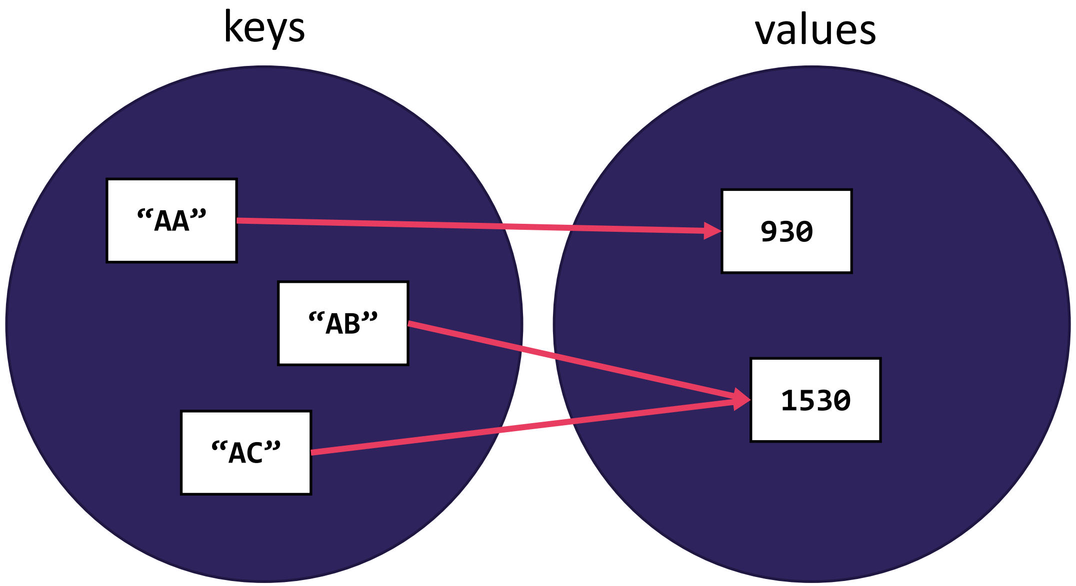
`put(key, value)` add value to collection, associated with key
`get(key)` return value associated with key
`containsKey(key)` return if key is associated
`remove(key)` remove key and associated value
`size()` return count

Abstract Representations of Maps

- Plenty of different ways you might think about the Map ADT:

```
{
  "AA": 930,
  "AF": 1530,
  "AI": 1530
}
```





- Be careful: remember these are still abstract! No assumption of how duplicates are actually stored
  - Doesn't matter: implementation must match behavior of Map ADT, regardless of how it stores

Implementing a Map with an Array

MAP ADT

State
- Set of keys, Collection of values
- Count of keys

Behavior

put(key, value) add value to collection, associated with key
get(key) return value associated with key
containsKey(key) return if key is associated
remove(key) remove key and associated value
size() return count

ArrayMap<K, V>

State
- `Pair<K, V>[] data`
- `size`

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

```
put('b', 97)
put('e', 20)
```

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

Big-Oh 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-Oh 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

Implementing a Map with Linked Nodes

MAP ADT

State

Set of keys, Collection of values
Count of keys

Behavior

`put(key, value)` add value to collection, associated with key
`get(key)` return value associated with key
`containsKey(key)` return if key is associated
`remove(key)` remove key and associated value
`size()` return count

LinkedMap<K, V>

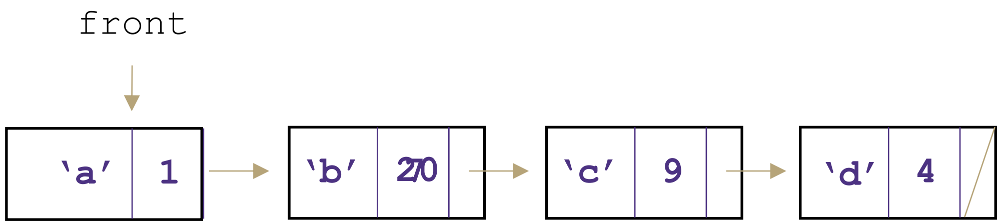
State

`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)
```



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

Consider: what if we delete `size`?

MAP ADT

State

Set of keys, Collection of values
Count of keys

Behavior

`put(key, value)` add value to collection, associated with key
`get(key)` return value associated with key
`containsKey(key)` return if key is associated
`remove(key)` remove key and associated value
`size()` return count

LinkedMap<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

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()`	$\boxed{\text{O(n) linear}}$

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()`	$\boxed{\text{O(n) linear}}$

1. Is this okay? What about "Count of keys" in the ADT?

Yes! The abstract state is still stored – just as # of nodes, not an int field

2. Would you ever do this? It only increases runtime.

Possibly, if you care *much* more about storage space than runtime

Takeaways

- We’ve seen how different implementations can make a huge runtime difference on the same ADT
  - E.g. implementing Queue with a resizable array
- These ADTs & data structures may be review for you
  - Either way, the skills of determining & comparing these runtimes are the real goals! ☺
- Starting to see that analyzing runtimes isn’t as simple as 143 made it seem
  - E.g. one operation *can* have multiple Big-Oh complexity classes
- Hard to go further without a more thorough understanding of this Big-Oh tool
  - Next up: Algorithmic Analysis (Wednesday)!