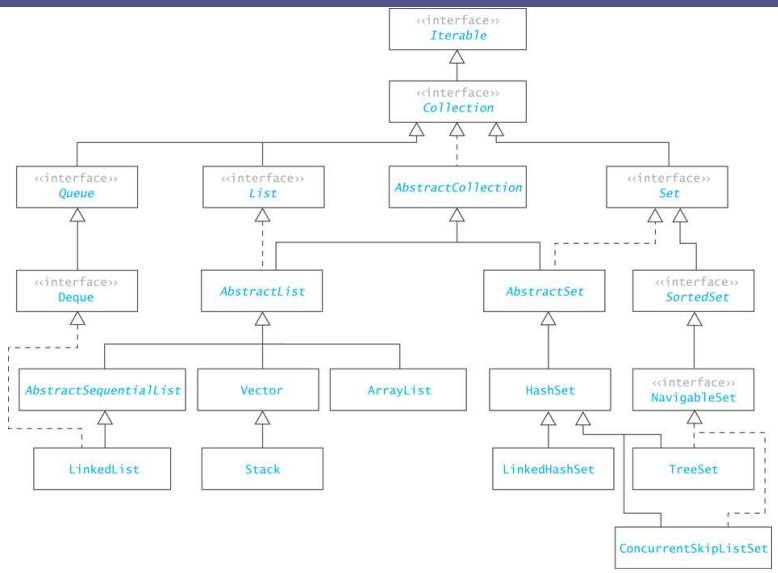
CHAPTER 3 & 4

Stacks & Queues

The `Collection` Framework



Stack Abstract Data Type

- A stack is one of the most commonly used data structures in computer science
- A stack can be compared to a Pez dispenser
  - Only the top item can be accessed
  - You can extract only one item at a time
- The top element in the stack is the last added to the stack (most recently)
- The stack's storage policy is *Last-In, First-Out*, or *LIFO*

Java Collections: Stack

- The Java API includes a `Stack` class as part of the package `java.util`:

```
Stack<String> myStringStack = new Stack<String>();
Stack<Place> myPlacesStack = new Stack<Places>();

myStringStack.push("Deepak");

myPlacesStack.push(new Place("19010", "Bryn Mawr", "PA"));

etc.
```

Specification of the Stack Abstract Data Type

- Only the top element of a stack is visible; therefore the number of operations performed by a stack are few
- We need the ability to
  - test for an empty stack (empty)
  - inspect the top element (peek)
  - retrieve the top element (pop)
  - put a new element on the stack (push)

Methods	Behavior
`boolean empty()`	Returns **`true`** if the stack is empty; otherwise, returns **`false`**.
`E peek()`	Returns the object at the top of the stack without removing it.
`E pop()`	Returns the object at the top of the stack and removes it.
`E push(E obj)`	Pushes an item onto the top of the stack and returns the item pushed.

A Stack of Strings

- "Rich" is the oldest element on the stack and "Jonathan" is the youngest (Figure a)
- `String last = names.peek();` stores a reference to "Jonathan" in `last`
- `String temp = names.pop();` removes "Jonathan" and stores a reference to it in `temp` (Figure b)
- `names.push("Philip");` pushes "Philip" onto the stack (Figure c)

Other examples of stacks

- Back button in browser
- Palindrome checker
  Go hang a salami, I'm a lasagna hog!
- Matching parentheses
- Expression evaluation
- printStackTrace()

Queue

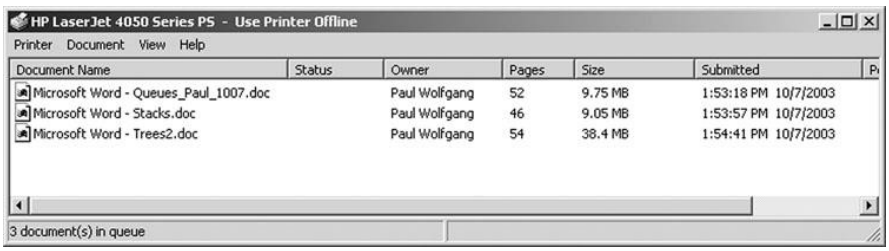
- The queue, like the stack, is a widely used data structure
- A queue differs from a stack in one important way
  - A stack is LIFO list – *Last-In, First-Out*
  - while a queue is FIFO list, *First-In, First-Out*

