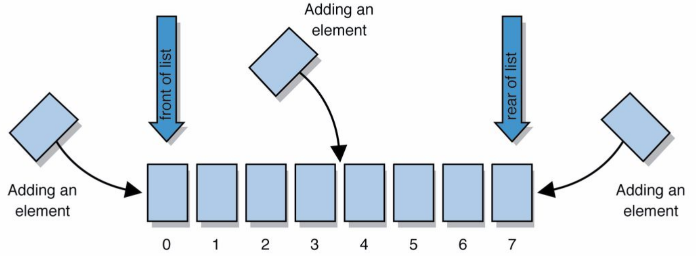
Slido Event #2048464
https://app.sli.do/event/hnnjzEubx73ASDfQCzhPXw

Lecture 3: ADT Implementation

CSE 373: Data Structures and Algorithms

Warm Up



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

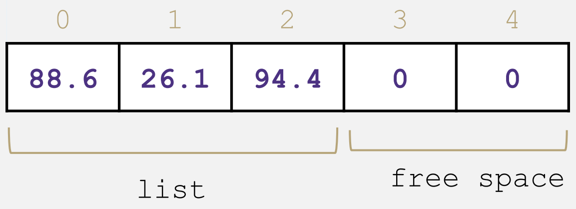
List ADT

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



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

Warm Up

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

Features to consider:

- add or remove songs from list
- change song order
- shuffle play

Q: Would you use a LinkedList or ArrayList implementation for this scenario?
Discuss with those around you!

Why ArrayList?

- optimized element access makes shuffle more efficient
- accessing next element faster in contiguous memory

Why LinkedList?

- easier to reorder songs
- memory right sized for changes in size of playlist, shrinks if songs are removed

Agenda

Design Decisions Review

Stacks

Queues

Dictionaries

Questions

Announcements

HW 0 – 143 Review Project

- Live on website
- Due Wednesday

Monday - Exercise 1 to be released

Design Decisions Review

Stacks

Queues

Dictionaries

Questions

Design Decisions

For every ADT there are lots of different ways to implement them

Based on your situation you should consider:

- Memory vs Speed
- Generic/Reusability vs Specific/Specialized
- One Function vs Another
- Robustness vs Performance

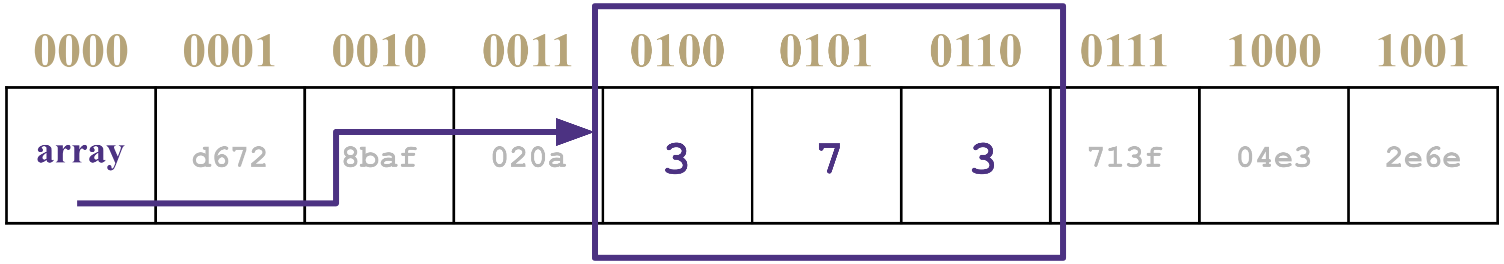
This class is all about implementing ADTs based on making the right design tradeoffs!

A common topic in interview questions!

