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 Aaron Johnston

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# Announcements

- Office Hours start today!
  - 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 6/31 11:59pm
- Project 1 (Deques) comes out the same day
  - Partner sign-up form published today, due Tuesday 6/30 11:59pm
  - Three options for projects:
    - **Choose a partner** – someone you know or meet in the class
    - **Join the partner pool** – we'll assign you a partner (default)
    - **Opt to work alone** – not recommended, but available

# 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"

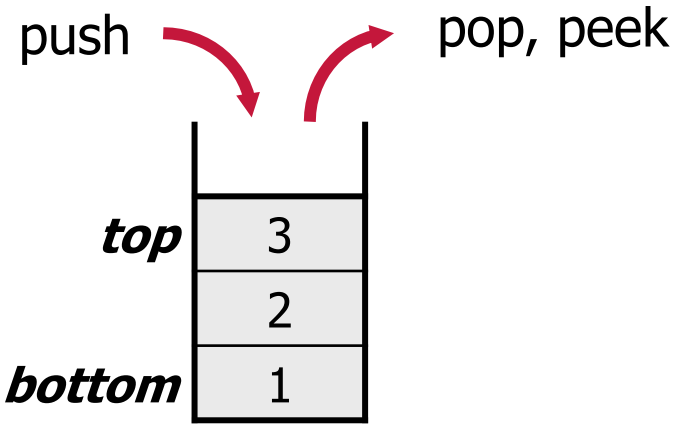
**STACK ADT**

State

Collection of ordered items
Count of items

Behavior

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



# Implementing a Stack with Linked Nodes

## STACK ADT

State
- Collection of ordered items
- Count of items

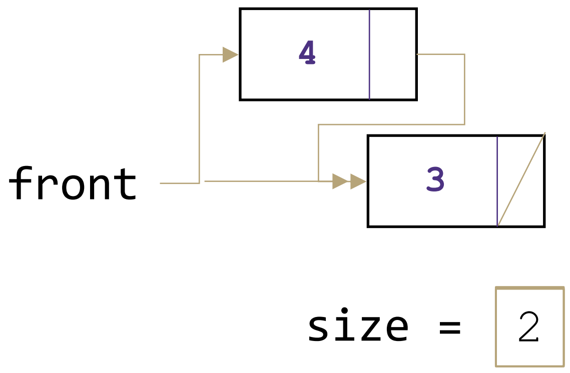
Behavior
- push(index) add item to top
- pop() return & remove item at top
- peek() return item at top
- size() count of items
- isEmpty() is count 0?

## 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() | |

# Poll Everywhere

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## 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()

front → 3

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

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

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| 3 | 5 | | |

size = 2

### Big-Oh Analysis

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

# Poll Everywhere

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## 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

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

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| 3 | 5 | | |

size = 2

### Big-Oh Analysis

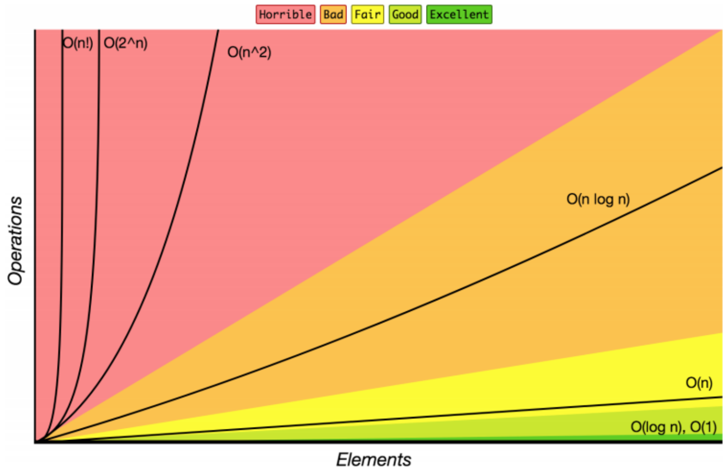
| | |
|---|---|
| pop() | O(1) Constant |
| peek() | O(1) Constant |
| size() | O(1) Constant |
| isEmpty() | O(1) Constant |
| push() | O(n) linear if you have to resize, O(1) otherwise |

