CS18000: Problem Solving and Object-Oriented Programming

Dynamic Data Structures

(revised 12/3/23)

Video 1
Implementing an ArrayList

Dynamic Data Structures

Dynamic Arrays
Linked Lists

"Algorithms + Data Structures = Programs"
Niklaus Wirth

Some Definitions

- *data structure*: a way to organize, store, and retrieve information in a program
- *dynamic data structure*: a data structure whose memory use can grow and shrink as necessary to store the information being maintained

ArrayList

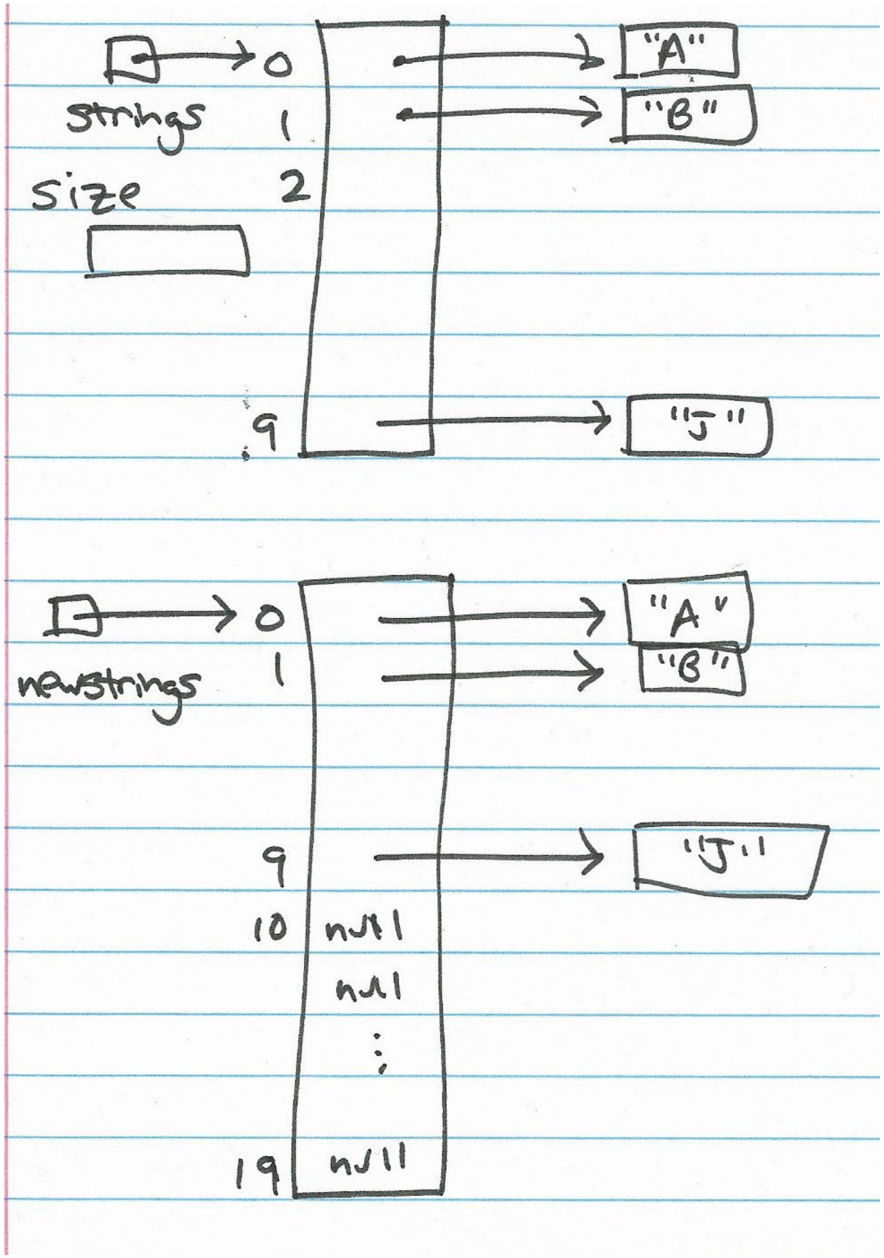
- Like an array, but grows as elements are added
- How can we write our own version of ArrayList?
- Use what you’ve got:
  - Fixed-sized arrays
  - Abstraction through class definition
  - Accessor and mutator methods

Implementing an ArrayList

- Hide details inside class (ArrayList)
- Use underlying fixed-size array
- Keep track of
  - actual number of elements currently stored vs.
  - capacity of the underlying array
- Use accessor and mutator methods to control access, enforcing the abstraction

Expanding the Underlying Array

- If actual number of elements becomes larger than current capacity…
- Allocate new underlying array
- Copy old array elements into it
- Free old array (and elements it references)



0
strings
1
size
2
9
"A"
"B"
"J"
0
newstrings
1
9
10
null
null
19
null
"A"
"B"
"J"

What Methods in ArrayList?

- Allocate new instances

```
ArrayList a = new ArrayList()
```

- Add elements to the end of the array

```
a.add("hello");
a.add("there");
```

- Replace (set) a specific element in the array

```
a.set(0, "world");
```

- Get a specific element of the array

```
System.out.println(a.get(1));
```

- Note: The underlying implementation is hidden

Example: ArrayList (1)

```
public class ArrayList {
    private String[] strings;
    private int size;

    public ArrayList() {
        strings = new String[10];
        size = 0;
    }

    public String get(int i) {
        return strings[i];
    }

    public void set(int i, String s) {
        strings[i] = s;
    }
```

Example: ArrayList (2)