Queue Abstract Data Type

- A queue can be visualized as a line of customers waiting for service
- The next person to be served is the one who has waited the longest
- New elements are placed at the end of the line

Print Queue

- Operating systems use queues to
  - keep track of tasks waiting for a scarce resource
  - ensure that the tasks are carried out in the order they were generated
- Print queue: printing is much slower than the process of selecting pages to print, so a queue is used



Specification for a Queue Interface

Method	Behavior
`boolean offer(E item)`	Inserts `item` at the rear of the queue. Returns **`true`** if successful; returns **`false`** if the item could not be inserted.
`E remove()`	Removes the entry at the front of the queue and returns it if the queue is not empty. If the queue is empty, throws a `NoSuchElementException`.
`E poll()`	Removes the entry at the front of the queue and returns it; returns **`null`** if the queue is empty.
`E peek()`	Returns the entry at the front of the queue without removing it; returns **`null`** if the queue is empty.
`E element()`	Returns the entry at the front of the queue without removing it. If the queue is empty, throws a `NoSuchElementException`.

- The `Queue` interface implements the `Collection` interface (and therefore the `Iterable` interface), so a full implementation of `Queue` must implement all required methods of `Collection` (and the `Iterable` interface)

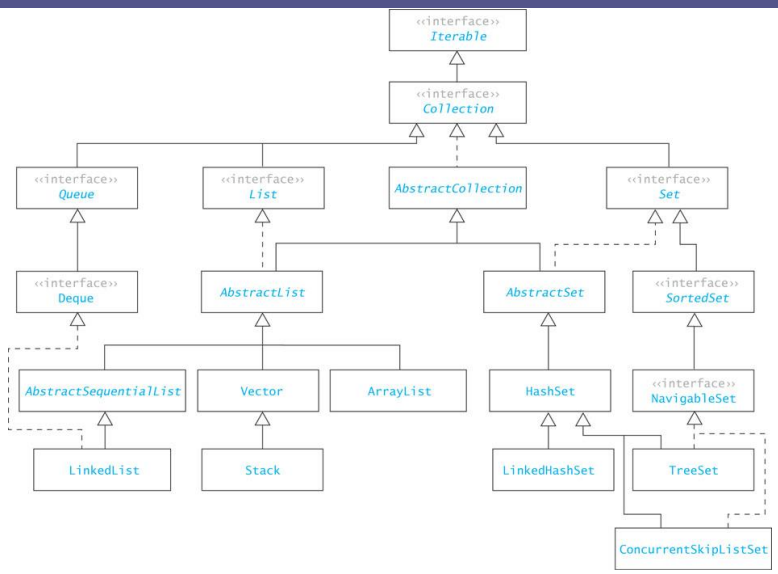
Class `LinkedList` Implements the `Queue` Interface

- The `LinkedList` class provides methods for inserting and removing elements at either end of a double-linked list, which means all `Queue` methods can be implemented easily
- The Java 5.0 `LinkedList` class implements the `Queue` interface

```
Queue<String> names = new LinkedList<String>();
```

  - creates a new `Queue` reference, `names`, that stores references to `String` objects
  - The actual object referenced by `names` is of type `LinkedList<String>`, but because `names` is a type `Queue<String>` reference, you can apply only the `Queue` methods to it

The `Collection` Framework



Java Collections: Queue

- The Java API includes a `Queue` interface as part of the package `java.util`:

```
Queue<String> myStringQueue = new LinkedList<String>();
Queue<Place> myPlacesQueue = new LinkedList<Places>();

myStringQueue.offer("Deepak");

myPlacesQueue.offer(new Place("19010", "Bryn Mawr", "PA"));

etc.
```

