
CS2040 Lecture Note #4: Stacks and Queues

Two basic ADTs and linear data structures

Lecture Note #4: Stacks and Queues

■ Objectives:

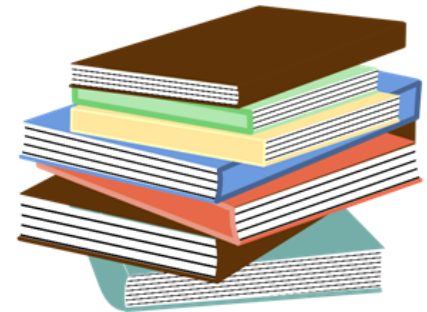
- Able to define a Stack ADT, and to implement it with array and linked list
- Able to define a Queue ADT, and to implement it with array and linked list
- Able to use stack and queue in applications
- Able to use Java API Stack class and Queue interface

Outline

1. Stack ADT (Motivation)
2. Stack Implementation via Array
3. Stack Implementation via Linked List
4. `java.util.Stack <E>`
5. Stack Applications
 - Bracket matching
 - Postfix calculation
6. Queue ADT (Motivation)
7. Queue Implementation via Array
8. Queue Implementation via Tailed Linked List
9. `java.util.interface Queue <E>`
10. Queue Application: Palindromes

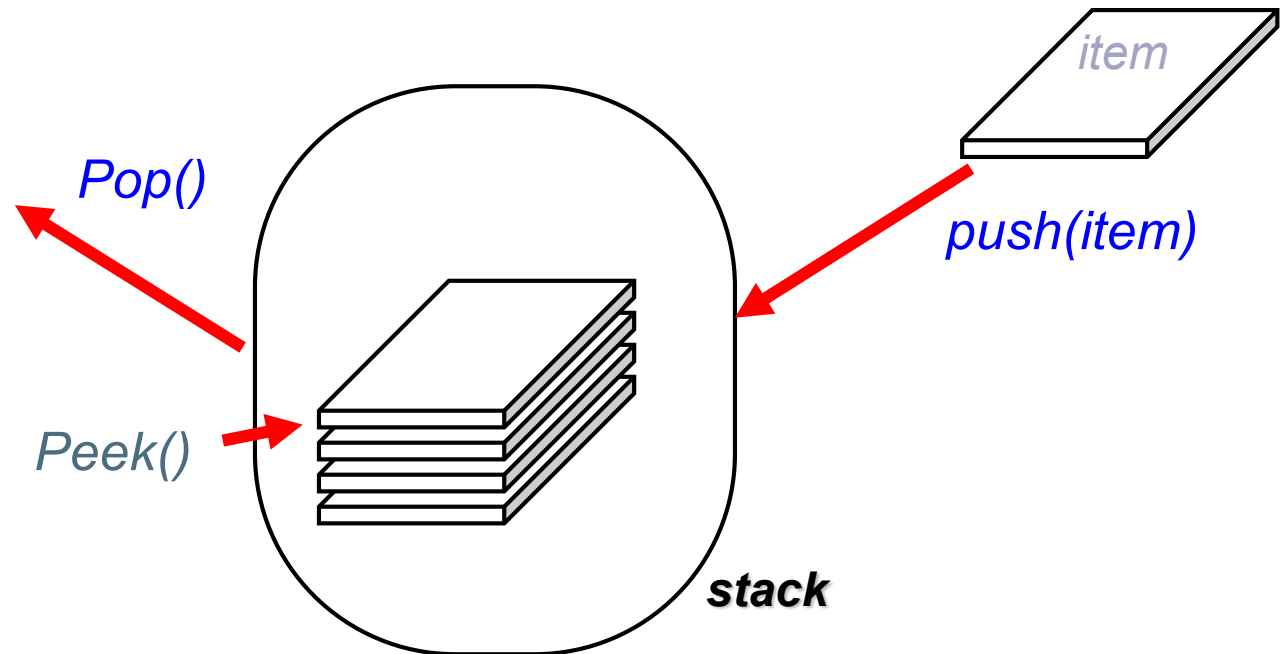
1-5 Stacks

Last-In-First-Out (LIFO)



1 Stack ADT: Operations

- ❑ A **Stack** is a collection of data that is accessed in a **last-in-first-out** (LIFO) manner
- ❑ Major operations: “**push**”, “**pop**”, and “**peek**”.



1 Stack ADT: Uses

- ❑ Calling a function
 - Before the call, the state of computation is saved on the stack so that we will know where to resume
- ❑ Recursion
- ❑ Matching parentheses
- ❑ Evaluating arithmetic expressions (e.g. $a + b - c$) :
 - postfix calculation
 - Infix to postfix conversion
- ❑ Traversing a maze

1 Stack ADT: Interface

StackADT.java

```
import java.util.*;

public interface StackADT <E> {
    // check whether stack is empty
    public boolean empty();

    // retrieve topmost item on stack
    public E      peek() throws EmptyStackException;

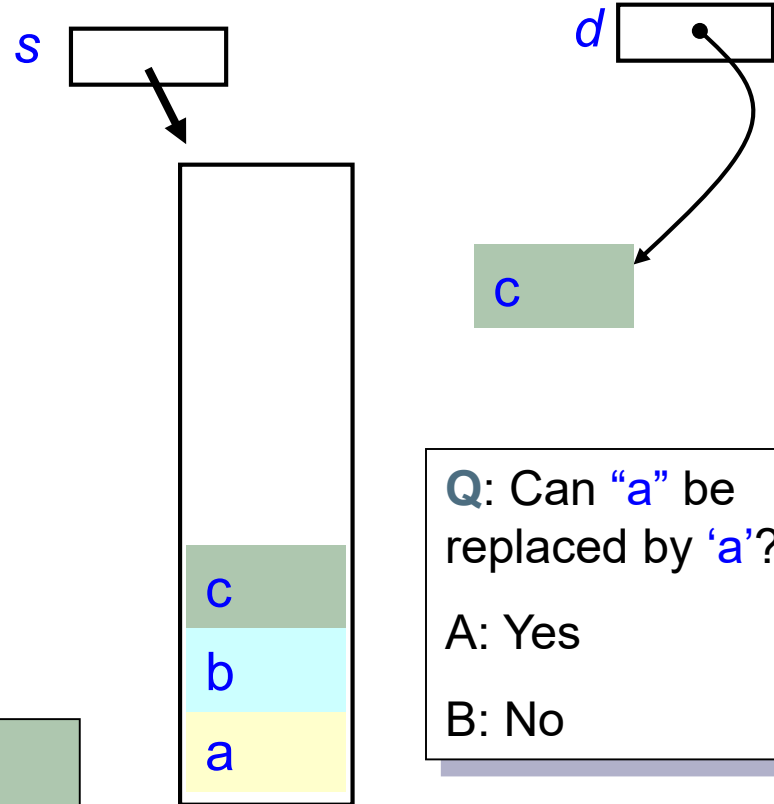
    // remove and return topmost item on stack
    public E      pop()  throws EmptyStackException;

    // insert item onto stack
    public void    push(E item);
}
```

1 Stack: Usage

```
➔ Stack s = new Stack();  
➔ s.push ("a");  
➔ s.push ("b");  
➔ s.push ("c");  
➔ d = s.peek ();  
➔ s.pop ();  
➔ s.push ("e");  
➔ s.pop ();
```

To be accurate, it is the references to
“a”, “b”, “c”, ..., being pushed or popped.