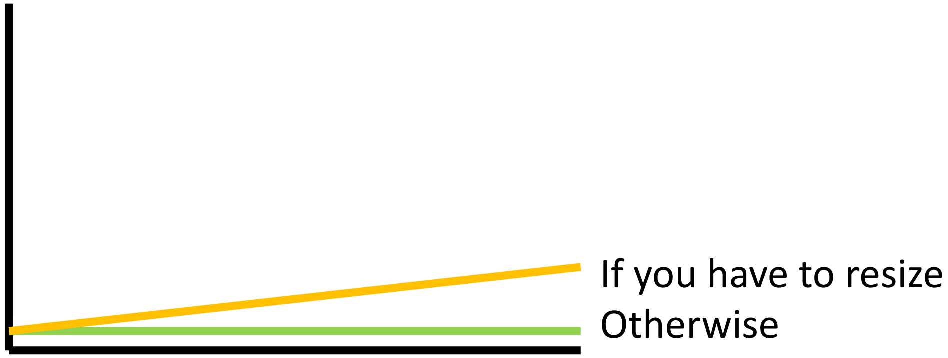
**What do you think the worst possible runtime of push() could be?**

# *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”

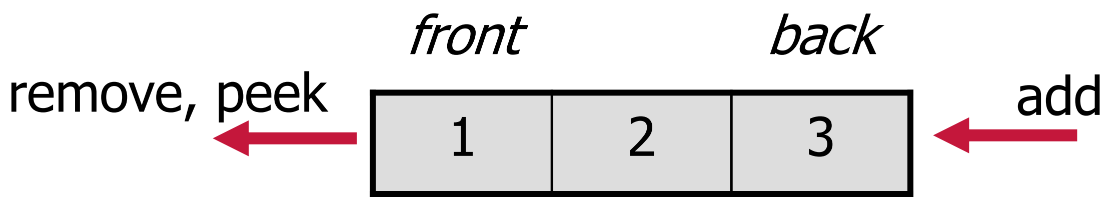
**QUEUE ADT**

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**

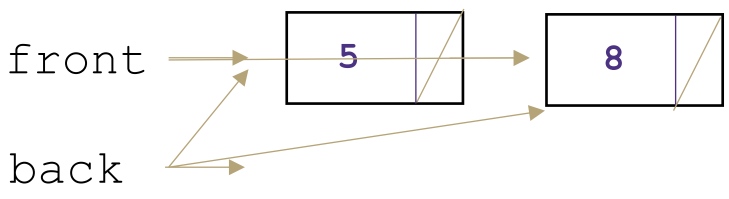
`add` – add node to back
`remove` – return and remove node at front
`peek` – return node at front
`size` – return size
`isEmpty` – return size == 0

## Big-Oh Analysis

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

size = 2

```
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

## Big-Oh Analysis

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

| 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 5 | 8 | 9 | | |

size = 3

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

# Poll Everywhere

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## 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 |
|---|---|---|---|---|
| 8 | 9 | | | |

size = 2

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

### 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 |

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

# Consider Data Structure Invariants

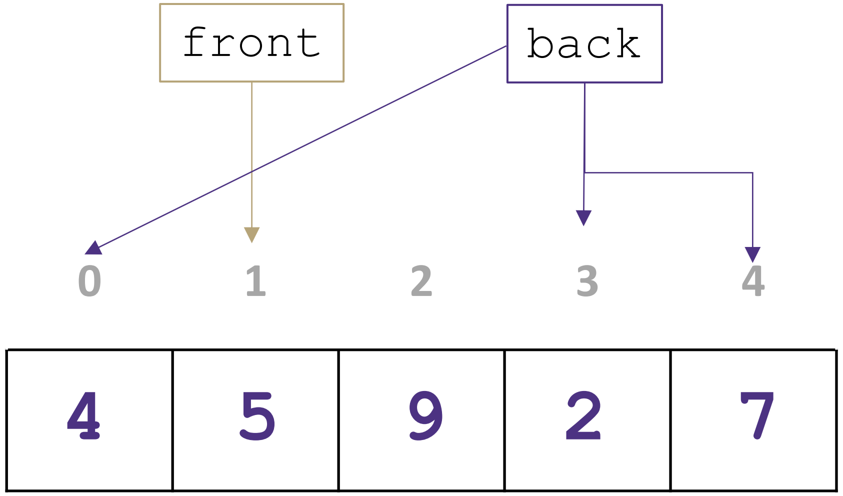
- **Invariant**: a property of a data structure that is always true between operations
  - true when finishing any operation, so it can be counted on to be true when starting an operation.

- 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?

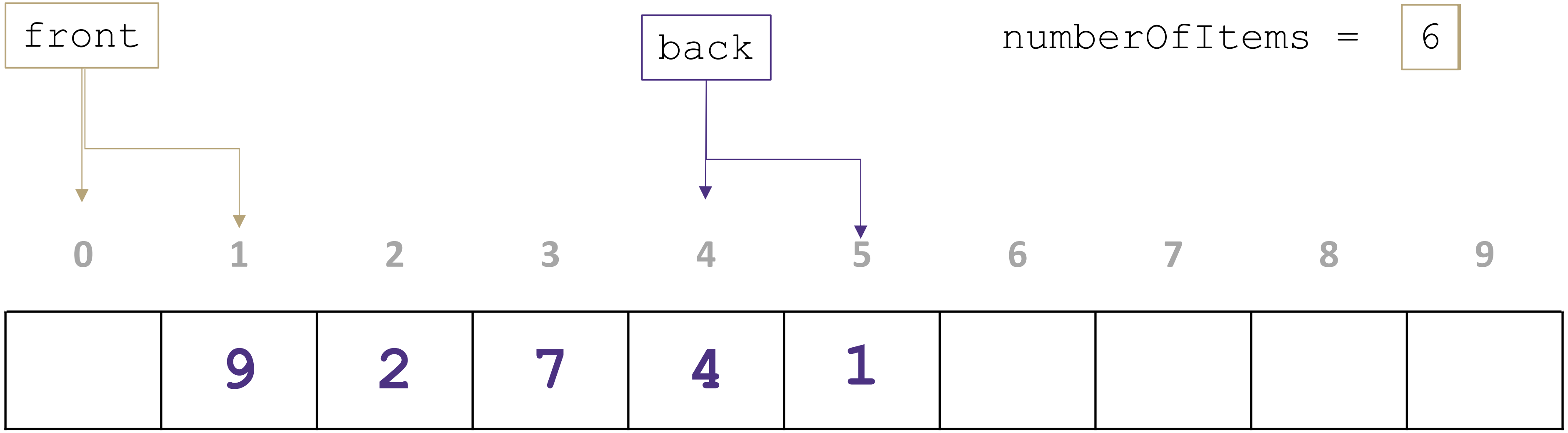
# Implementing a Queue with an Array

## *Wrapping Around with “front” and “back” pointers*

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




`numberOfItems = 6`



# 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
```