Examples of Queues

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- Simulations of real life situations: Service Queues
- Scheduling processes in Operating Systems
- Keep track of state in systematic searches

Stacks & Queues

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java.util.Stack<E>

boolean empty()
E peek()
E pop()
- Both raise EmptyStackException

E push(e)
+ all List<E> operations

java.util.Queue<E>

boolean add(e)
boolean offer(e)

E remove()
E poll()

E peek()
E element()
- Return T/F/null
- Raise NoSuchElementException

Stack Applications

Section 3.2

Finding Palindromes

- Palindrome: a string that reads identically in either direction, letter by letter (ignoring case)
  - kayak
  - "I saw I was I"
  - “Able was I ere I saw Elba”
  - "Level madam level"
- Problem: Write a program that reads a string and determines whether it is a palindrome

Finding Palindromes (cont.)

Data Fields	Attributes
`private String inputString`	The input string.
`private Stack<Character> charStack`	The stack where characters are stored.
Methods	**Behavior**
`public PalindromeFinder(String str)`	Initializes a new `PalindromeFinder` object, storing a reference to the parameter `str` in `inputString` and pushing each character onto the stack.
`private void fillStack()`	Fills the stack with the characters in `inputString`.
`private String buildReverse()`	Returns the string formed by popping each character from the stack and joining the characters. Empties the stack.
`public boolean isPalindrome()`	Returns **`true`** if `inputString` and the string built by `buildReverse` have the same contents, except for case. Otherwise, returns **`false`**.

Finding Palindromes (cont.)

```
import java.util.*;

public class PalindromeFinder {
  private String inputString;
  private Stack<Character> charStack = new
                                      Stack<Character>();

 public PalindromeFinder(String str) {
   inputString = str;
   fillStack(); // fills the stack with the characters in
                   inputString
 }
 ...
```

Finding Palindromes (cont.)

- Solving using a stack:
  - Push each string character, from left to right, onto a stack

k a y a k

```
private void fillStack() {
  for(int i = 0; i < inputString.length(); i++) {
    charStack.push(inputString.charAt(i));
  }
}
```

Finding Palindromes (cont.)

- Solving using a stack:
  - Pop each character off the stack, appending each to the `StringBuilder result`

k a y a k

```
private String buildReverse(){
 StringBuilder result = new StringBuilder();
 while(!charStack.empty()) {
  result.append(charStack.pop());
 }
 return result.toString();
}
```

Finding Palindromes (cont.)

```
...

  public boolean isPalindrome() {
    return inputString.equalsIgnoreCase(buildReverse());
  }
}
```

Queue Applications

Discrete Event Simulation

Discrete Event Simulation

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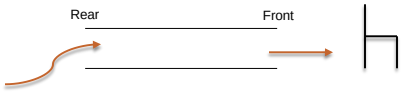
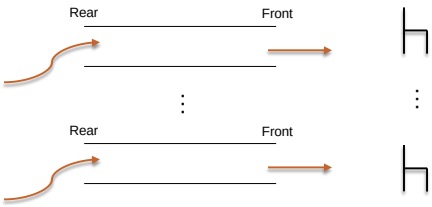
- Single Queue, single server



- Single Queue, multiple servers

- Multiple Queue, multiple servers



Example: Single Queue, Single Server

Front

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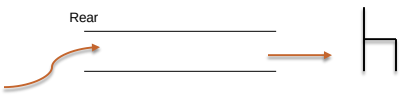
- Arrival process
  - How customers arrive: What is inter-arrival time? E.g. between 1-3 min
  - Service mechanism: How long will service take? E.g. 0.5 to 2.0 min
  - Queue characteristics: FIFO



Example Data

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Customer	Inter-arrival Time	Service Time (min)
C1	1.9	1.7
C2	1.3	1.8
C3	1.1	1.5
C4	1.0	0.9