A quick aside: Types of memory

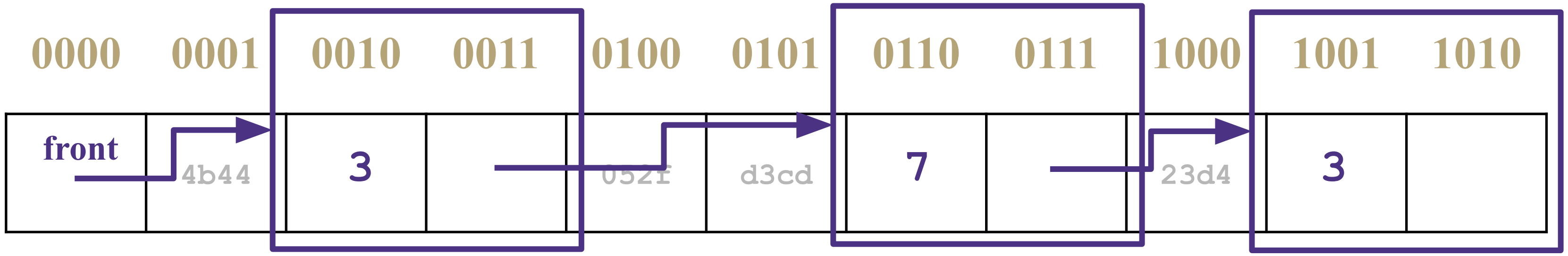
Arrays – **contiguous memory**: when the “new” keyword is used on an array the operating system sets aside a single, right-sized block of computer memory

```
int[] array = new int[3];
array[0] = 3;
array[1] = 7;
array[2] = 3;
```



Nodes– **non-contiguous memory**: when the “new” keyword is used on a single node the operating system sets aside enough space for that object at the next available memory location

```
Node front = new Node(3);
front.next = new Node(7);
front.next.next = new Node(3);
```



More on how memory impacts runtime later in this course…

Design Decisions

Slido Event #24766140
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Situation: Write a data structure that implements the List ADT that will be used to store the history of a bank customer's transactions.

Features to consider:

- adding a new transaction
- reviewing/retrieving transaction history

Q: Would you use a LinkedList or ArrayList implementation for this scenario?

Discuss with those around you!

Why ArrayList?

- optimized element access makes reviewing based on order easier
- contiguous memory more efficient and less waste than usual array usage because no removals

Why LinkedList?

- if structured with front pointing to most recent transaction, addition of transactions constant time
- memory right sized for large variations in different account history size

Real-World Scenarios: Lists

LinkedList

- Image viewer
  - Previous and next images are linked, hence can be accessed by next and previous button
- Dynamic memory allocation
  - We use linked list of free blocks
- Implementations of other ADTs such as Stacks, Queues, Graphs, etc.

ArrayList

- Maintaining Database Records
  - List of records you want to add / delete from and maintain your order after
- Implementations of other ADTs such as Stacks, Queues, Graphs, etc.

Questions?

Design Decisions Review

Stacks

Queues

Dictionaries

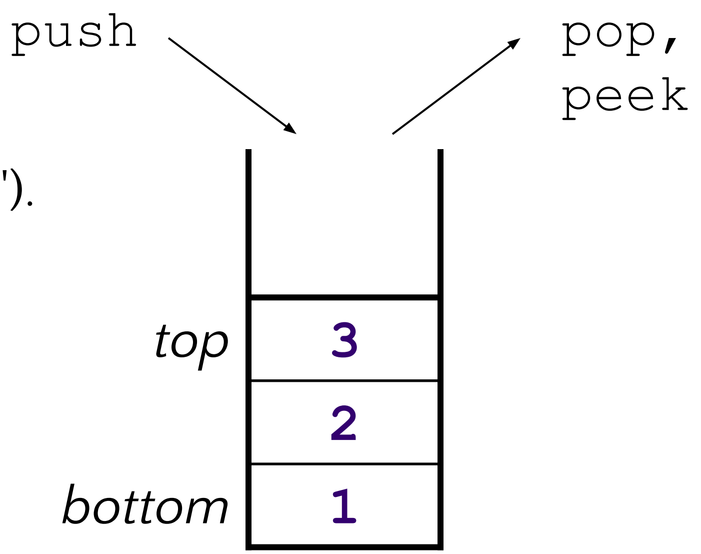
Questions

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 a resize is required O(1) Otherwise