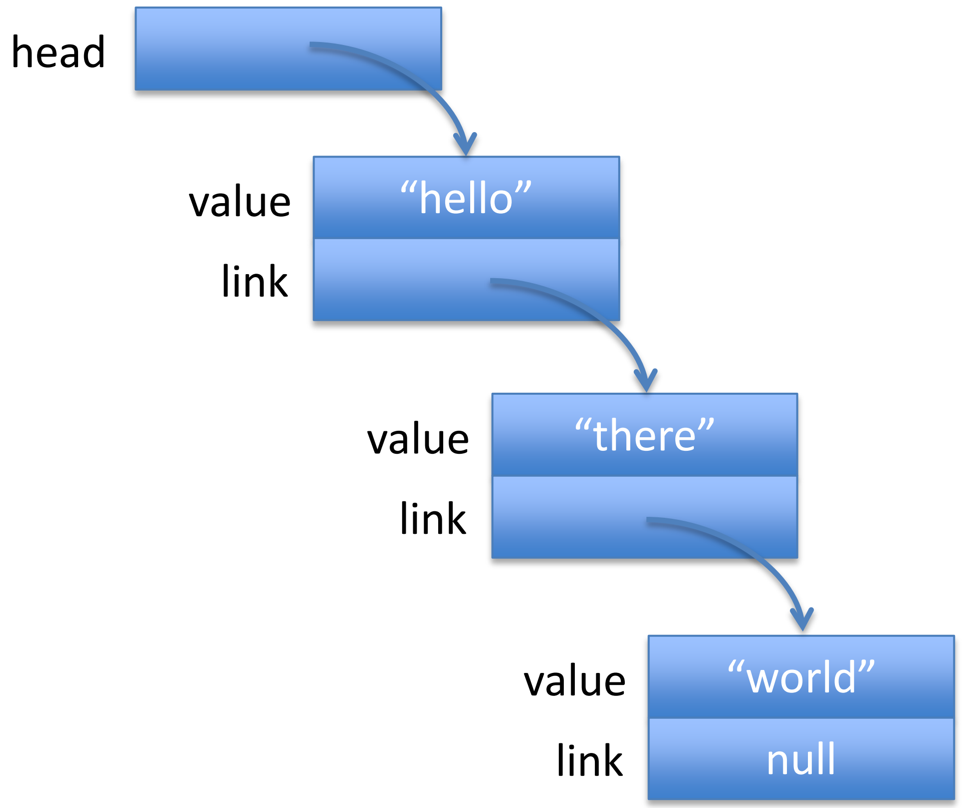
```
    public void add(String string) {
        if (size >= strings.length)
            reallocate();
        strings[size++] = string;
    }

    private void reallocate() {
        String[] newstrings = new String[strings.length * 2];
        for (int i = 0; i < size; i++)
            newstrings[i] = strings[i];
        strings = newstrings;
    }
}
```

Video 2
Linked Lists

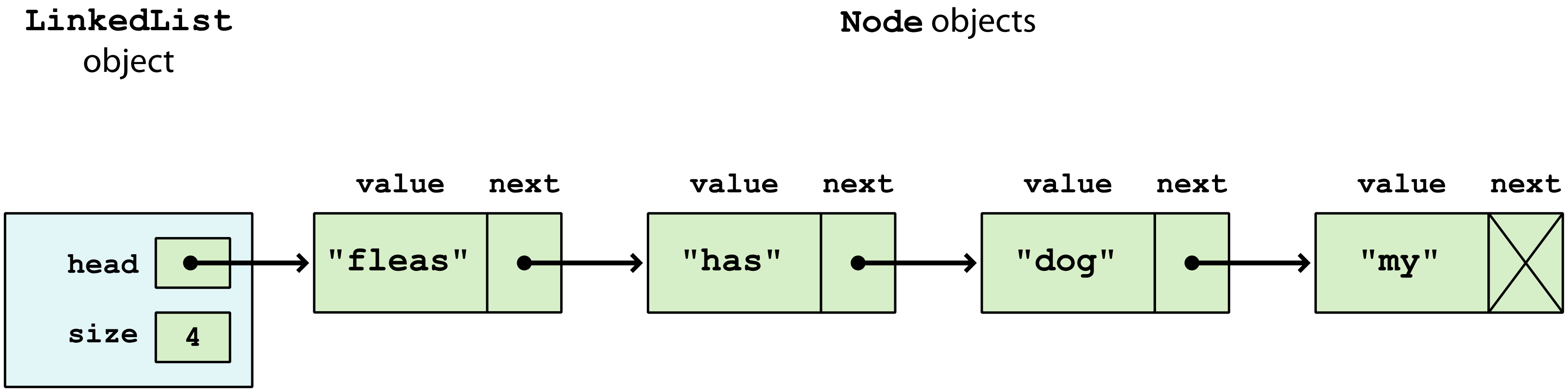
What’s Wrong with this ArrayList

- Holds only a single type
  - Elements are Strings
  - What if we want to store ints (Integers) or Trees?
  - Must create a new ArrayList class for each type, or use “generics”
- Efficiency considerations
  - Doubling each time can mean substantial wasted space
  - Performance hit every time new internal array is allocated and must be initialized from old internal array
- An Alternate Approach: Linked List