Queue Simulation

T	Arrival	Queue	Server	Depart
0		[]	Idle	
1.9	C1	[]	C1	
3.2	C2	[C2]	C1	
3.6		[]	C2	C1
4.3	C3	[C3]	C2	
5.3	C4	[C4, C3]	C2	
5.4		[C4]	C3	C2
6.9		[]	C4	C2
7.8		[]		C4

Application: Lab Printer Simulation

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- There is one printer in the Computer Science Lab
- At any given time, there may be as many as 10 students working in the lab
- Each student may print upto twice in an hour
- Print jobs are 1-20 pages long
- ∴ There are up to 20 print jobs in an hour
- Question: What is the chance that in any given second there will be a print job scheduled?

Application: Lab Printer Simulation

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- At any given time, there may be as many as 10 students working in the lab
- Each student may print upto twice in an hour
- Print jobs are 1-20 pages long
- ∴ There are up to 20 print jobs in an hour
- Question: What is the chance that in any given second there will be a print job scheduled?

$$\frac{20}{1\ hour} * \frac{1\ hour}{60\ min} * \frac{1\ min}{60\ sec} = \frac{20}{3600} = \frac{1\ task}{180\ sec}$$

Application: Lab Printer Simulation

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- There is one printer in the CS Lab (10 ppm)
- At any given time, there may be as many as 10 students working in the lab
- Each student may print upto twice in an hour
- Print jobs are 1-20 pages long
- ∴ There are up to 20 print jobs in an hour
- Question: What will the average wait time be for students to receive their printouts?
- Question: What would the average wait time be if the printer were upgraded to 20 ppp?

Implementing a Stack

Section 3.3

Java Collections: Stack

- The Java API includes a `Stack` class as part of the package `java.util`:

```
Stack<String> myStringStack = new Stack<String>();
Stack<Place> myPlacesStack = new Stack<Places>();

myStringStack.push("Deepak");

myPlacesStack.push(new Place("19010", "Bryn Mawr", "PA"));

etc.
```

Implementing a Stack with a List Component

- We can write a class, `ListStack`, that has a `List` component (in the example below, `theData`)
- We can use either the `ArrayList`, or the `LinkedList` classes, as all implement the `List` interface. The `push` method, for example, can be coded as

```
public E push(E obj) {
  theData.add(obj);
  return obj;
}
```

- A class which adapts methods of another class by giving different names to essentially the same methods (`push` instead of `add`) is called an *adapter class*
- Writing methods in this way is called *method delegation*

Implementing a Stack Using an Array

- If we implement a stack as an arr
  we would need . . .

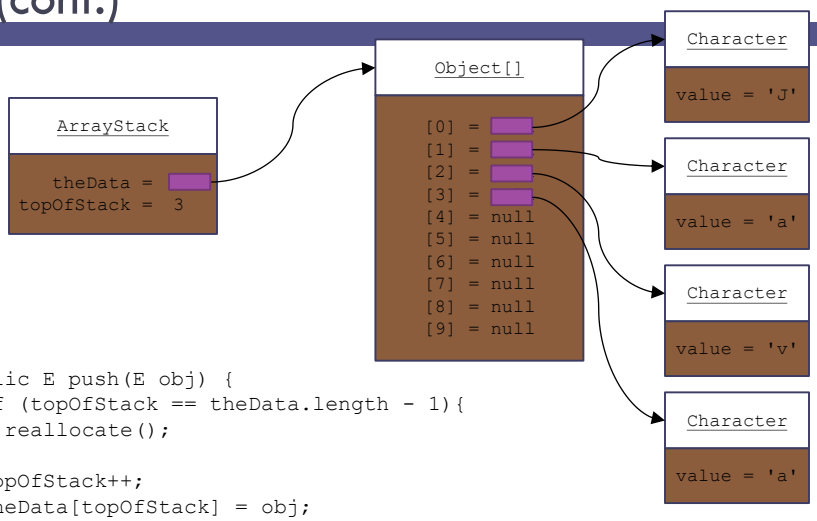
```
public class ArrayStack<E> implements
  private E[] theData;
  int topOfStack = -1;
  private static final int INITIAL_CA

  public ArrayStack() {
    th                          _CAPACITY];
  } //
```