Q: Can “a” be
replaced by ‘a’?

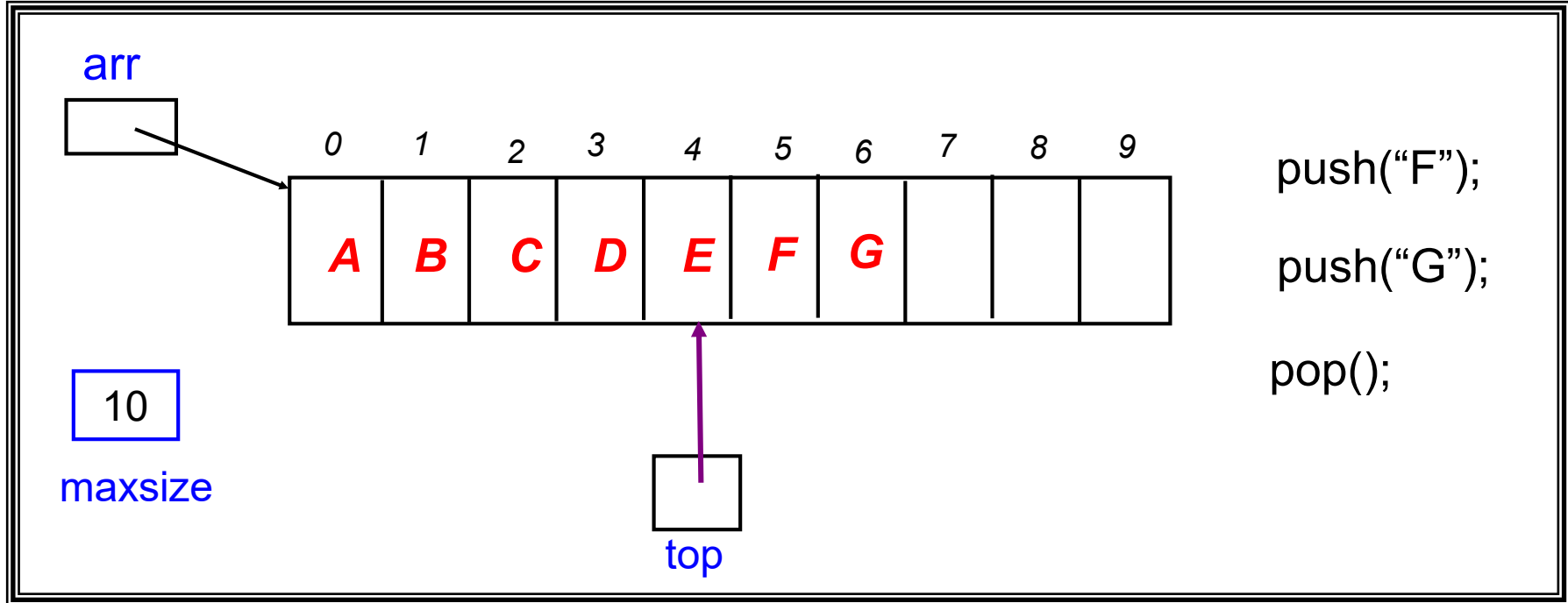
A: Yes

B: No

2 Stack Implementation: Array (1/4)

- Use an Array with a **top** index pointer

StackArr




2 Stack Implementation: Array (2/4)

StackArr.java

```
import java.util.*;

class StackArr <E> implements StackADT <E> {
    private E[] arr;
    private int top;
    private int maxSize;
    private final int INITSIZE = 1000;

    public StackArr() {
        arr = (E[]) new Object[INITSIZE]; // creating array of type E
        top = -1;  // empty stack - thus, top is not on an valid array element
        maxSize = INITSIZE;
    }

    public boolean empty() {
        return (top < 0);
    }
}
```

2 Stack Implementation: Array (3/4)

- `pop()` uses `peek()`

StackArr.java

```
public E peek() throws EmptyStackException {  
    if (!empty()) return arr[top];  
    else throw new EmptyStackException();  
}
```

```
public E pop() throws EmptyStackException {  
    E obj = peek();  
    top--;  
    return obj;  
}
```

2 Stack Implementation: Array (4/4)

- `push()` needs to consider overflow

StackArr.java

```
public void push(E obj) {
    if (top >= maxSize - 1) enlargeArr();
    top++;
    arr[top] = obj;
}

private void enlargeArr() {
    // When there is not enough space in the array
    // we use the following method to double the number
    // of entries in the array to accommodate new entry
    int newSize = 2*maxSize;
    E[] x = (E[]) new Object[newSize];

    for (int j=0; j < maxSize; j++) {
        x[j] = arr[j];
    }
    maxSize = newSize;
    arr = x;
}
```

3 Stack Implementation: Linked List (1/7)

- A class can be defined in 2 ways:

via composition:

```
class A {  
    B b = new B (...); // A is composed of instance of B  
    ...  
}
```

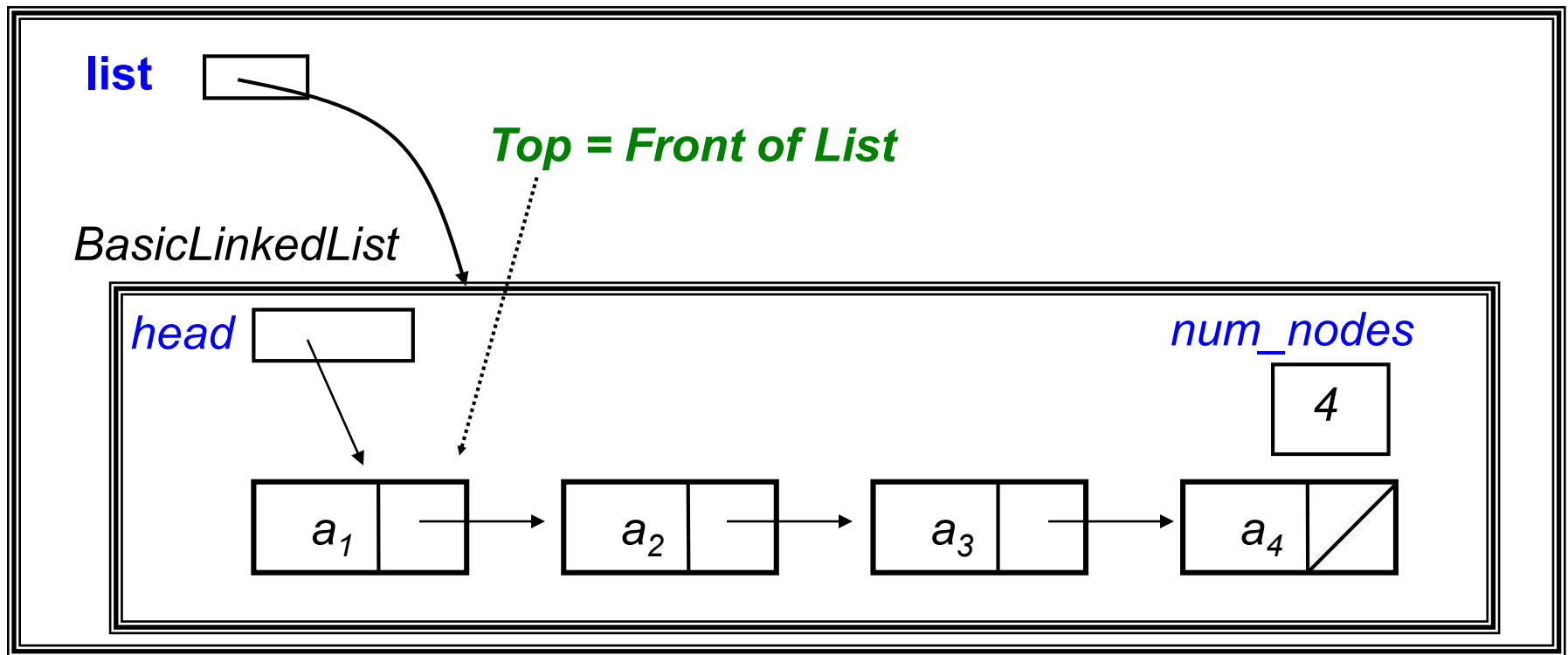
via inheritance:

```
class A extends B { // A is an extension of B  
    ....  
}
```