A Linked List



Linked List: Another View



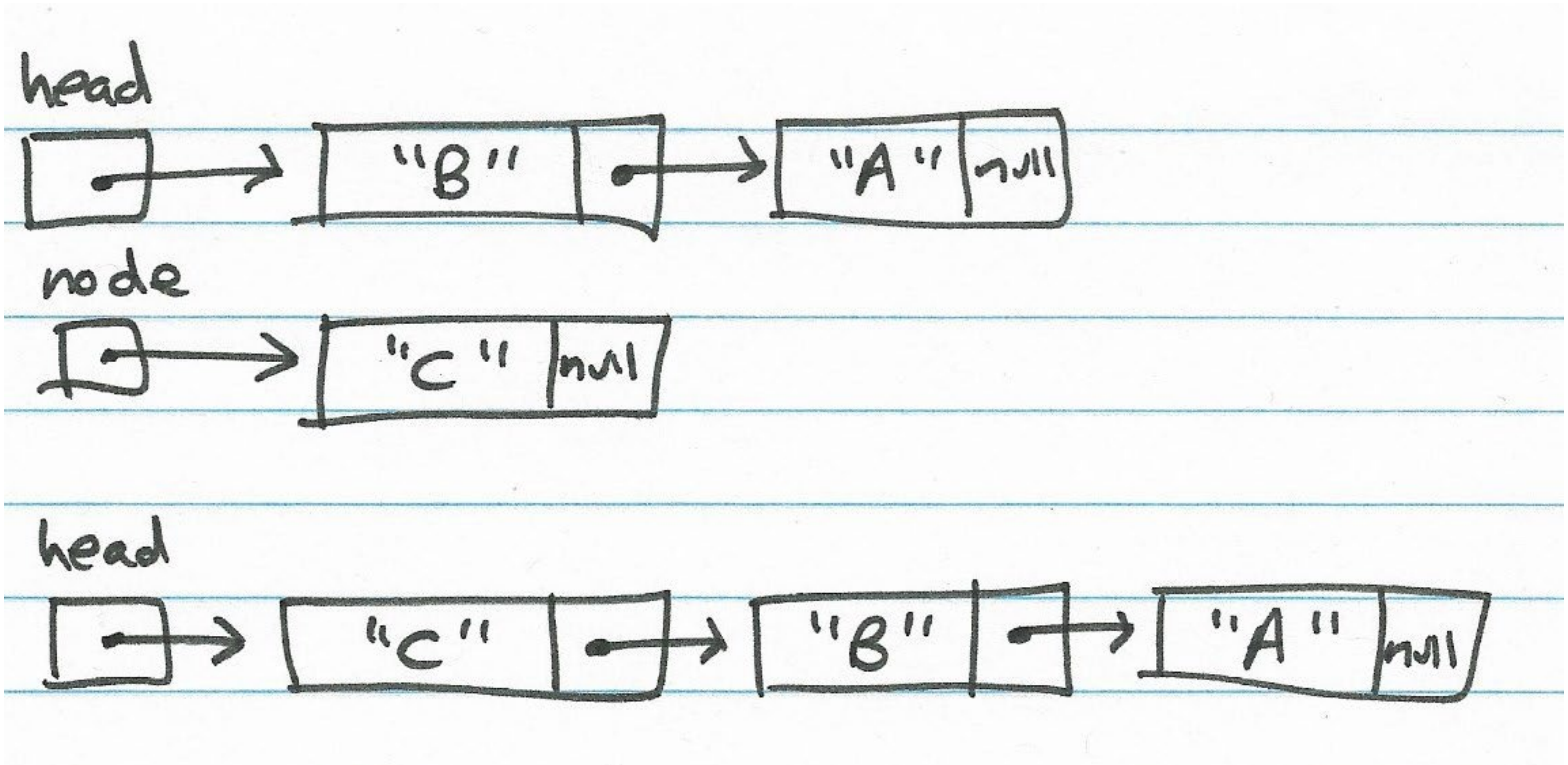
Creating a LinkedList Class

- "Outer" (LinkedList) class:
  - Implements accessor and mutator methods like ArrayList
  - Keeps "head pointer" to head of linked list
  - Keeps "size" variable to track the size
- "Inner" (nested) class
  - Implements individual nodes
  - Each node is linked to another node (except the last)

Adding to a Linked List

- Variable head points to “head node”
- Create new node with link field pointing to current “head node”
- Update head with new node just created

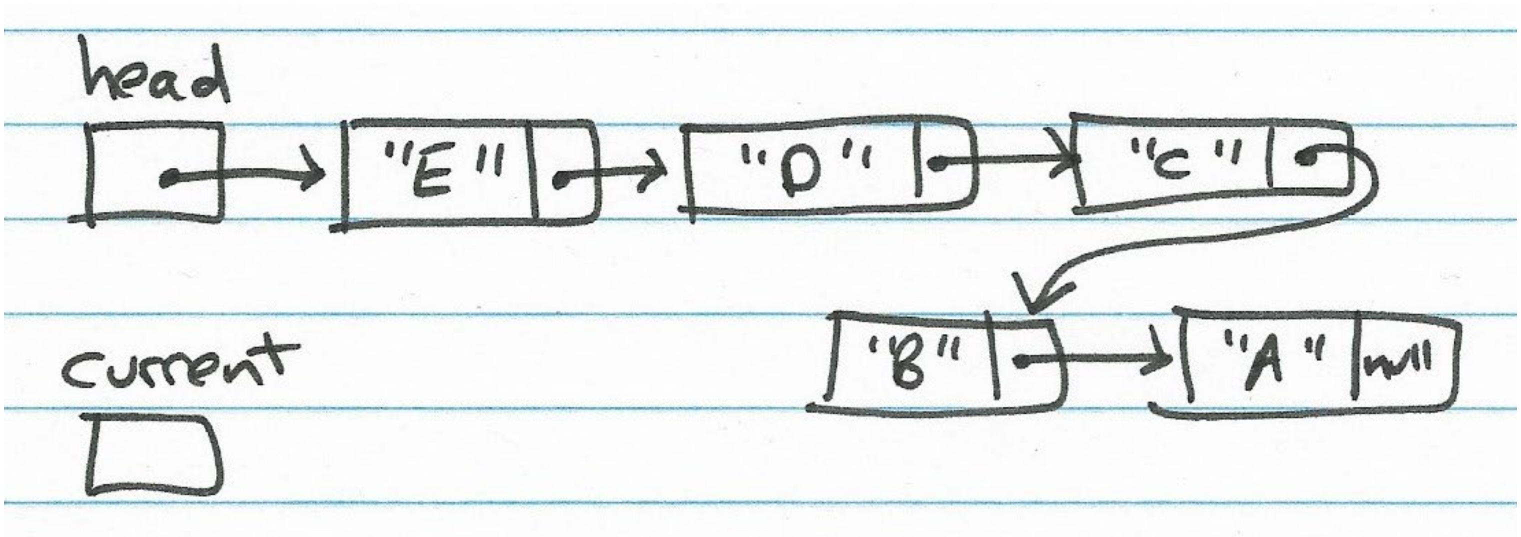
- Creates linked list “backwards”



head
"B"
"A"
null
node
"C"
null
head
"C"
"B"
"A"
null

Walking a Linked List

- Start "current node" at "head node"
- While "current node" is not null
  - "Visit" it (access value stored there)
  - Replace "current node" with link to next node
- When "current node" is null, we've reached the end of the list


head
"E"
"D"
"C"
current
"B"
"A"
null

Other Linked List Operations

- Get i^{th} element of list
  - "Walk" through i nodes
  - May be slow for long lists
- Use "tail pointer" to append to end of list
- Use multiple pointers to insert in middle of list

LinkedList: Basic Definition

```
public class LinkedList {
    private Node head;

    private class Node {
        String value;
        Node link;
    }
}
```

- Need accessor and mutator methods to use!

Video 1
Implementing a Linked List

LinkedList: Operations

- LinkedList() null constructor
- void add(String s)
  add String s to the linked list
- String[] toArray()
  create and return an array with all elements
- int getSize()
  returns the number of items currently in the linked list

Problem: ProcessFile

- Read lines from a file one at a time
- Unknown number of lines
- Store in a data structure (linked list)
- Create array with one element per line

Example: ProcessFile

```
import java.io.File;
import java.io.FileNotFoundException;
import java.util.Scanner;

public class ProcessFile {
    public static void main(String[] args) throws FileNotFoundException {
        LinkedList list = new LinkedList();

        Scanner in = new Scanner(new File("dickens-tale-of-two-cities.txt"));
        while (in.hasNextLine()) {
            list.add(in.nextLine());
        }

        String[] array = list.toArray();
        System.out.printf("read %d lines\n", list.getSize());
        for (int i = 0; i < array.length; i++)
            System.out.println(array[i]);
    }
}
```

Example: LinkedList Version 1 (1)