Allocate storage for an array with a default

Keep track of the top of the stack (subscript of the element at the top of the stack; for empty stack = -1)

There is no `size` variable or method

Implementing a Stack Using an Array (cont.)




```
public E push(E obj) {
  if (topOfStack == theData.length - 1){
    reallocate();
  }
  topOfStack++;
  theData[topOfStack] = obj;
  return obj;
}
```

Implementing a Stack Using an Array (cont.)

```
public E pop() {
  if (empty()) {
    throw new EmptyStackException();
  }
  return theData[topOfStack--];
} // pop()
```

Implementing a Stack using an array

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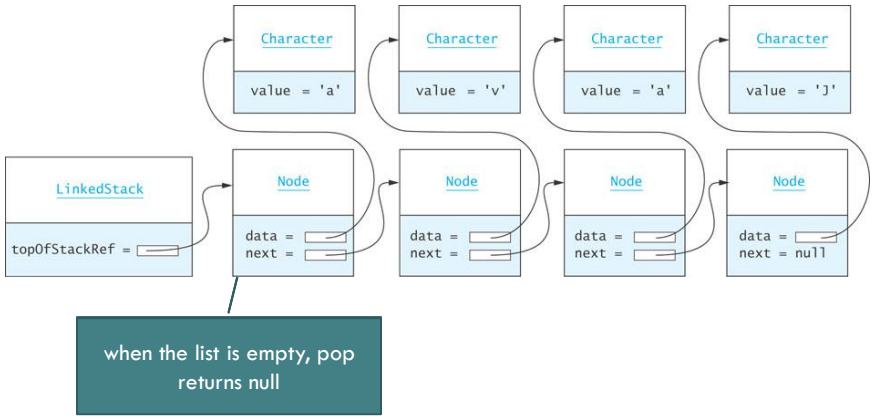
```
import java.util.EmptyStackException;
public class ArrayStack<E> implements StackInt<E> {

   E[] theData;
   int topOfStack = -1; // Initially empty stack.
   private static final int INITIAL_CAPACITY = 10;

   public ArrayStack() {
      theData = (E[]) new Object[INITIAL_CAPACITY];
   } // ArrayStack()

   public E push(E obj) {
      if (topOfStack == theData.length - 1) {
         reallocate();
      }
      topOfStack++;
      theData[topOfStack] = obj;
      return obj;
   } // push()

   public E pop() {
      if (empty()) {
         throw new EmptyStackException();
      }
      return theData[topOfStack--];
   } // pop()

} // class ArrayStack<E>
```

Implementing a Stack as a Linked Data Structure

- We can also implement a stack using a linked list of nodes



Implementing a Stack as a Linked Data Structure (cont.)

- Listing 3.5 (`LinkedStack.java`, pages 168 - 169)

Comparison of Stack Implementations

- The easiest implementation uses a `List` component (`ArrayList` is the simplest) for storing data
  - An underlying array requires reallocation of space when the array becomes full, and
  - an underlying linked data structure requires allocating storage for links
  - As all insertions and deletions occur at one end, they are constant time, O(1), regardless of the type of implementation used

Additional Stack Applications

Section 3.4

Additional Stack Applications

- Postfix and infix notation
  - Expressions normally are written in infix form, but
  - it easier to evaluate an expression in postfix form since there is no need to group sub-expressions in parentheses or worry about operator precedence