3 Stack Implementation: Linked List (2/7)

- Method #1 (Composition): Use BasicLinkedList

StackLL



3 Stack Implementation: Linked List (3/7)

■ Method #1 (Composition): Use BasicLinkedList

StackLL.java

```
import java.util.*;

class StackLL <E> implements StackADT <E> {
    private BasicLinkedList <E> list;

    public StackLL() {
        list = new BasicLinkedList <E> ();
    }

    public boolean empty() { return list.isEmpty(); }

    public E peek() throws EmptyStackException {
        try {
            return list.getFirst();
        } catch (NoSuchElementException e) {
            throw new EmptyStackException();
        }
    }
}
```

3 Stack Implementation: Linked List (4/7)

■ Method #1 (Composition): Use BasicLinkedList

StackLL.java

```
public E pop() throws EmptyStackException {  
    E obj = peek();  
    list.removeFirst();  
    return obj;  
}  
  
public void push(E o) {  
    list.addFirst(o);  
}  
}
```

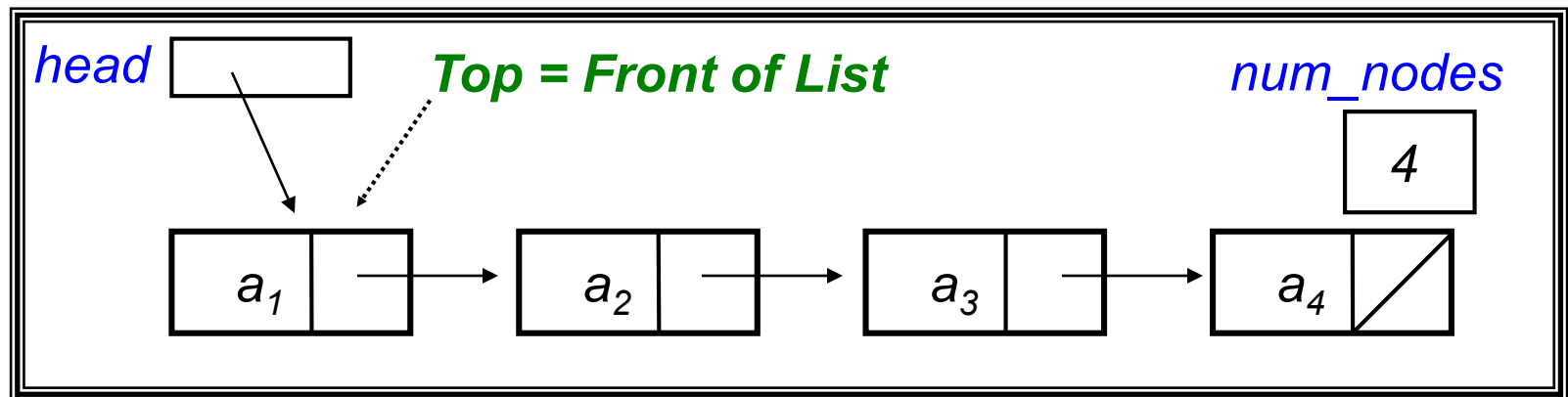
Do you need to worry about overflow with LinkedList implementation?

3 Stack Implementation: Linked List (5/7)

- Method #2 (Inheritance): **Extend** BasicLinkedList

StackLLE

BasicLinkedList



3 Stack Implementation: Linked List (6/7)

■ Method #2 (Inheritance): **Extend** BasicLinkedList

StackLLE.java

```
import java.util.*;

class StackLLE <E> extends BasicLinkedList <E> implements StackADT <E> {

    public boolean empty() {
        return isEmpty();
    }

    public E peek() throws EmptyStackException {
        try {
            return getFirst();
        } catch (NoSuchElementException e) {
            throw new EmptyStackException();
        }
    }
}
```

3 Stack Implementation: Linked List (7/7)

■ Method #2 (Inheritance): **Extend** BasicLinkedList

StackLLE.java

```
public E pop() throws EmptyStackException {  
    // write your code below  
  
}  
  
public void push (E o) {  
    // write your code below  
  
}  
}
```

3 Uses of Stacks

TestStack.java

```
import java.util.*;
class TestStack {
    public static void main (String[] args) {

        // You can use any of the following 4 implementations of Stack
        StackArr <String> stack = new StackArr <String>(); // Array
        //StackLL <String> stack = new StackLL <String>(); // LinkedList composition
        //StackLLE <String> stack = new StackLLE <String>(); // LinkedList inheritance
        //Stack <String> stack = new Stack <String>(); // Java API

        System.out.println("stack is empty? " + stack.empty());
        stack.push("1");
        stack.push("2");
        System.out.println("top of stack is " + stack.peek());
        stack.push("3");
        System.out.println("top of stack is " + stack.pop());
        stack.push("4");
        stack.pop();
        stack.pop();
        System.out.println("top of stack is " + stack.peek());
    }
}
```

4 java.util.Stack <E> (1/2)

Constructor Summary

Stack()
Creates an empty Stack.

Method Summary

boolean	<u>empty</u> ()	Tests if this stack is empty.
<u>E</u>	<u>peek</u> ()	Looks at the object at the top of this stack without removing it from the stack.
<u>E</u>	<u>pop</u> ()	Removes the object at the top of this stack and returns that object as the value of this function.
<u>E</u>	<u>push</u> (<u>E</u> item)	Pushes an item onto the top of this stack.
int	<u>search</u> (<u>Object</u> o)	Returns the 1-based position where an object is on this stack.

Note: The method “int search (Object o)” is not commonly known to be available from a Stack.