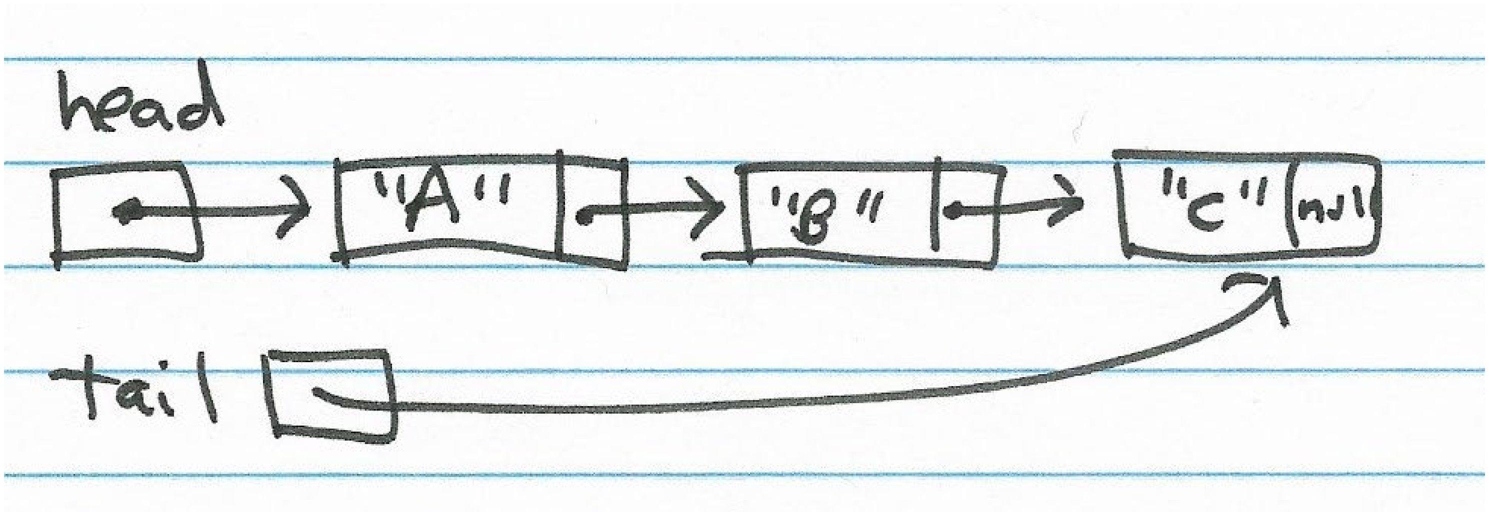
```
public class LinkedList {
    private Node head;
    private int size;

    private class Node {
        String value;
        Node link;

        Node(String value) {
            this.value = value;
            size++;
        }
    }

    public LinkedList() {
        head = null;
        size = 0;
    }
    // continued...
```

Example: LinkedList Version 1 (2)

```
// ...continued
    public void add(String s) {
        Node node = new Node(s);
        node.link = head;
        head = node;
    }
    public int getSize() {
        return size;
    }
    public String[] toArray() {
        String[] array = new String[size];
        int i = 0;
        Node node = head;
        while (node != null) {
            array[i++] = node.value;
            node = node.link;
        }
        return array;
    }
}
```

LinkedList Version 1: Problem

- List created in reverse order
- Head points to last element added
- Array elements in reverse order
- Solution:
  - Add tail pointer
  - As nodes are added, update tail rather than head
- With head and tail pointer, linked list can have nodes added at either end

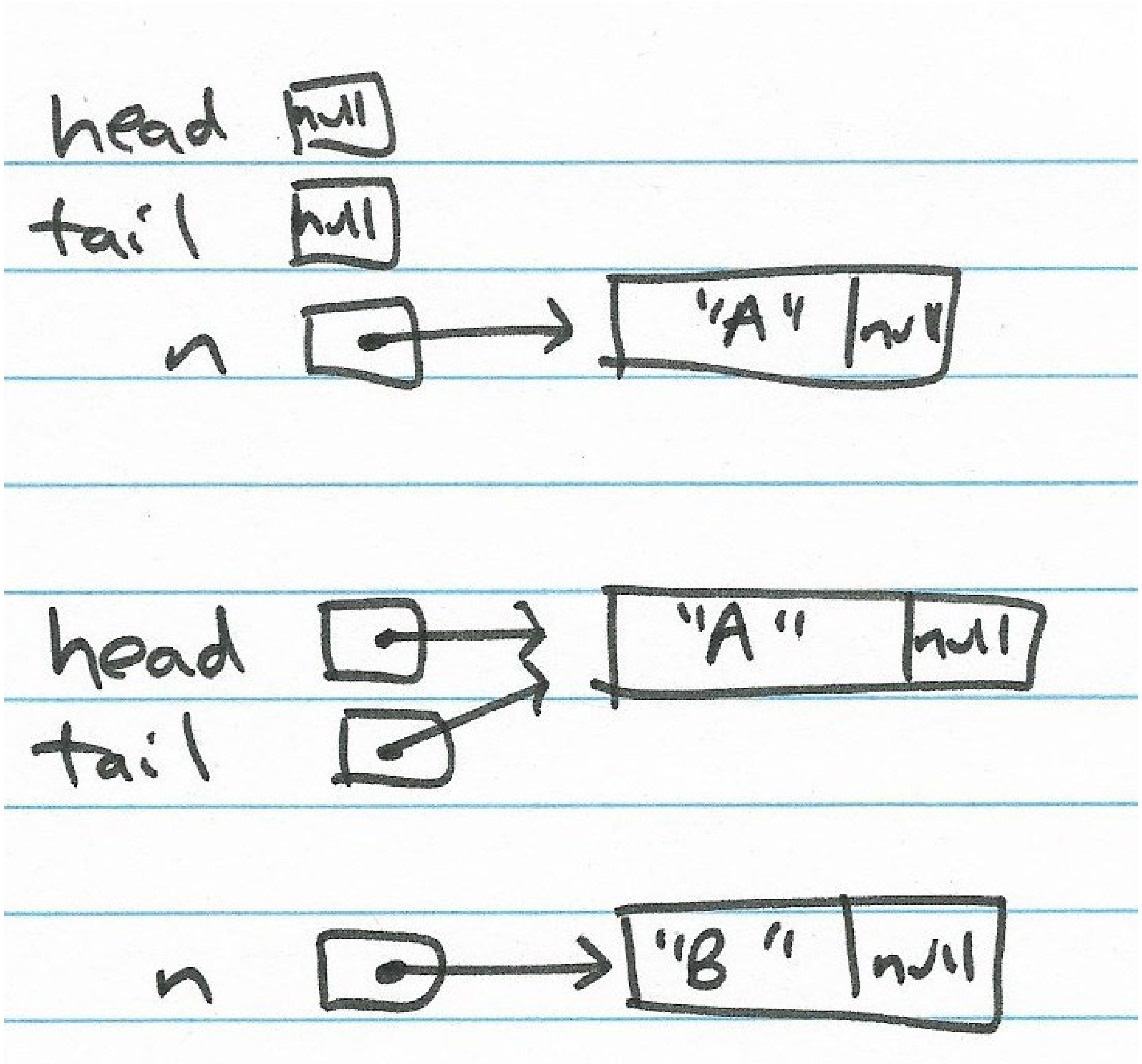

head
"A"
"B"
"C"
null
tail

Example: LinkedList Version 2 (1)

```
public class LinkedList {
    private Node head;
    private Node tail;
    private int size;

    private class Node {
        String value;
        Node link;

        Node(String value) {
            this.value = value;
            size++;
        }
    }

// continued...
```