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

0	1	2	3
3	5		

`numberOfItems = 2`

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

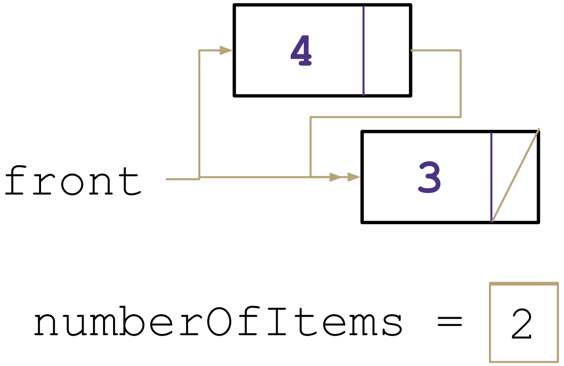
```
Node top
size
```

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()
```



Real-World Scenarios - Stacks

- Undo/Redo Feature in editing software
  - push for every action
  - pop for every click of "undo"
- Matching tags/curly braces
  - push at every opening
  - pop at every closing, check if there's a match
- DNA Parsing Implementation
  - stack is able to record combinations of two different DNA signals, release the signals into solution in reverse order, and then re-record
  - social implications + ethical concerns?
    - performance of stack dependent on efficiency of "washing steps" between stack operations
      - what if certain DNA needs more stack operations to parse than other? what kind of inequalities can this create between more common and more rare DNA? what are some social consequences of using a stack for DNA sequencing?

Design Decisions Review

Stacks

Queues

Dictionaries

Questions

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.

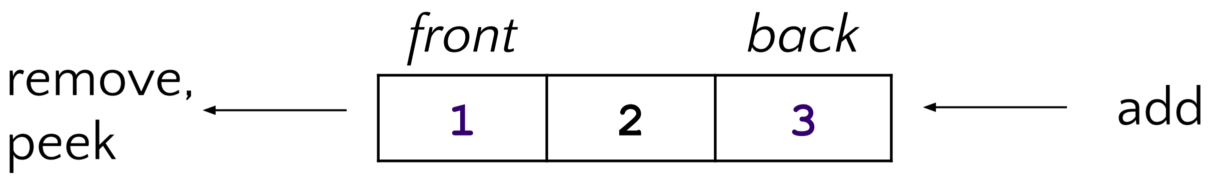
Queue ADT

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 a resize is required O(1) Otherwise

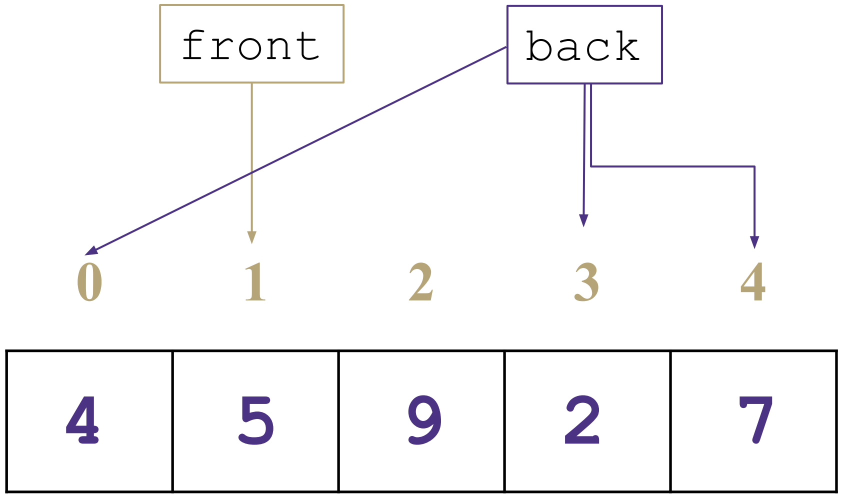
```
add(5)
add(8)
add(9)
remove()
```

0	1	2	3	4
5	8	9		

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

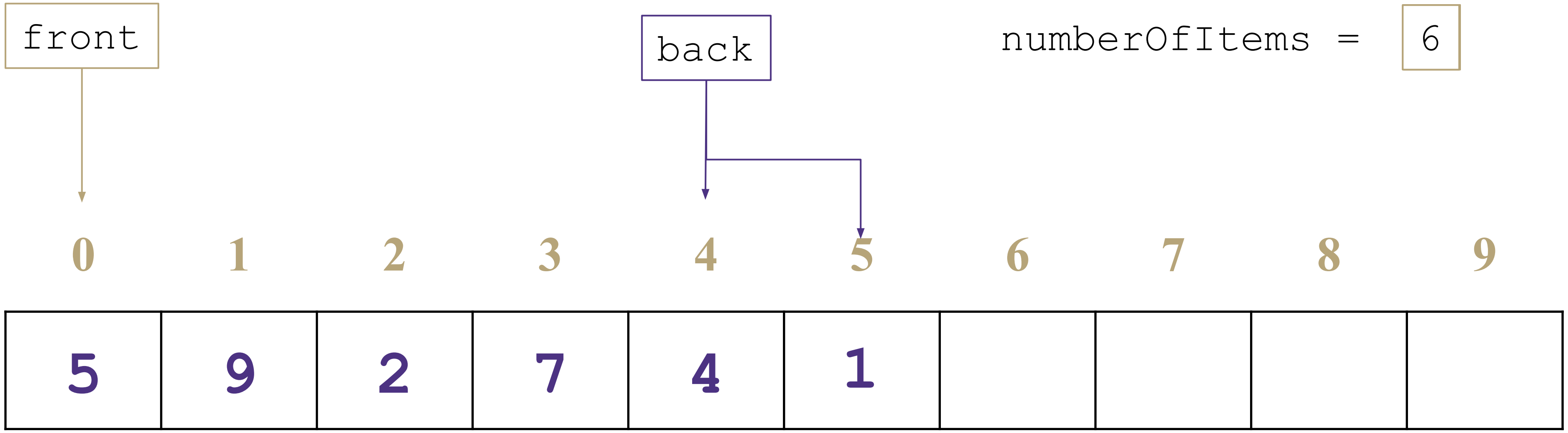
Implementing a Queue with an Array (Wrap around)

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



0	1	2	3	4
4	5	9	2	7

`numberOfItems = 6`



0	1	2	3	4	5	6	7	8	9
5	9	2	7	4	1				

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
```