4 java.util.Stack <E> (2/2)

Methods inherited from class java.util.Vector

add, add, addAll, addAll, addElement, capacity, clear, clone, contains, containsAll, copyInto, elementAt, elements, ensureCapacity, equals, firstElement, get, hashCode, indexOf, indexOf, insertElementAt, isEmpty, lastElement, lastIndexOf, lastIndexOf, remove, remove, removeAll, removeAllElements, removeElement, removeElementAt, removeRange, retainAll, set, setElementAt, setSize, size, subList, toArray, toArray, toString, trimToSize

Methods inherited from class java.util.AbstractList

iterator, listIterator, listIterator

Methods inherited from class java.lang.Object

finalize, getClass, notify, notifyAll, wait, wait, wait

Methods inherited from interface java.util.List

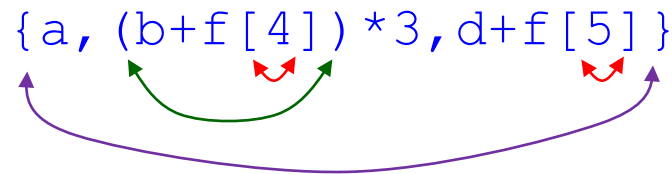
iterator, listIterator, listIterator

5 Application 1: Bracket Matching (1/2)

- Ensures that pairs of brackets are properly matched

An example:

`{a, (b+f[4])*3, d+f[5]}`



Incorrect examples:

`(. .) . .)`

// too many close brackets

`(. . (. .)`

// too many open brackets

`[. . (. .] . .)`

// mismatched brackets

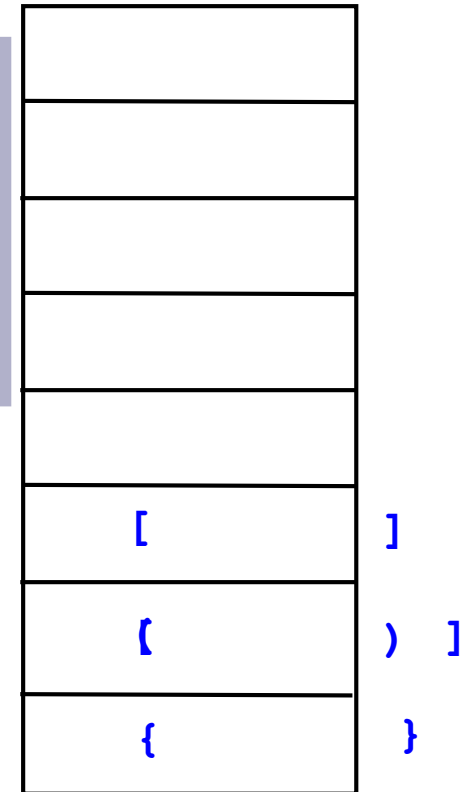


5 Application 1: Bracket Matching (2/2)

```
create empty stack
for every char read
{
  if open bracket then
    push onto stack
  if close bracket, then
    pop from the stack
    if doesn't match or underflow then flag error
}
if stack is not empty then flag error
```

Q: What type of error does the last line test for?

A: too many closing brackets
B: too many opening brackets
C: bracket mismatch



Stack

Example

{ a , (b + f [4]) * 3 , d + f [5] }



5 Application 2: Arithmetic Expression (1/6)

■ Terms

- Expression: $a = b + c * d$
- Operands: a, b, c, d
- Operators: $=, +, -, *, /, \%$

■ Precedence rules: Operators have priorities over one another as indicated in a table (which can be found in most books)

- Example: $*$, $/$ have higher precedence over $+$, $-$.
- For operators at the same precedence (such as $*$ and $/$, we associate them from left to right

5 Application 2: Arithmetic Expression (2/6)

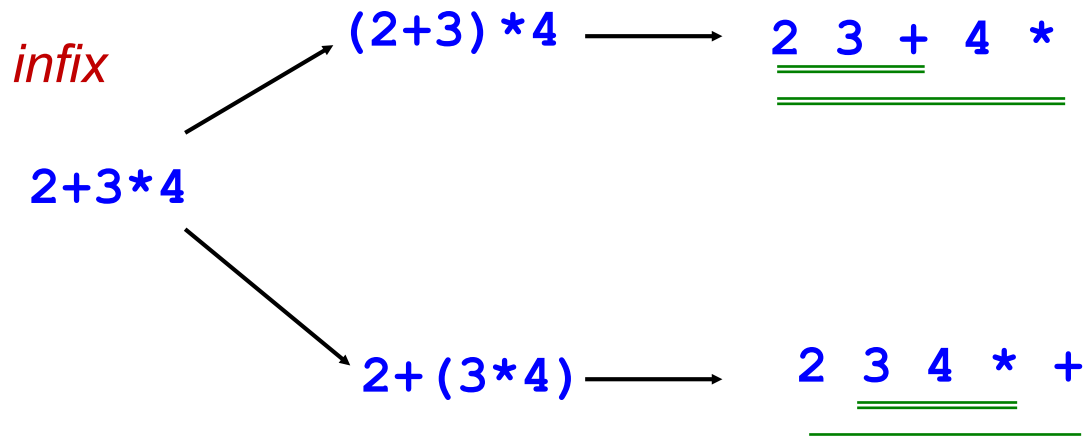
Infix - operand1 **operator** operand2

Prefix - **operator** operand1 operand2

Postfix - operand1 operand2 **operator**

Ambiguous, need ()
or precedence rules

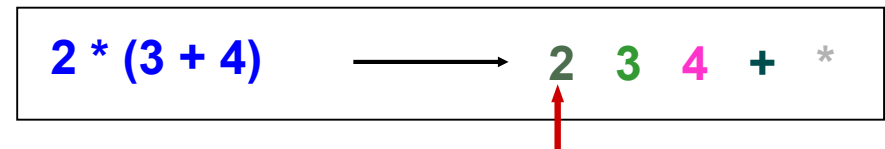
Unique interpretation



5 Application 2: Arithmetic Expression (3/6)

Algorithm: Calculating Postfix expression with stack

Create an empty **stack**
for each item of the expression,
 if it is an **operand**,
 push it on the **stack**
 if it is an **operator**,
 pop arguments from **stack**;
 perform the operation;
 push the result onto the **stack**



2 s.push(2)
3 s.push(3)
4 s.push(4)
+ arg2 = s.pop ()
 arg1 = s.pop ()
 s.push (arg1 + arg2)
* arg2 = s.pop ()
 arg1 = s.pop ()
 s.push (arg1 * arg2)

Stack



5 Application 2: Arithmetic Expression (4/6)

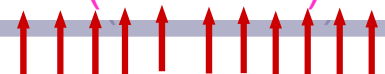
Algorithm: Converting Infix to an equivalent Postfix

```
String postfixExp = "";
for (each character ch in the infix expression) {
    switch (ch) {
        case operand: postfixExp = postfixExp + ch; break;
        case '(': stack.push(ch); break;
        case ')':
            while ( stack.peek() != '(' )
                postfixExp = postfixExp + stack.pop();
            stack.pop(); break;    // remove '('
        case operator:
            while ( !stack.empty() && stack.peek() != '(' &&
                precedence(ch) <= precedence(stack.peek()) )
                postfixExp = postfixExp + stack.pop();
            stack.push(ch); break;
    } // end switch
} // end for

while ( !stack.empty() )
    postfixExp = postfixExp + stack.pop();
```

5 Application 2: Arithmetic Expression (5/6)

Algorithm: Converting Infix to an equivalent Postfix

<u>ch</u>	<u>Stack (bottom to top)</u>	<u>postfixExp</u>	<div>Example: $a - (b + c * d) / e$</div> 
a	—	a	
—	—	a	
(— (a	
b	— (a b	
+	— (+	a b	
c	— (+	a b c	
*	— (+ *	a b c	
d	— (+ *	a b c d	
)	— (+	a b c d *	
	— (a b c d * +	
	—	a b c d * +	
/	— /	a b c d * +	
e	— /	a b c d * + e	
		a b c d * + e / —	