Example: LinkedList Version 2 (2)

```
// ... continued

    public LinkedList() {
        head = tail = null;
        size = 0;
    }

    public void add(String s) {
        Node n = new Node(s);
        if (head == null)
            head = n;
        if (tail != null)
            tail.link = n;
        tail = n;
    }

// getSize and toArray unchanged from version 1
}
```


head
null
tail
null
n
"A"
null
head
"A"
null
tail
n
"B"
null

Video 2
Stacks and Queues

Dynamic Data Structures

Stacks

Queues

What methods does a data structure provide?

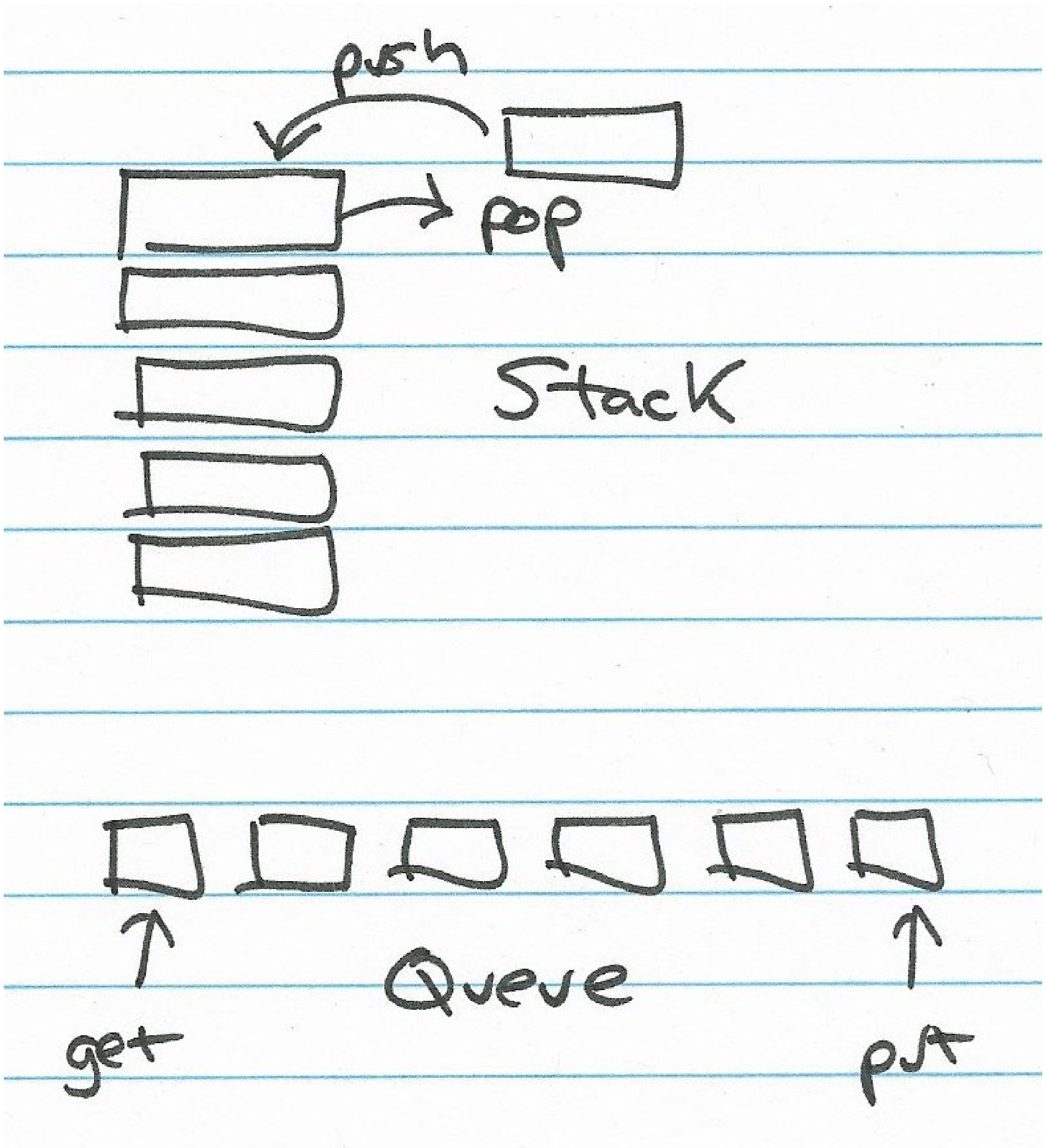
- When asking “What methods?”…
  - ArrayList: add, get, set, …
  - LinkedList: add, toArray, …
- … answers reveal the “features” of the data structure…
- How is the data *accessed*?
- Not how those features are *implemented?*
- Implementation is hidden or “abstract”

Abstract Data Type (ADT)

- A description of the behavior of a data type (class) without specifying an implementation of that behavior
- User of data type unaware of implementation details
- User does not (cannot) make assumptions about the implementation
- Gives implementer of ADT maximum flexibility

Two Common ADTs

- Stack (LIFO)
  - Models a “stack of plates” (for example)
  - Operations:
    - push an element on the stack
    - pop an element off the stack
    - isEmpty: check if the stack is empty
- Queue (FIFO)
  - Models a “line of people” (for example)
  - Operations:
    - put an element at the end of the queue
    - get next element from the front of the queue
    - isEmpty: check if the queue is empty


push
pop
Stack
Queue
get
put

Stack Uses

- RPN expression evaluation (coming up)
  Same as used in Java Virtual Machine (JVM)
- Managing the storage of local variables for methods being executed
- Undo operations

