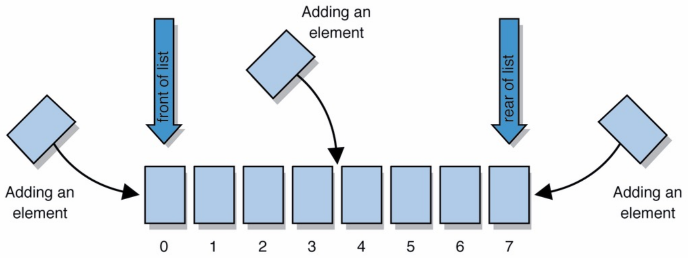
Please fill out the Poll at- pollev.com/21sp373

Lecture 3: Stacks, Queues, and Dictionaries

CSE 373: Data Structures and Algorithms

Warm Up



Please fill out the Poll at- pollev.com/21sp373

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

List ADT

state
Set of ordered items
Count of items

behavior
get(index) return item at index
set(item, index) replace item at index
append(item) add item to end of list
insert(item, index) add item at index
delete(index) delete item at index
size() count of items

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
```

0	1	2	3	4
88.6	26.1	94.4	0	0

list   free space

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

Announcements

Course website live with slides

HW 0 – 143 Review Project

- Live on website
- Due Wednesday April 7th

Find a partner by next Wednesday

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)

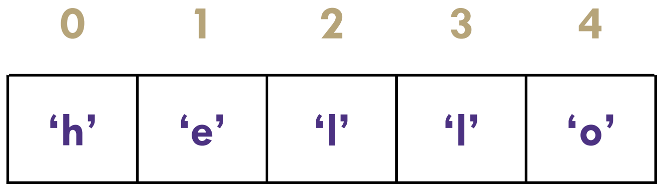
For ArrayLists and LinkedLists, what is the O() for each of these operations?

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

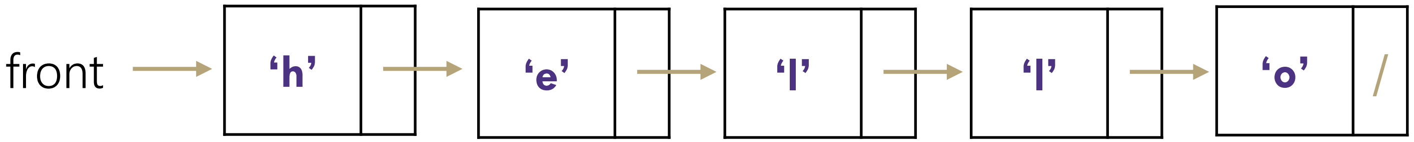
What are the memory tradeoffs for our two implementations?

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

`ArrayList<Character> myArr`