Move operators from stack to postfixExp until '('

Copy remaining operators from stack to postfixExp

5 Application 2: Arithmetic Expression (6/6)

- How to code the above algorithm in Java?
 - Complete [Postfix.java](#)
- How to do conversion of infix to prefix?
 - See [Prefix.java](#)

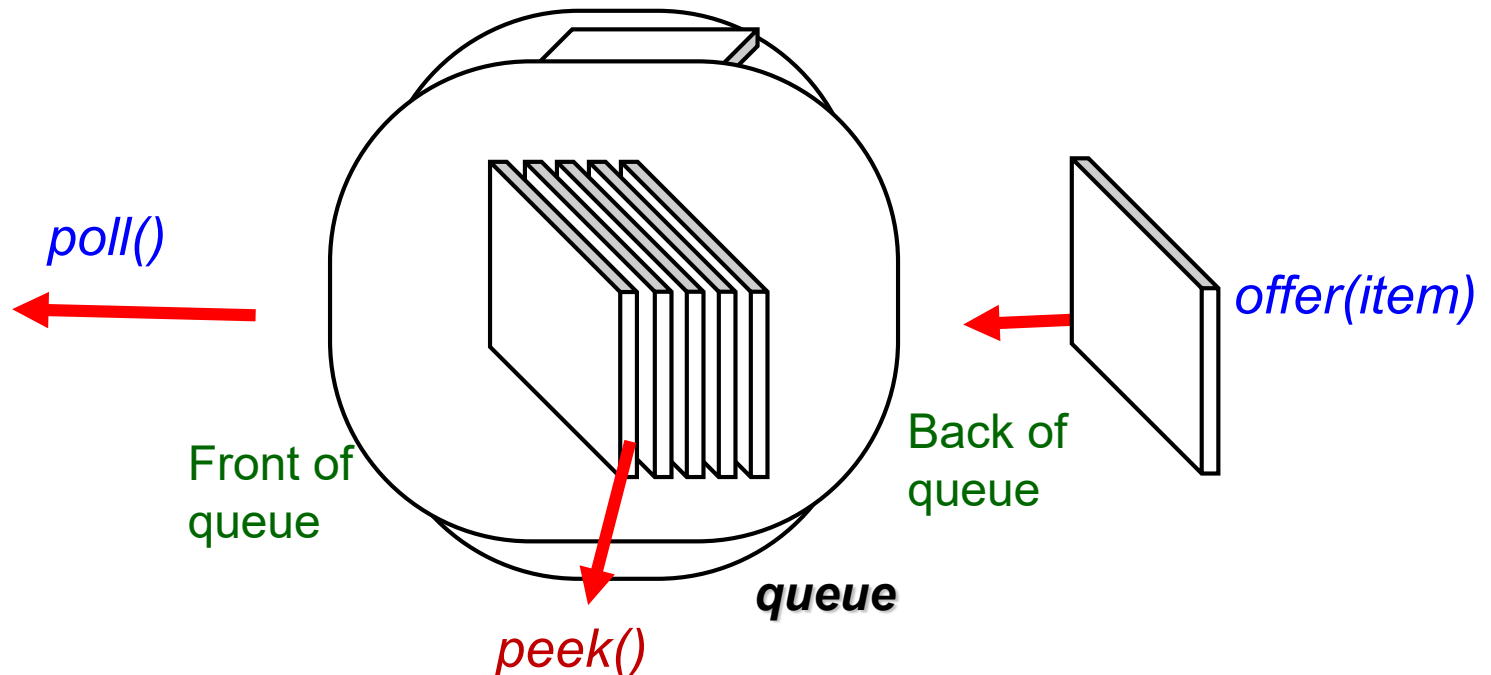
6-10 Queues

First-In-First-Out (FIFO)



6 Queue ADT: Operations

- ❑ A **Queue** is a collection of data that is accessed in a **first-in-first-out** (FIFO) manner
- ❑ Major operations: “**poll**” (or “**dequeue**”), “**offer**” (or “**enqueue**”), and “**peek**”.



6 Queue ADT: Uses

- ☐ Print queue
- ☐ Simulations
- ☐ Breadth-first traversal of trees
- ☐ Checking palindromes - for illustration only as it is not a real application of queue

6 Queue ADT: Interface

QueueADT.java

```
import java.util.*;

public interface QueueADT <E> {

    // return true if queue has no elements
    public boolean isEmpty();

    // return the front of the queue
    public E peek();

    // remove and return the front of the queue
    public E poll(); // also commonly known as dequeue

    // add item to the back of the queue
    public boolean offer(E item); // also commonly known as enqueue
}
```

6 Queue: Usage

Queue q = new Queue ();

→ q.offer ("a");

→ q.offer ("b");

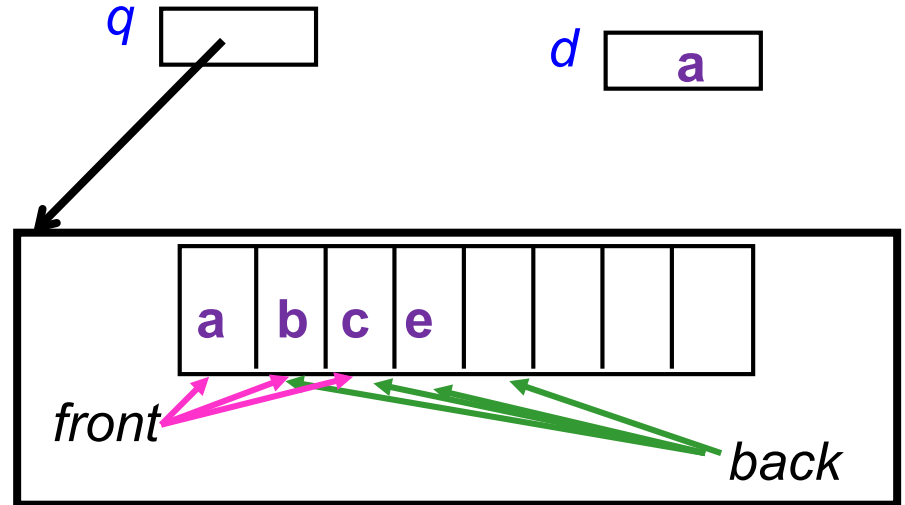
→ q.offer ("c");

→ d = q.peek ();

→ q.poll ();

→ q.offer ("e");