Queue Uses

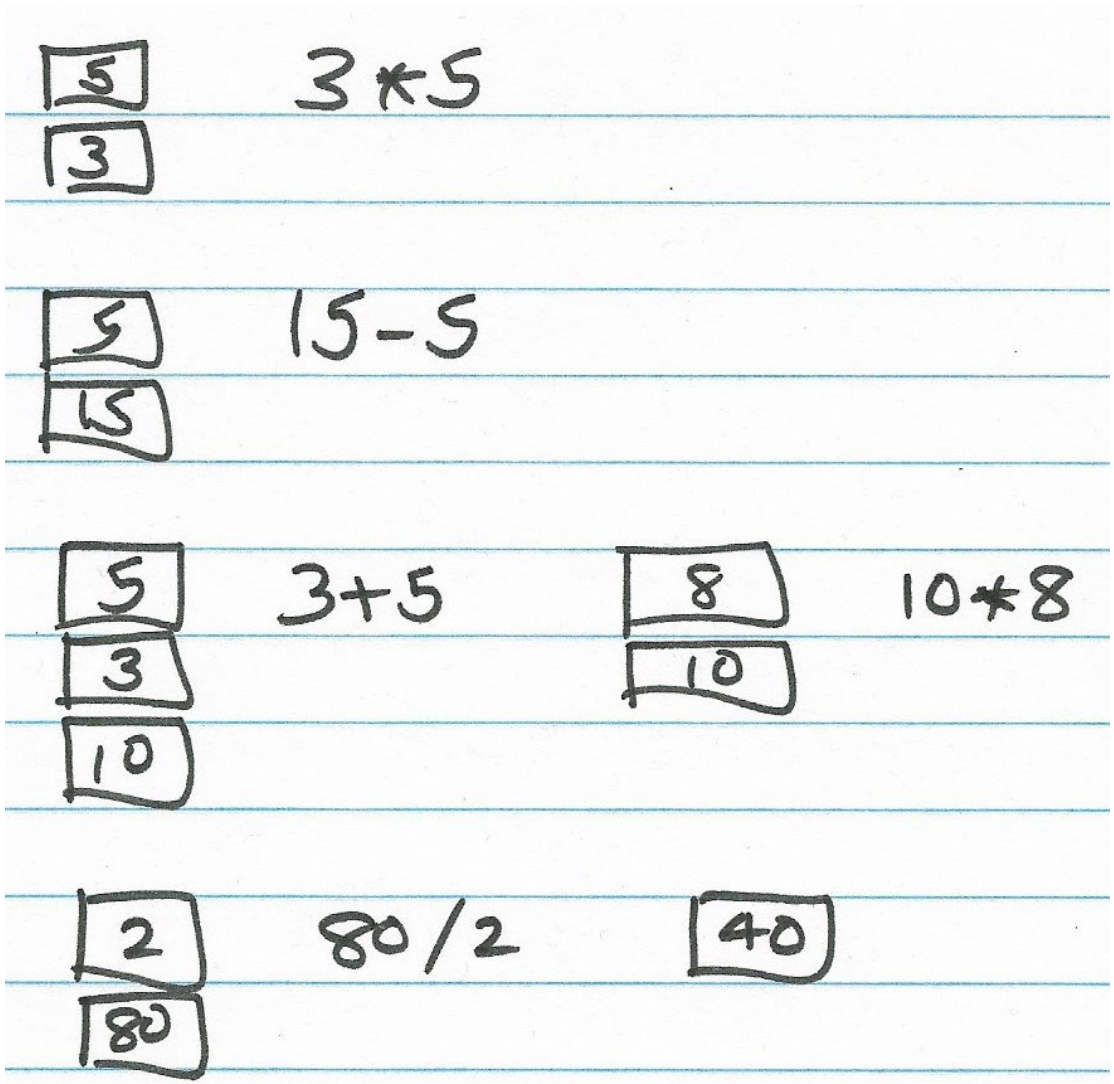
- Files sent to a printer
- Threads (or processes) waiting for access to the CPU (or a core)
- Network packets waiting for transmission
- Producer/consumer relationships:
  - producers generate requests,
  - enqueue them,
  - consumers remove from queue and process them

Problem: RPN Evaluation

- Input is a string of space-separated numbers and operators
- (3*5 - 5) * (3+5) / 2 = 40
- Treat as mathematical expression in “Reverse-Polish Notation” (RPN)
- Reminder: similar to Java byte code
- Example:

```
3 5 * 5 – 3 5 + * 2 /
= 40
```

- Use a stack to carry out the computation


5
3
3*5
5
15
15-5
5
3
10
3+5
8
10
10*8
2
80
80/2
40

Example: RPN Evaluator (1)

```
public class Evaluator {
    public static int evaluate(String s) {
        Stack stack = new LinkedListStack();
        String[] tokens = s.split(" ");
        for (String token : tokens) {
            if (token.matches("[0-9]"))
                stack.push(Integer.parseInt(token));
            else { // note non-standard compact formatting to fit slide...
                int op2 = stack.pop(); int op1 = stack.pop();
                if (token.equals("+")) stack.push(op1 + op2);
                else if (token.equals("-")) stack.push(op1 - op2);
                else if (token.equals("*")) stack.push(op1 * op2);
                else if (token.equals("/")) stack.push(op1 / op2);
                else throw new RuntimeException("unknown operator");
            }
        }
        return stack.pop();
    }
```

Example: RPN Evaluator (2)

```
// main method...

    public static void main(String[] args) {
        String s = "3 5 * 5 - 3 5 + * 2 /";
        System.out.printf("%s = %d\n", s, evaluate(s));
    }
}
```