`LinkedList<Character> myLl`



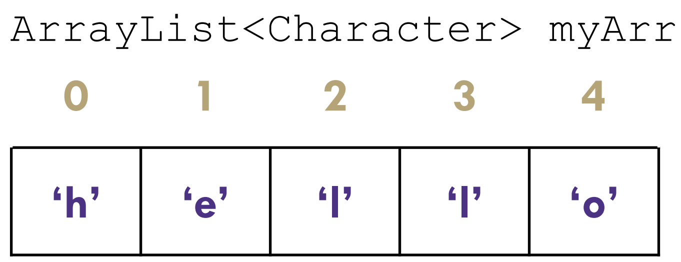
List ADT tradeoffs

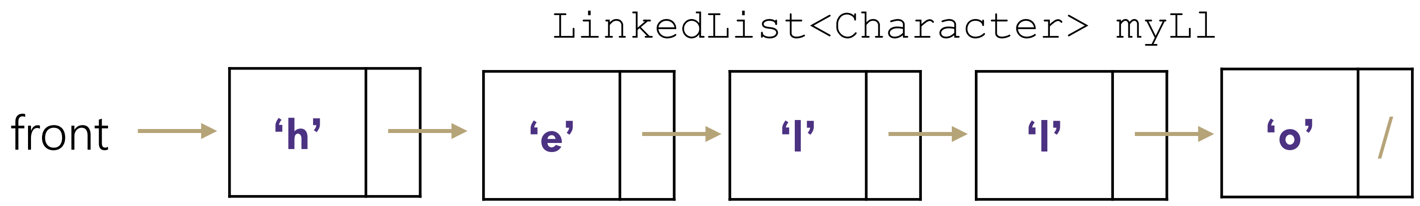
Time needed to access N^{th} element:
- ArrayList: O(1) constant time
- LinkedList: O(N) linear time

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



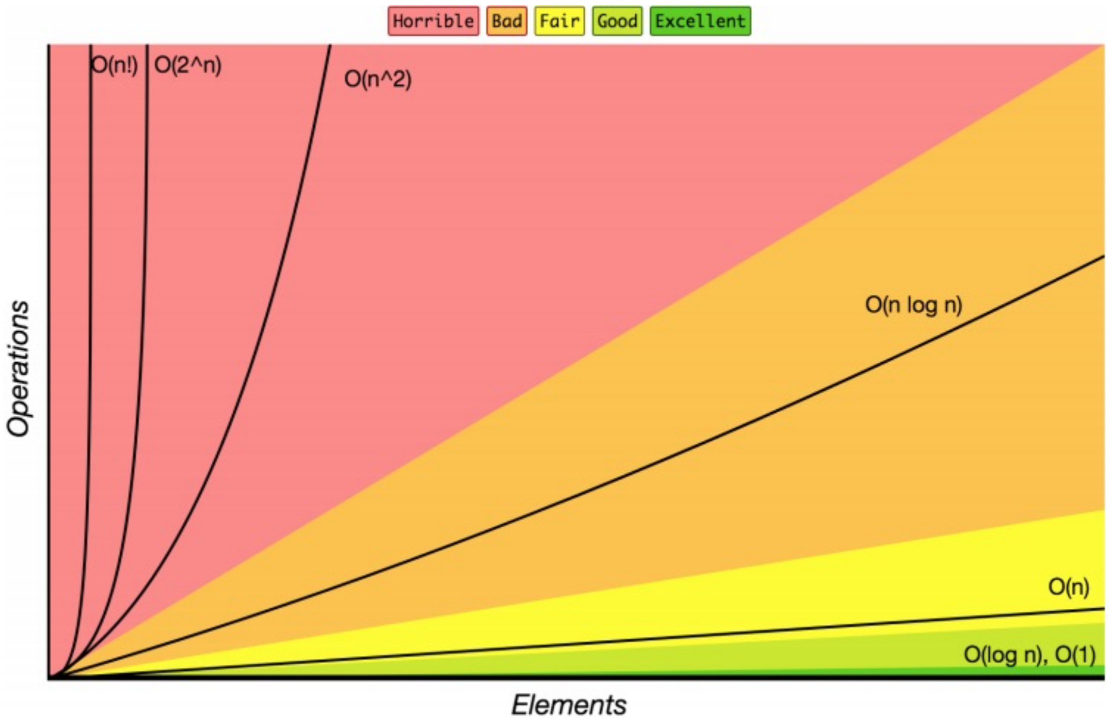


Review: Complexity Class

Note: You don't have to understand all of this right now – we'll dive into it soon.

complexity class: A category of algorithm efficiency based on the algorithm's relationship to the input size N.

Complexity Class	Big-O	Runtime if you double N	Example Algorithm
constant	O(1)	unchanged	Accessing an index of an array
logarithmic	$O(\log_2 N)$	increases slightly	Binary search
linear	O(N)	doubles	Looping over an array
log-linear	$O(N \log_2 N)$	slightly more than doubles	Merge sort algorithm
quadratic	$O(N^2)$	quadruples	Nested loops!
...	...	...	...
exponential	$O(2^N)$	multiplies drastically	Fibonacci with recursion

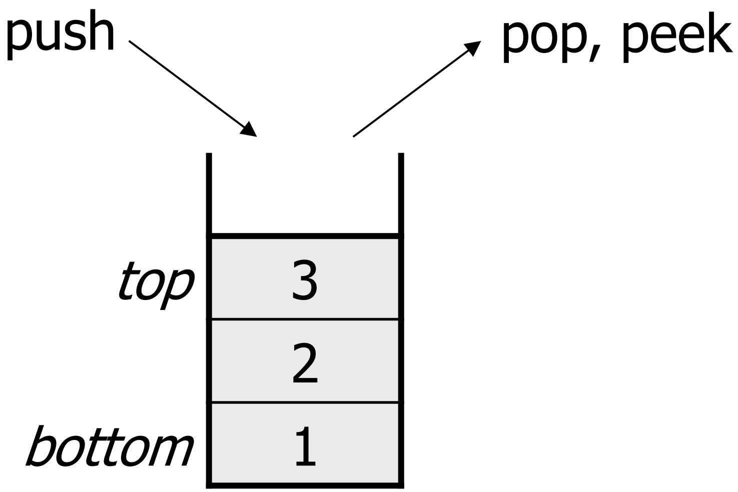


Questions?

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
```

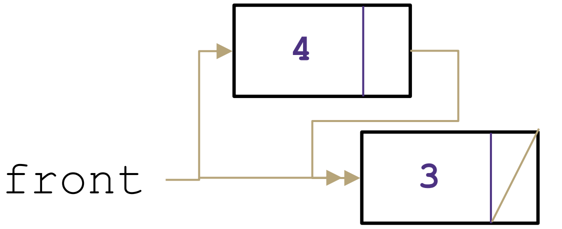
behavior

```
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()
```



`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?