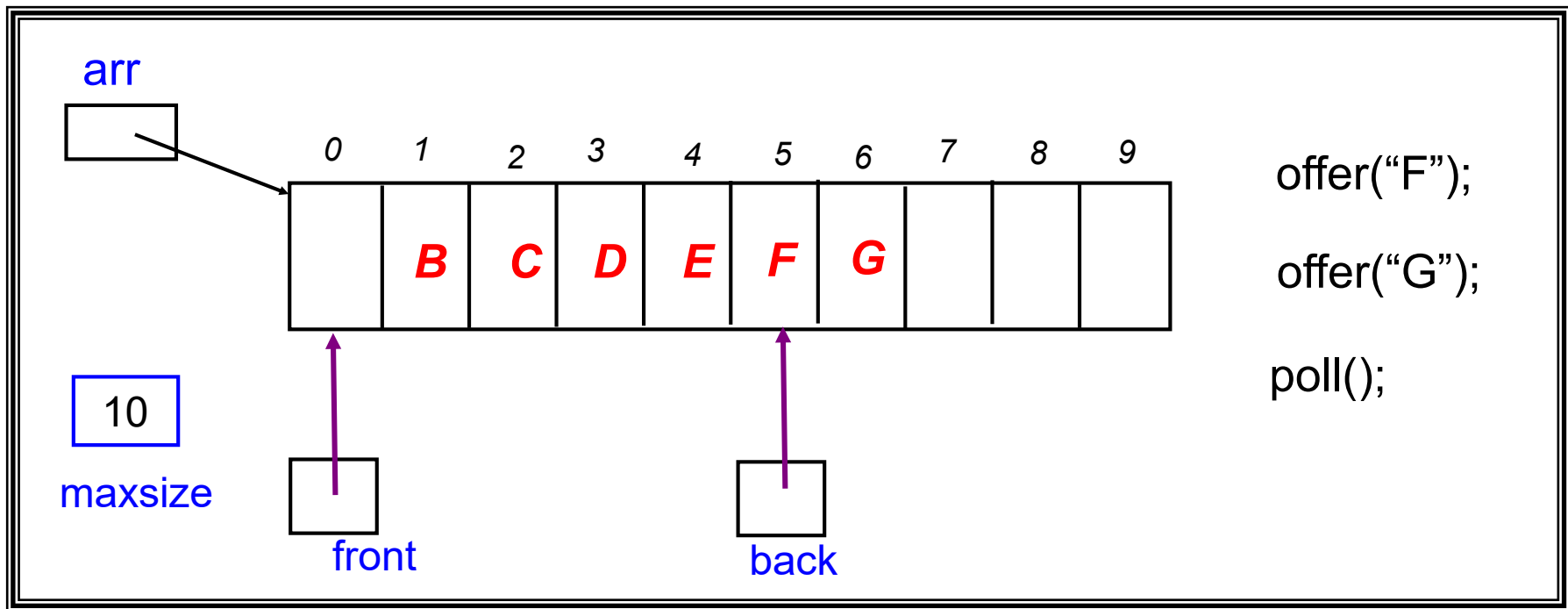
→ q.poll ();



7 Queue Implementation: Array (1/7)

- Use an Array with **front** and **back** pointer

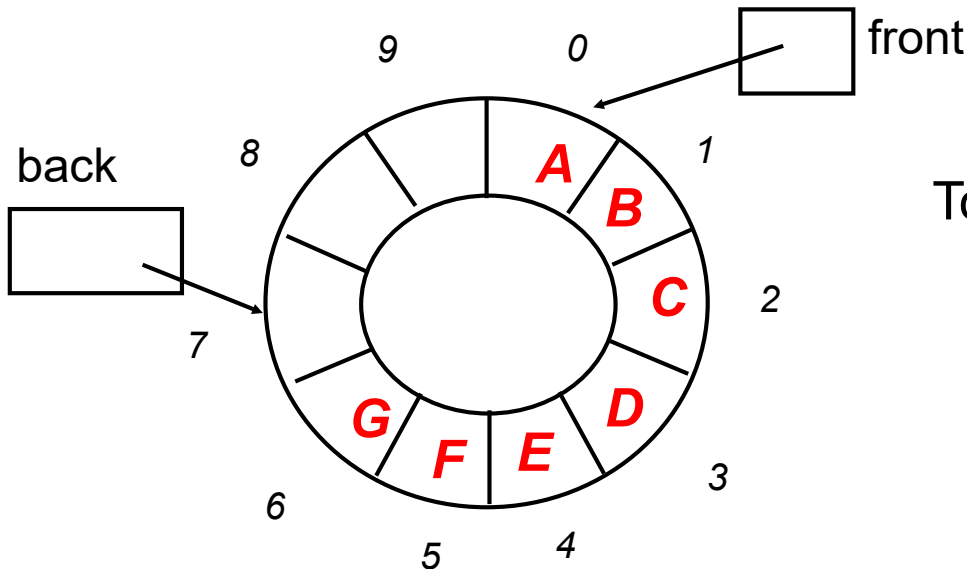
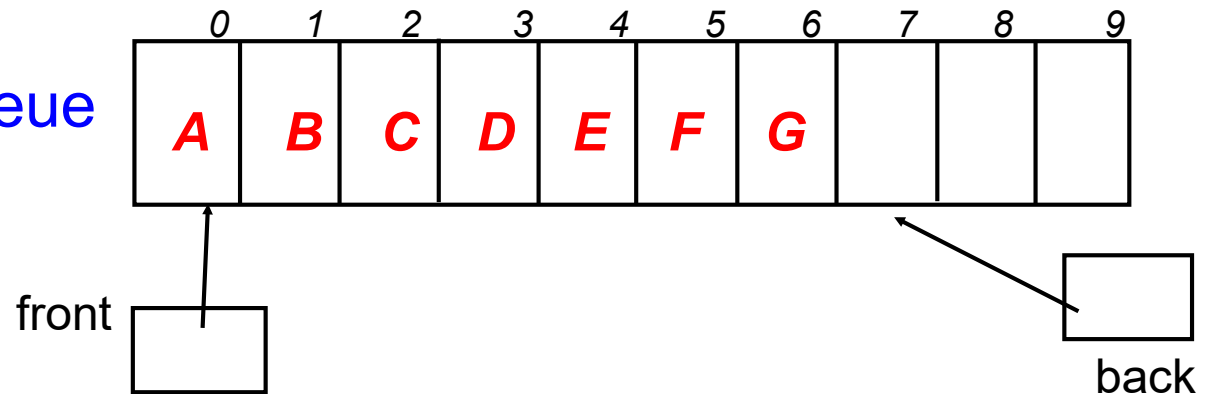
QueueArr



7 Queue Implementation: Array (2/7)

- “Circular” Array needed to recycle space

Given a queue



To advance the indexes, use

$\text{front} = (\text{front} + 1) \% \text{maxsize};$

$\text{back} = (\text{back} + 1) \% \text{maxsize};$

7 Queue Implementation: Array (3/7)

■ Question: what does `(front == back)` mean?

A: Full queue

B: Empty queue

C: Both A and B

D: Neither A nor B

7 Queue Implementation: Array (4/7)

■ Ambiguous full/empty state

Queue

--	--	--	--

Empty State F
 B

e	f	c	d
---	---	---	---

 Queue
 F Full State
 B

Solution 1 – Maintain queue size or full status

size

0

size

4

Solution 2 (Preferred and used in our codes) – Leave a gap!