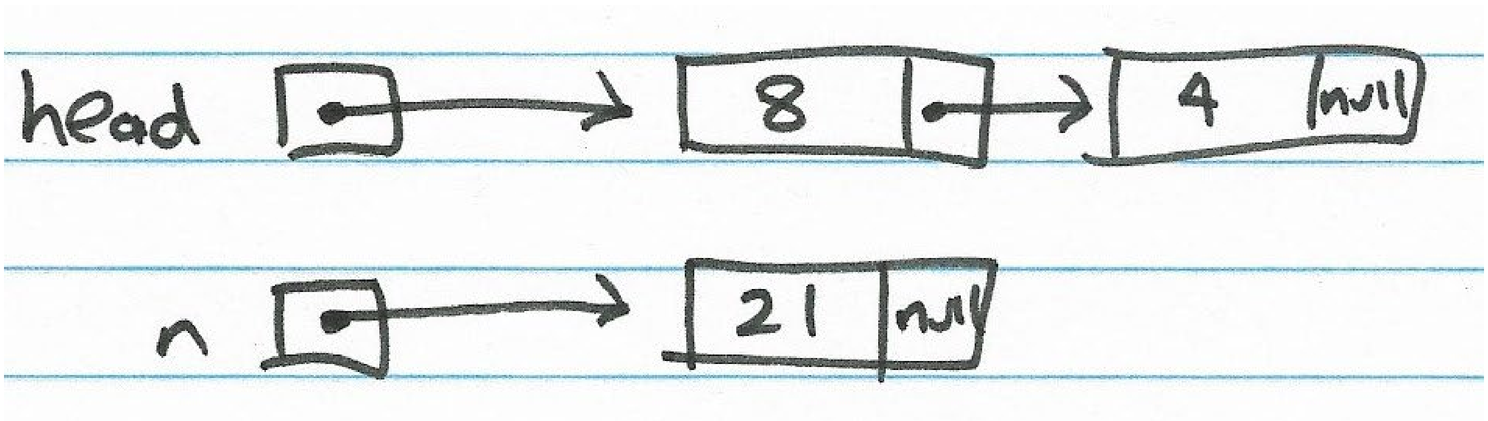
Video 1
Implementing a Stack

Example: Stack Interface

```
public interface Stack {
    boolean isEmpty();     // true if there are no elements on the stack
    void push(int value);  // push element on the top of the stack
    int pop();             // remove element from the top of the stack
}
```

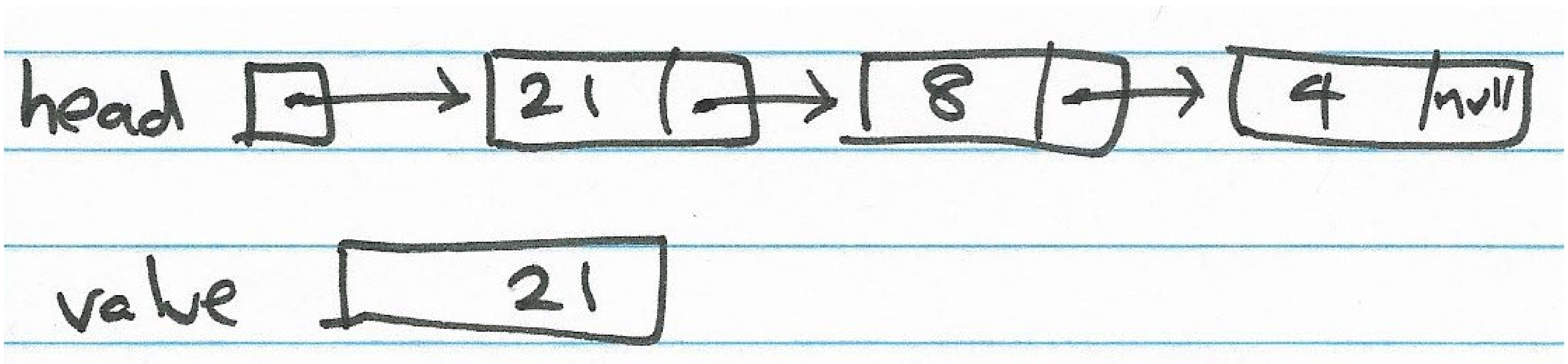
Example: LinkedListStack

```
public class LinkedListStack implements Stack {
    private class Node {
        int value;
        Node link;
    }

    private Node head = null;

    public void push(int x) {
        Node n = new Node();
        n.value = x;
        n.link = head;
        head = n;
    }

// continued…
```


head
8
4
null
n
21
null

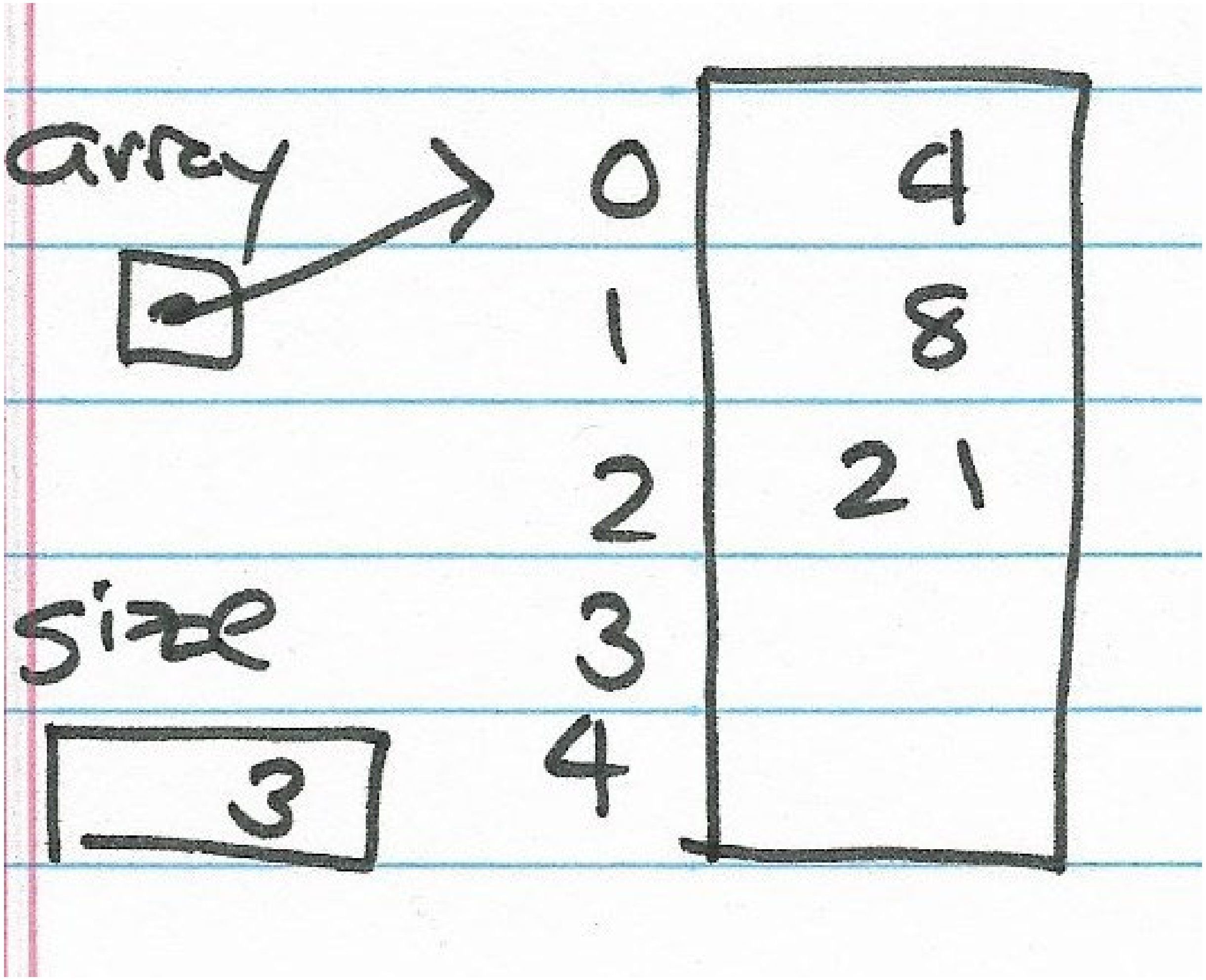
Example: LinkedListStack

```
// continued...

    public int pop() {
        if (isEmpty())
            throw new RuntimeException("Can't pop empty stack");
        int value = head.value;
        head = head.link;
        return value;
    }

    public boolean isEmpty() {
        return head == null;
    }

}
```