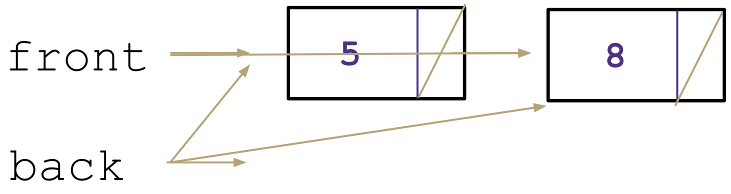
behavior

```
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

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

`numberOfItems = 2`



Real-World Examples

Serving requests on a single shared resource

- e.g. a printer, CPU task scheduling, etc.

Call Center phone systems us Queues to hold people calling them in order, until a service representative is free.

Handling of interrupts in real-time systems. The interrupts are handled in the same order as they arrive, i.e. first come first served.

Questions?

Design Decisions Review

Stacks

Queues

Dictionaries

Questions

Dictionaries (aka Maps)

Every Programmer's Best Friend

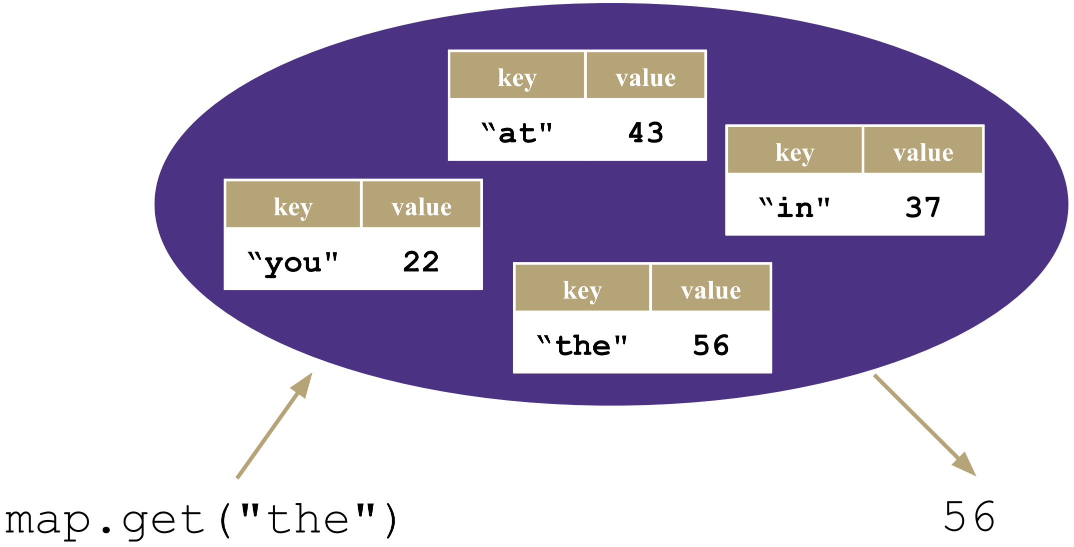
You'll probably use one in almost every programming project.
Because it's hard to make a big project without needing one sooner or later.