Don't need the size field this way

e		c	d
---	--	---	---

 B F

Full Case: $((B+1) \% \text{maxsize}) == F$

Empty Case: $F == B$

7 Queue Implementation: Array (5/7)

QueueArr.java

```
import java.util.*;

// This implementation uses solution 2 to resolve full/empty state
class QueueArr <E> implements QueueADT <E> {
    private E [] arr;
    private int front, back;
    private int maxSize;
    private final int INITSIZE = 1000;

    public QueueArr() {
        arr = (E []) new Object[INITSIZE]; // create array of E objects
        front = 0; // the queue is empty
        back = 0;
        maxSize = INITSIZE;
    }


    public boolean isEmpty() {
        return (front == back);
    }
}
```


7 Queue Implementation: Array (6/7)

QueueArr.java





```
public E peek() {  
    if (isEmpty()) return null;  
    else return arr[front];  
}
```

```
public E poll() {  
    if (isEmpty()) return null;  
    E obj = arr[front];  
    arr[front] = null;  
    front = (front + 1) % maxSize;  
    return obj;  
}
```

```
public boolean offer(E o) {  
    if (((back+1)%maxSize) == front) // array is full  
        if (!enlargeArr()) return false; // no more memory to  
             // enlarge the array  
    arr[back] = o;  
    back = (back + 1) % maxSize;  
    return true;  
}
```

7 Queue Implementation: Array (7/7)

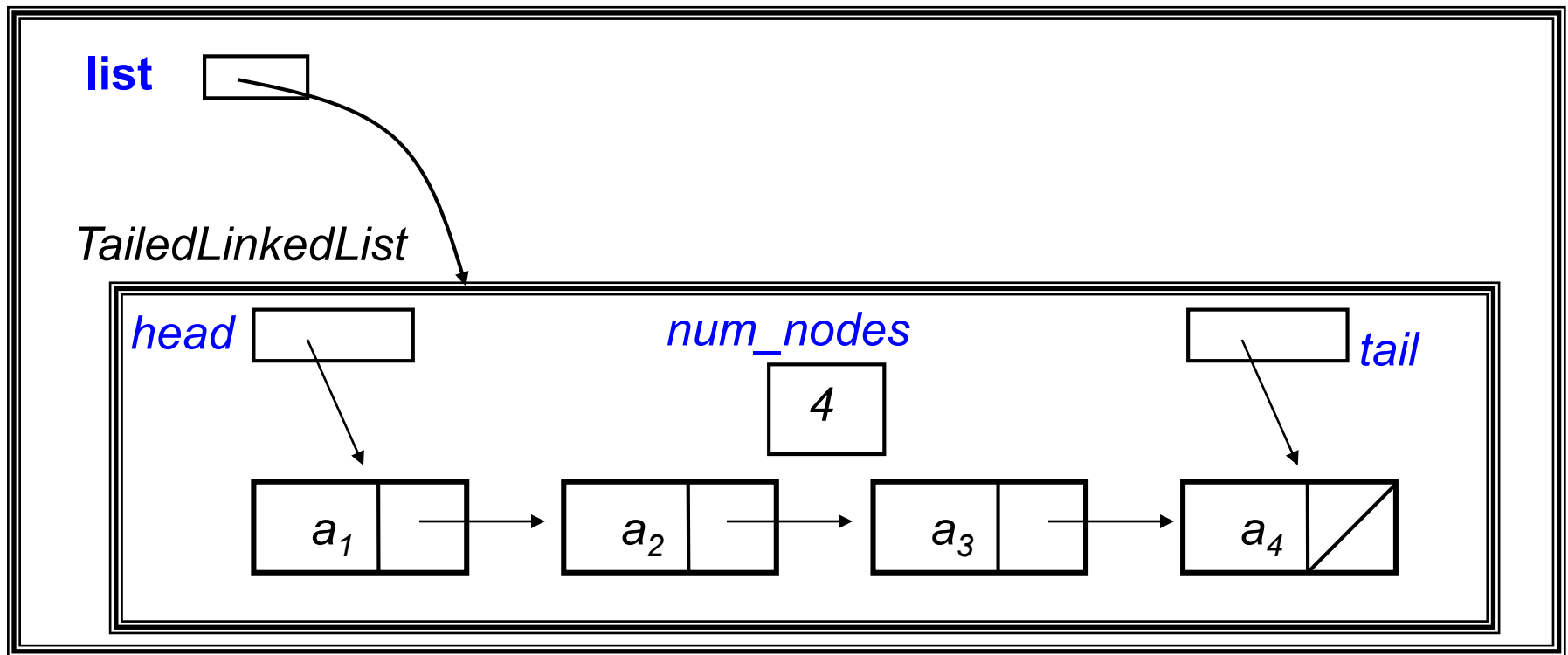
QueueArr.java

```
private boolean enlargeArr() {  
    int newSize = maxSize * 2;  
    E[] x = (E []) new Object[newSize];  
    if (x == null) // i.e. no memory allocated to array of E objects  
        return false;   
  
    for (int j=0; j < maxSize; j++) {  
        // copy the front (1st) element, 2nd element, ..., in the  
        // original array to the 1st (index 0), 2nd (index 1), ...,  
        // positions in the enlarged array   
        x[j] = arr[(front+j) % maxSize];  
    }  
    front = 0;    
    back = maxSize - 1;  
    arr = x;  
    maxSize = newSize;  
    return true;  
}
```

8 Queue Implementation: Linked List (1/4)

- **Method #1 (Composition): Use TailedLinkedList**
 - Do not use BasicLinkedList as we would like to have AddLast()

QueueLL



8 Queue Implementation: Linked List (2/4)

■ Method #1 (Composition): Use TailedLinkedList

QueueLL.java

```
import java.util.*;
class QueueLL <E> implements QueueADT <E> {
    private TailedLinkedList <E> list;
    public QueueLL() { list = new TailedLinkedList <E> (); }
    public boolean isEmpty() { return list.isEmpty(); }

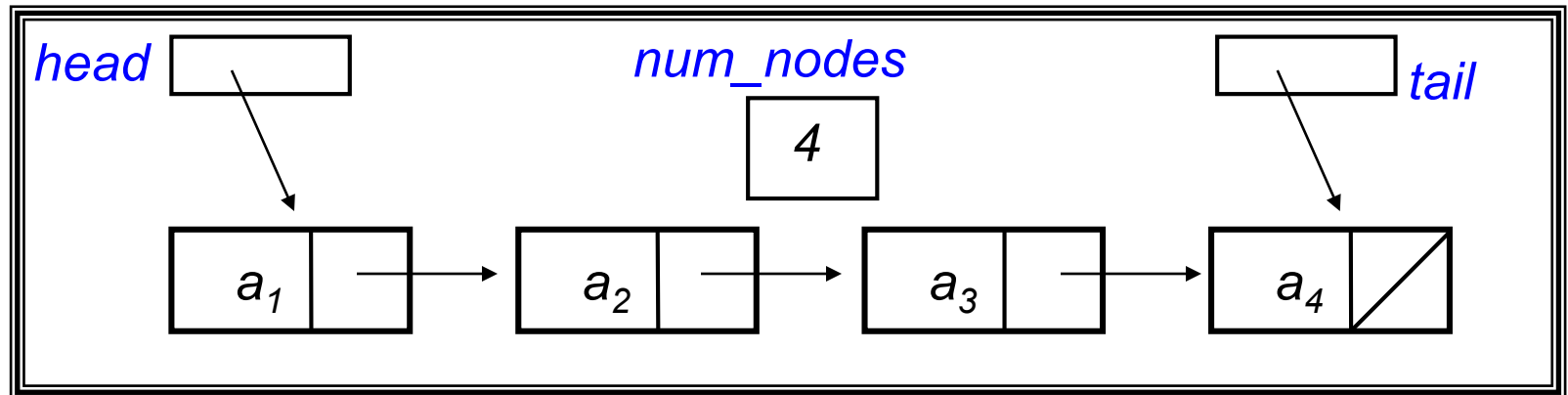
    public boolean offer(E o) {
        list.addLast(o);
        return true;
    }
    public E peek() {
        if (isEmpty()) return null;
        return list.getFirst();
    }
    public E poll() {
        E obj = peek();
        if (!isEmpty()) list.removeFirst();
        return obj;
    }
}
```