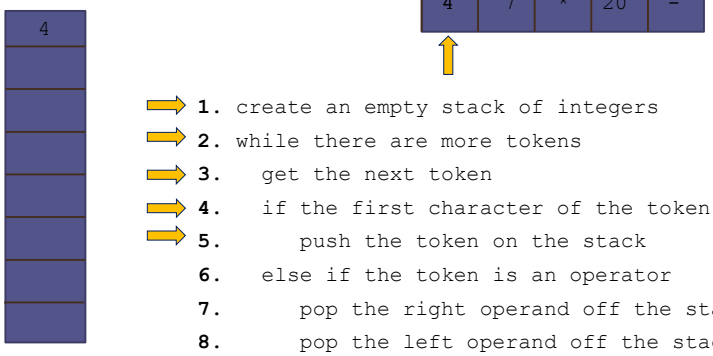
Postfix Expression	Infix Expression	Value
4 7 *	4 * 7	28
4 7 2 + *	4 * (7 + 2)	36
4 7 * 20 -	(4 * 7) - 20	8
3 4 7 * 2 / +	3 + ((4 * 7) / 2)	17

Evaluating Postfix Expressions

- Write a class that evaluates a postfix expression
- Use the space character as a delimiter between tokens

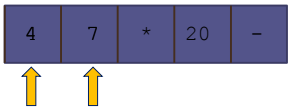
Data Field	Attribute
`Stack<Integer> operandStack`	The stack of operands (`Integer` objects).
Method	**Behavior**
`public int eval(String expression)`	Returns the value of `expression`.
`private int evalOp(char op)`	Pops two operands and applies operator `op` to its operands, returning the result.
`private boolean isOperator(char ch)`	Returns **`true`** if `ch` is an operator symbol.

Evaluating Postfix Expressions (cont.)




```
1.  create an empty stack of integers
2.  while there are more tokens
3.     get the next token
4.     if the first character of the token is a digit
5.        push the token on the stack
6.     else if the token is an operator
7.        pop the right operand off the stack
8.        pop the left operand off the stack
9.        evaluate the operation
10.       push the result onto the stack
11. pop the stack and return the result
```

Evaluating Postfix Expressions (cont.)

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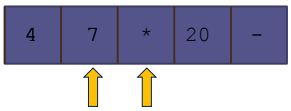
2.  while there are more tokens
3.    get the next token
4.    if the first character of the token is a digit
5.       push the token on the stack
6.    else if the token is an operator
7.       pop the right operand off the stack
8.       pop the left operand off the stack
9.       evaluate the operation
10.      push the result onto the stack
11. pop the stack and return the result
```

Evaluating Postfix Expressions (cont.)

4 * 7

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Evaluating Postfix Expressions (cont.)

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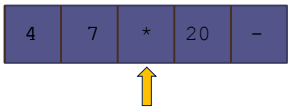


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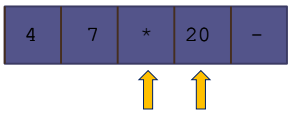
Evaluating Postfix Expressions (cont.)

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2. while there are more tokens
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7.      pop the right operand off the stack
8.      pop the left operand off the stack
9.      evaluate the operation
10.     push the result onto the stack
11. pop the stack and return the result
```
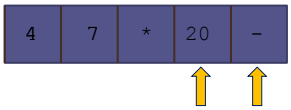

Evaluating Postfix Expressions (cont.)

28 - 20

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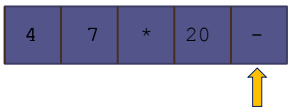
2. while there are more tokens
3.    get the next token
4.    if the first character of the token is a digit
5.       push the token on the stack
6.    else if the token is an operator
7.       pop the right operand off the stack
8.       pop the left operand off the stack
9.       evaluate the operation
10.      push the result onto the stack
11. pop the stack and return the result
```

Evaluating Postfix Expressions (cont.)

8

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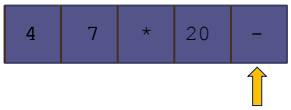
Evaluating Postfix Expressions (cont.)

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8.       pop the left operand off the stack
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10.      push the result onto the stack
11. pop the stack and return the result
```

Evaluating Postfix Expressions (cont.)