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.

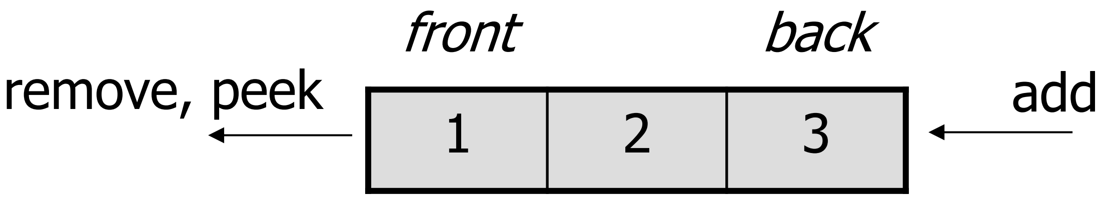
Queue ADT

state

Set of ordered items
Number of items

behavior

<u>add(item)</u> add item to back
<u>remove()</u> remove and return item at front
<u>peek()</u> return item at front
<u>size()</u> count of items
<u>isEmpty()</u> 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		

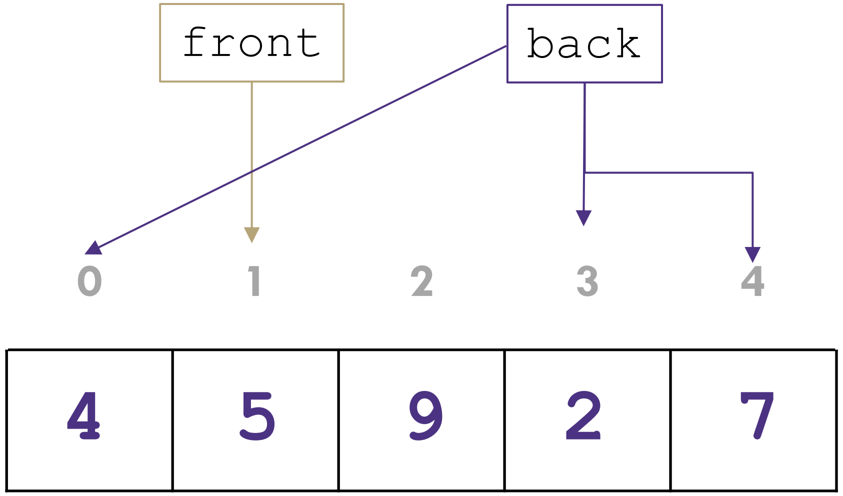
```
numberOfItems = 3
front = 1
back = 2
```

Take 1 min to respond to activity

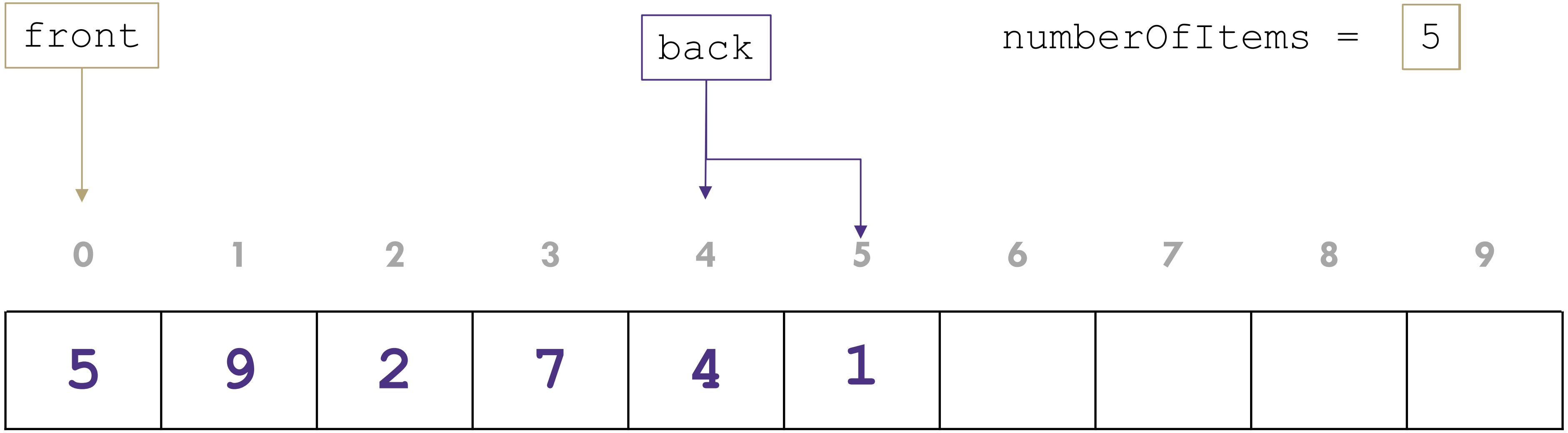
www.pollev.com/cse373activity
What do you think the worst possible runtime of the "add()" operation will be?