CORRECTED AFTER LECTURE

## Big-Oh Analysis

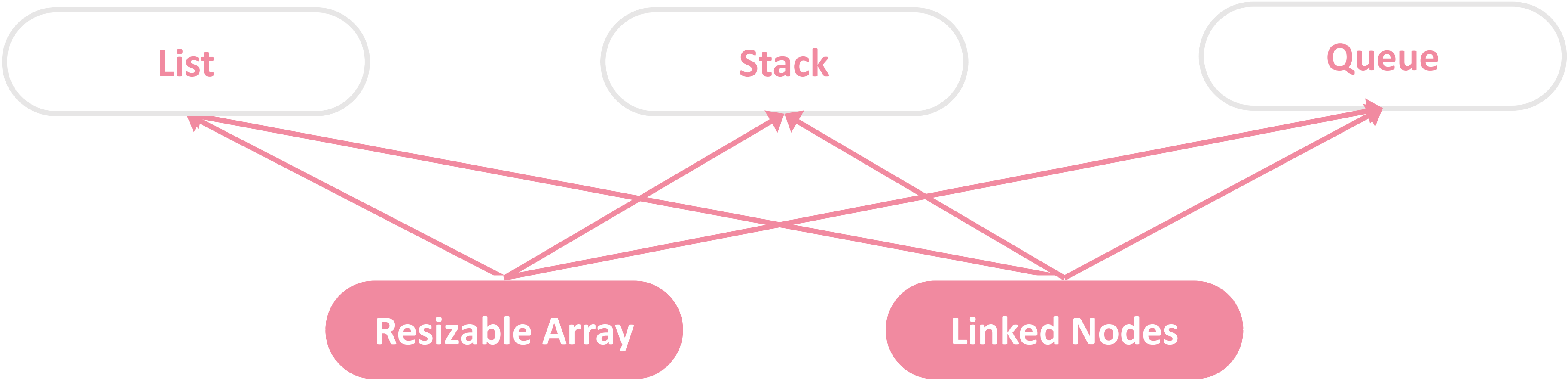
| | |
|---|---|
| `peek()` | O(1) Constant |
| `size()` | O(1) Constant |
| `isEmpty()` | O(1) Constant |
| `add()` | O(n) Linear if you have to resize, O(1) otherwise |
| `remove()` | O(1) Constant |

# 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

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# Design Decisions: Stacks & Queues

- **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 have large differences in the volume of jobs sent. Which ADT and what implementation would you use to store the jobs sent to the printer? Why?

**ADT options:**
- List
- Stack
- Queue

**Implementation options**:
- Resizable Array
- Linked Nodes

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# Design Decisions: Stacks & Queues

- **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 have large differences in the volume of jobs sent. Which ADT and what implementation would you use to store the jobs sent to the printer? Why?