- Listing 3.6 (`PostfixEvaluator.java`, pages 173 - 175)

Converting from Infix to Postfix

- Convert infix expressions to postfix expressions
- Assume:
  - expressions consists of only spaces, operands, and operators
  - space is a delimiter character
  - all operands that are identifiers begin with a letter or underscore
  - all operands that are numbers begin with a digit

Data Field	Attribute
`private Stack<Character> operatorStack`	Stack of operators.
`private StringBuilder postfix`	The postfix string being formed.
Method	**Behavior**
`public String convert(String infix)`	Extracts and processes each token in `infix` and returns the equivalent postfix string.
`private void processOperator(char op)`	Processes operator `op` by updating `operatorStack`.
`private int precedence(char op)`	Returns the precedence of operator `op`.
`private boolean isOperator(char ch)`	Returns **`true`** if `ch` is an operator symbol.

Converting from Infix to Postfix (cont.)

- Example: convert

  w – 5.1 / sum * 2

  to its postfix form

  w 5.1 sum / 2 * -

Converting from Infix to Postfix (cont.)

Next Token	Action	Effect on operatorStack	Effect on postfix
w	Append w to postfix.	[ ]	w
-	The stack is empty Push - onto the stack	[-]	w
5.1	Append 5.1 to postfix	[-]	w 5.1
/	precedence(/) > precedence(-), Push / onto the stack	[/ -]	w 5.1
sum	Append sum to postfix	[/ -]	w 5.1 sum
*	precedence(*) equals precedence(/) Pop / off of stack and append to postfix	[-]	w 5.1 sum /

Converting from Infix to Postfix (cont.)

Next Token	Action	Effect on operatorStack	Effect on postfix
*	precedence(*) > precedence(-), Push * onto the stack	[* -]	w 5.1 sum /
2	Append 2 to postfix	[* -]	w 5.1 sum / 2
End of input	Stack is not empty, Pop * off the stack and append to postfix	[-]	w 5.1 sum / 2 *
End of input	Stack is not empty, Pop - off the stack and append to postfix	[ ]	w 5.1 sum / 2 * -

Converting from Infix to Postfix (cont.)

Algorithm for Method convert

```
1.  Initialize postfix to an empty StringBuilder.
2.  Initialize the operator stack to an empty stack.
3.  while there are more tokens in the infix string
4.      Get the next token.
5.      if the next token is an operand
6.          Append it to postfix.
7.      else if the next token is an operator
8.          Call processOperator to process the operator.
9.      else
10.         Indicate a syntax error.
11. Pop remaining operators off the operator stack and append them
    to postfix.
```

Converting from Infix to Postfix (cont.)

Algorithm for Method processOperator

```
1.  if the operator stack is empty
2.      Push the current operator onto the stack.
    else
3.      Peek the operator stack and let topOp be the top operator.
4.      if the precedence of the current operator is greater than the
        precedence of topOp
5.          Push the current operator onto the stack.
        else
6.          while the stack is not empty and the precedence of the current
            operator is less than or equal to the precedence of topOp
7.              Pop topOp off the stack and append it to postfix.
8.              if the operator stack is not empty
9.                  Peek the operator stack and let topOp be the top
                    operator.
10.         Push the current operator onto the stack.
```

Converting from Infix to Postfix (cont.)

- Listing 3.7 (`InfixToPostfix.java`, pages 181 - 183)

Converting from Infix to Postfix (cont.)

- Testing
  - Use enough test expressions to satisfy yourself that the conversions are correct for properly formed input expressions
  - Use a driver to catch `InfixToPostfix.SyntaxErrorException`
- Listing 3.8 (`TestInfixToPostfix.java`, page 184)

Converting Expressions with Parentheses

- The ability to convert expressions with parentheses is an important (and necessary) addition
- Modify `processOperator` to push each opening parenthesis onto the stack as soon as it is scanned
- When a closing parenthesis is encountered, pop off operators until the opening parenthesis is encountered
- Listing 3.9 (`InfixToPostfixParens.java`, pages 186 - 188)