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>

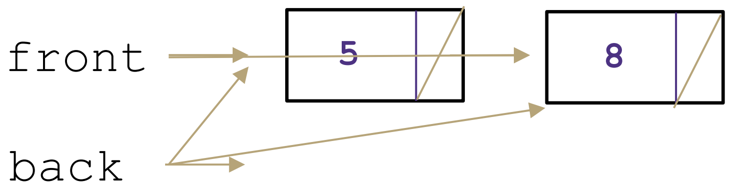
```
state
  Node front
  Node back
  size

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_FFhmoWFyT2I25G06o/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)

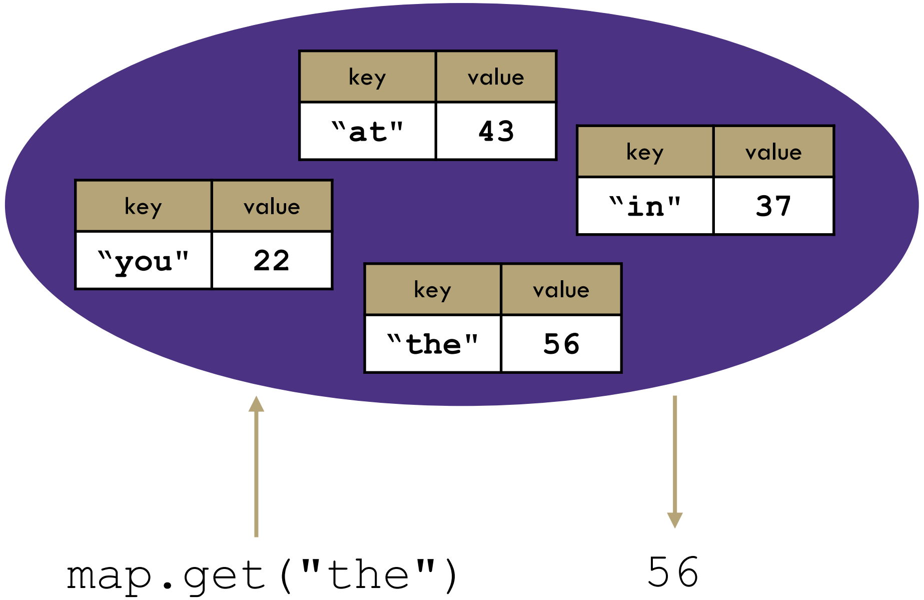
Every Programmer's Best Friend

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

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

Aug → 37.3

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>

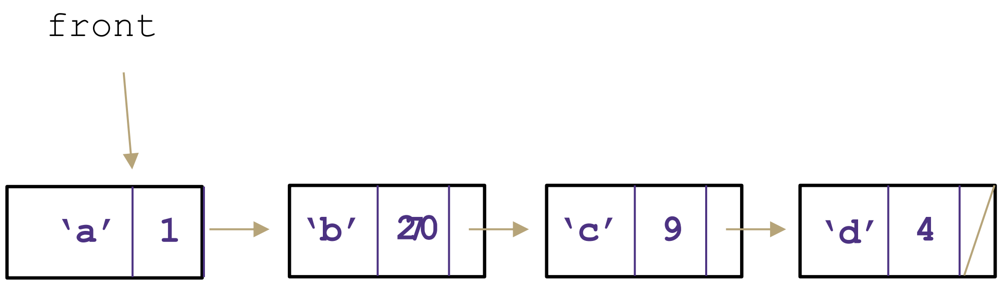
state

```
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)
```



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