8 Queue Implementation: Linked List (3/4)

- Method #2 (Inheritance): **Extend** TailedLinkedList

QueueLLE

TailedLinkedList



8 Queue Implementation: Linked List (4/4)

■ Method #2 (Inheritance): Extend TailedLinkedList

QueueLLE.java

```
import java.util.*;

class QueueLLE <E> extends TailedLinkedList <E> implements QueueADT <E> {
    public boolean offer(E o) {
        // write your code below

    }

    public E peek() {
        // write your code below

    }

    public E poll() {
        // write your code below

    }
}
```

8 Uses of Queues (1/2)

TestQueue.java

```
import java.util.*;
class TestStack {
    public static void main (String[] args) {
        // you can use any one of the following implementation
        //QueueArr <String> queue= new QueueArr <String> (); // Array
        QueueLL <String> queue= new QueueLL <String> (); // LinkedList composition
        //QueueLLE <String> queue= new QueueLLE <String> (); // LinkedList inheritance

        System.out.println("queue is empty? " + queue.isEmpty());
        queue.offer("1");
        System.out.println("operation: queue.offer(\"1\")");
        System.out.println("queue is empty? " + queue.isEmpty());
        System.out.println("front now is: " + queue.peek());
        queue.offer("2");
        System.out.println("operation: queue.offer(\"2\")");
        System.out.println("front now is: " + queue.peek());
        queue.offer("3");
        System.out.println("operation: queue.offer(\"3\")");
        System.out.println("front now is: " + queue.peek());
    }
}
```

8 Uses of Queues (2/2)

TestQueue.java

```
queue.poll();
System.out.println("operation: queue.poll()");
System.out.println("front now is: " + queue.peek());
System.out.print("checking whether queue.peek().equals(\"1\"): ");
System.out.println(queue.peek().equals("1"));
queue.poll();
System.out.println("operation: queue.poll()");
System.out.println("front now is: " + queue.peek());
queue.poll();
System.out.println("operation: queue.poll()");
System.out.println("front now is: " + queue.peek());
}
```


9 java.util.interface Queue <E>

Method Summary

<u>E</u>	<u>element()</u> Retrieves, but does not remove, the head of this queue.
boolean	<u>offer</u> (<u>E</u> o) Inserts the specified element into this queue, if possible.
<u>E</u>	<u>peek()</u> Retrieves, but does not remove, the head of this queue, returning null if this queue is empty.
<u>E</u>	<u>poll()</u> Retrieves and removes the head of this queue, or null if this queue is empty.
<u>E</u>	<u>remove()</u> Retrieves and removes the head of this queue.

Methods inherited from interface java.util.Collection

add, addAll, clear, contains, containsAll, equals, hashCode, isEmpty, iterator, remove, removeAll, retainAll, size, toArray, toArray

Note: The methods “E element()” and “E remove()” are not in our own Queue ADT .

10 Application: Palindromes (1/3)

- A string which reads the same either left to right, or right to left is known as a **palindrome**
 - Palindromes: “radar”, “deed”, “aibohphobia”
 - Non-palindromes: “data”, “little”

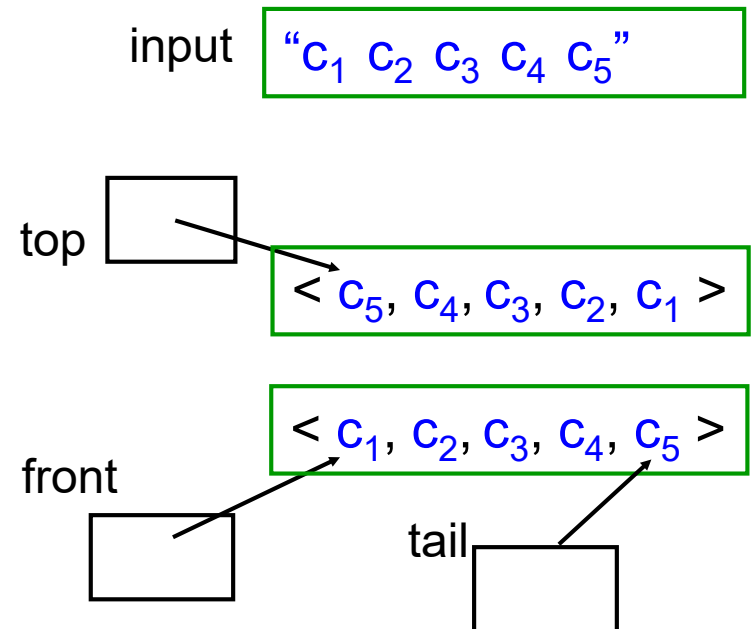
Algorithm

Given a string, use:

a **Stack** to *reverse* its order

a **Queue** to *preserve* its order

Check if the sequences are the same



10 Application: Palindromes (2/3)

Palindromes.java

```
import java.util.*;
class Palindromes {

    public static void main (String[] args) throws NoSuchElementException {
        // you can use any of the following stack/queue implementations
        //StackLLE <String> stack = new StackLLE <String> ();
        Stack <String> stack = new Stack <String> ();
        //StackLL <String> stack = new StackLL <String> ();
        //StackArr <String> stack = new StackArr <String> ();
        //QueueLL <String> queue = new QueueLL <String> ();
        //QueueLLE <String> queue = new QueueLLE <String> ();
        //QueueArr <String> queue = new QueueArr <String> ();
        Queue <String> queue = new LinkedList <String> ();

        Scanner scanner = new Scanner(System.in);
        System.out.print("Enter text: ");
        String inputStr = scanner.next();
        for (int i=0; i < inputStr.length(); i++) {
            String ch = inputStr.substring(i, i+1);
            stack.push(ch);
            queue.offer(ch);
        }
    }
}
```

Queue is an interface in Java API.

LinkedList is a class that implements Queue and other interfaces, such as Serializable, Cloneable, Iterable<E>, Collection<E>, Deque<E>, List<E>.

10 Application: Palindromes (3/3)

Palindromes.java

```
boolean ans = true;
try {
    while (!stack.isEmpty() && ans) {
        if (!(stack.pop().equals(queue.poll())))
            ans = false;
    }
} catch (NoSuchElementException e) {
    throw new NoSuchElementException();
}

System.out.print(inputStr + " is ");
if (ans)
    System.out.println("a palindrome");
else
    System.out.println("NOT a palindrome");
}
```

6 Summary

- We learn to create our own data structures from array and linked list
 - LIFO vs FIFO – a simple difference that leads to very different applications
 - Drawings can often help in understanding the cases still
- Please do not forget that the Java Library class is much more comprehensive than our own – for sit-in lab or exam, please use the one as told.