**ADT options:**
- List
- Stack
- Queue

**Implementation options**:
- Resizable Array
- Linked Nodes

**Which ADT and what implementation would you use to store the jobs sent to the printer? Why?**

Top

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# Lecture Outline

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

# *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

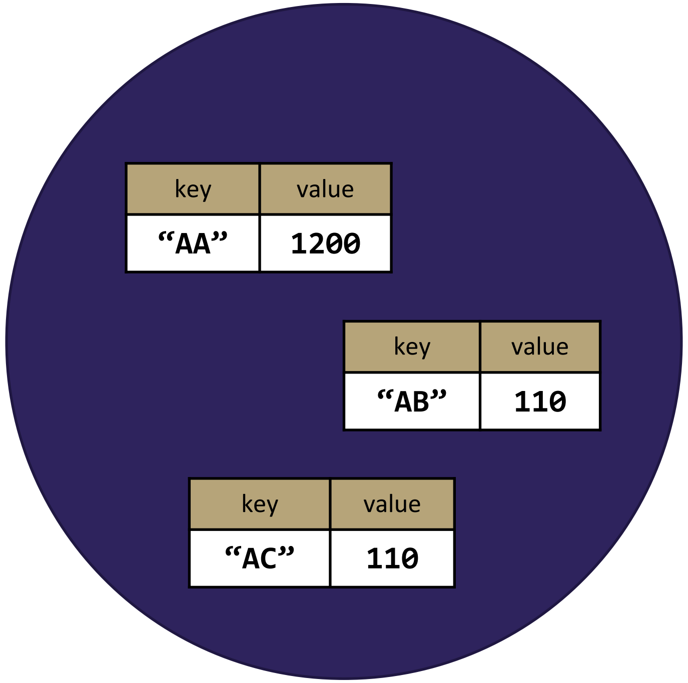
**Behavior**

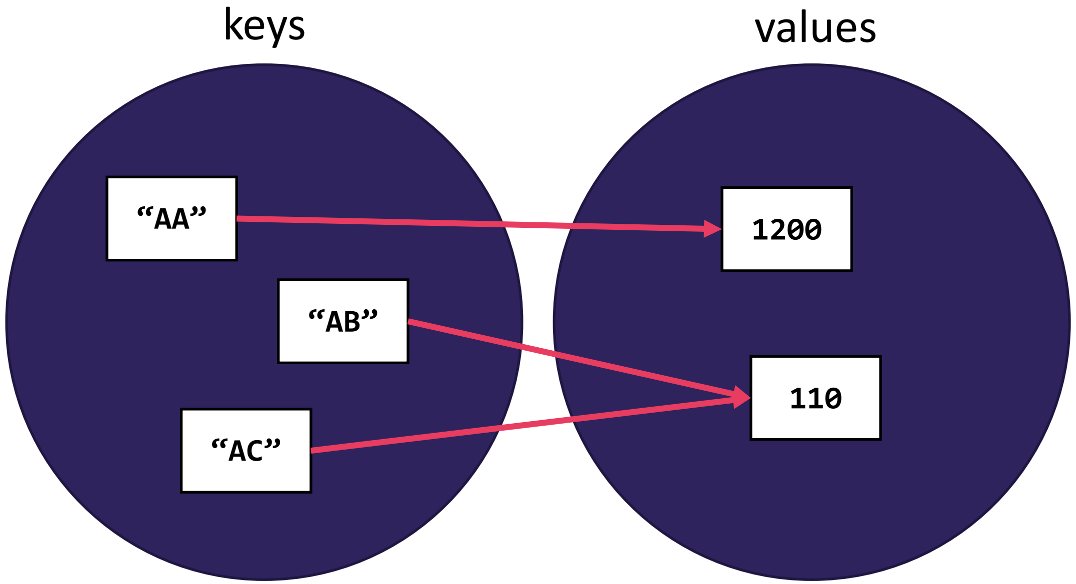
`put(key, value)` add value to collection, associated with key
`get(key)` return value associated with key
`containsKey(key)` return if key is associated
`remove(key)` remove key and associated value
`size()` return count

# Abstract Representations of Maps

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

```
{
  "AA": 1200,
  "AB": 110,
  "AC": 110
}
```




- 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`

**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>

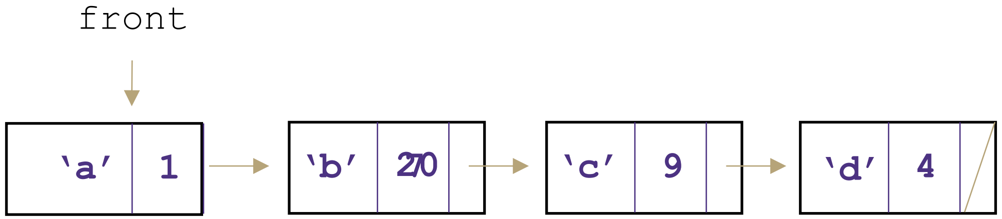
**State**

`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 (Monday)!