```
// two types of Map implementations supposedly covered in CSE 123
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

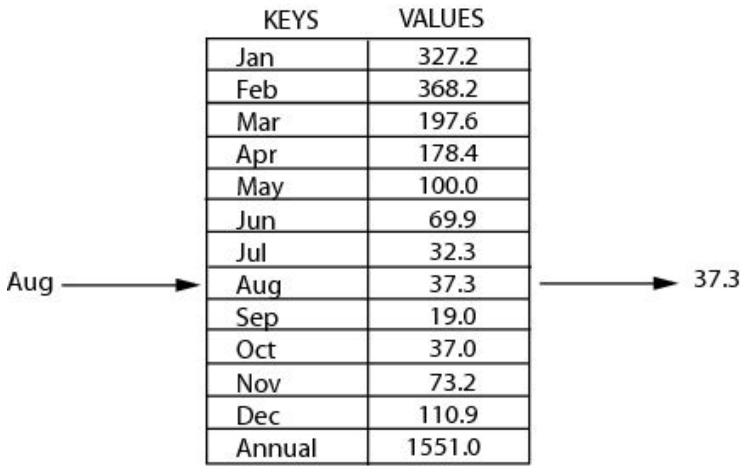
Set of items & keys
Count of items

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

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 the key is the last one looked at / is 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

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

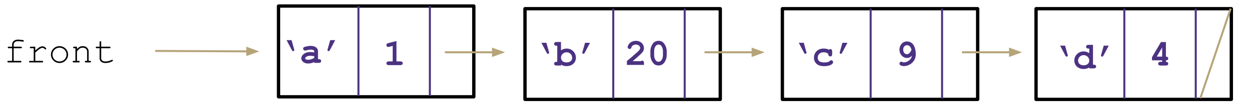
```
front
size
```

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
```

Big O Analysis: if the key is the last one looked at / is 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

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



Real-World Examples

- Symbol table for compilers
  - Key = symbol, Value = command meaning
- Database indexing
  - Data stored in databases is generally of the key-value format which is typically implemented using a HashTable data structure Dictionary.
- Computer File Managing
  - each file has two very crucial information that is, filename and file path, in order to make a connection between the filename to its corresponding file path hash tables are used

Design Decisions

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Discuss with your neighbors: For the following scenario select the appropriate ADT and implementation and explain why they are optimal for this situation.

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

Kasey's Answer

LinkedQueue

This will maintain the original order of the print jobs, but allow you to easily cancel jobs stuck in the middle of the queue. This will also keep the space used by the queue at the minimum required levels despite the fact the queue will have very different lengths at different times.

Design Decisions Review

Stacks

Queues

Dictionaries

Questions?

That’s all!

Have a great weekend!