head
21
8
4
null
value
21

Stack Implementation with Array

- Use a static array that is “big enough” or a dynamic array like an ArrayList
- Maintain a separate “size” variable that tracks the current stack size
- isEmpty: size == 0
- push: array[size++] = value
- pop: return array[--size]
- Add error checking for empty stack and overflow


array
size
3
0
1
2
3
4
4
8
21

Stacks in Java Utils Package

- Basic stack…

  http://docs.oracle.com/javase/8/docs/api/java/util/Stack.html
- Generalized stack…

  http://docs.oracle.com/javase/8/docs/api/java/util/Deque.html
  - Deque (pronounced “deck”): “double-ended queue”
  - Provides methods for both stack-access and queue access

Video 2
Implementing a Queue

The Queue ADT

- Java operations
  - add
  - remove
  - peek
- Other names
  - enqueue
  - dequeue
  - front

Example: Queue Interface

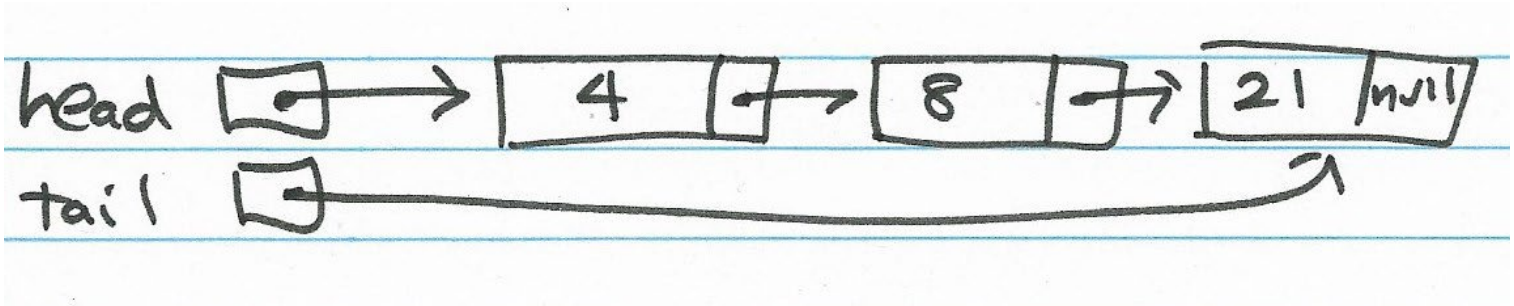
```
public interface Queue {
    boolean isEmpty();    // true if there are no elements in the queue
    void add(int value);  // add element to the end of the queue
    int remove();         // remove element from front of the queue
    int peek();           // “peek” at front element
}
```

Example: LinkedListQueue (1)

```
public class LinkedListQueue implements Queue {
    private class Node {
        int value;
        Node link;

        Node(int value) {
            this.value = value;
        }
    }

    private Node head = null;
    private Node tail = null;

    public boolean isEmpty() {
        return head == null;
    }

// continued...
```

Example: LinkedListQueue (2)

```
// continued...

    public void add(int value) {
        Node node = new Node(value);
        if (isEmpty()) {
            head = tail = node;
        } else {
            tail.link = node;
            tail = node;
        }
    }
    public int remove() {
        int value = head.value;
        head = head.link;
        if (head == null)
            tail = null;
        return value;
    }
// continued...
```


head
4
8
21
null
tail

Example: LinkedListQueue (3)

```
// continued...

    public int peek() {
        return head.value;
    }
}

// continued...
```

Same Concepts, Many Names

- Stack…
  - push, pop, top
  - push, pop, peek
- Queue…
  - put, get, peek
  - enqueue, dequeue, front
- Deque…
  - Stack: addFirst, removeFirst, peekFirst
  - Queue: addLast, removeFirst, peekFirst

Video 3
Generic Classes

Generic Classes

- Given the need for a …
  - Stack of Integers
  - Stack of Strings
  - Stack of Trees
- Would like to just implement once
- Allow the type to be a parameter
- Generics allow <T> notation to indicate a “type parameter”
- Examples:

```
var s = new Stack<Integer>();
var list = new ArrayList<String>();
```

Examples from the Java Library

- ArrayList (already seen)
- Stack, Queue (interface), Deque (interface)
- LinkedList (implements Stack, Queue, Deque)
- HashMap (very useful!)

HashMap

- Stores “values” referenced by a “key”
- A “dictionary” data structure
  - “word” -> “definition”
  - We say, “maps keys to values”
- Also known as an “associative array”
- HashMap<K,V>
  - K: type of the “key”
  - V: type of the “value”

```
var map = new HashMap<String, Tree>();
map.put("elm", new Tree("elm", 34.5));
map.put("maple", new Tree("maple", 14.2));
Tree t = map.get("elm");
```

Making Your Own Generic Class (1)

```
ArrayList<String> = new ArrayList<String> ();
```

```
ArrayList<Integer> = new ArrayList<Integer> ();
```

Note: Java does not allow a generic array. So, we must use an array of Objects and cast each of the values to the generic type as needed.

Making Your Own Generic Class (2)

```
public class ArrayList<Ty> {
    private Object[] values;
    private int size;

    public ArrayList() {
        values = new Object[10];
        size = 0;
    }

    public Ty get(int i) {
        return (Ty) values[i];
    }

    public void set(int i, Ty s) {
        values[i] = s;
    }
```

Making Your Own Generic Class (3)

```
    public void add(Ty item) {
        if (size >= values.length)
            reallocate();
        values[size++] = item;
    }

    private void reallocate() {
        Object[] newvalues = new Object[values.length * 2];
        for (int i = 0; i < size; i++)
            newvalues[i] = values[i];
        values = newvalues;
    }
}
```