CSC 427: Data Structures and Algorithm Analysis

Fall 2011

- Java review (or What I Expect You to Know from 221/222)
  - class, object, fields, methods, private vs. public, parameters
  - variables, primitive vs. objects, expressions, if, if-else, while, for
  - object-oriented design: cohesion, coupling
  - String, Math, arrays, ArrayList
  - interfaces, List, LinkedList, iterators
  - searching and sorting, algorithm efficiency, recursion
  - Stack class, Queue interface
  - inheritance, polymorphism

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Class structure

```
/**
 * This class models a simple die object,
 * which can have any number of sides.
 *   @author Dave Reed
 *   @version 8/25/11
 */
public class Die {

  private int numSides;
  private int numRolls;

  /**
   * Constructs a 6-sided die object
   */
  public Die() {
    this.numSides = 6;
    this.numRolls = 0;
  }

  /**
   * Constructs an arbitrary die object.
   *   @param sides the number of sides on the die
   */
  public Die(int sides) {
    this.numSides = sides;
    this.numRolls = 0;
  }

  . . .
```

a *class* defines a new type of object

- *fields* are variables that belong to the object (and maintain its state)
- typically *private,* so can only be accessed from within the class
- *note: "this." is optional, but instructive*

- *methods* define the actions that can be performed on an object
- typically *public*, so can be called by client code
- *note: "this." is optional, but instructive*

- a *constructor* is a special method that automatically initializes the object when it is created
- can have more than one constructor

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Class structure (cont.)

```
  . . .

  /**
   * Gets the number of sides on the die object.
   *   @return  the number of sides (an N-sided die can roll 1 through N)
   */
  public int getNumberOfSides() {
    return this.numSides;
  }

  /**
   * Gets the number of rolls by on the die object.
   *   @return  the number of times roll has been called
   */
  public int getNumberOfRolls() {
    return this.numRolls;
  }

  /**
   * Simulates a random roll of the die.
   *   @return  the value of the roll (for an N-sided die,
   *            the roll is between 1 and N)
   */
  public int roll() {
    this.numRolls++;
    return (int)(Math.random()*this.getNumberOfSides() + 1);
  }
}
```

a *return statement* specifies the value returned by a call to the method

accessor method: provides access to a private field

mutator method: changes one or more fields

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public static void main

using the BlueJ IDE, we could

- create objects by right-clicking on the class icon
- call methods on an object by right-clicking on the object icon

the more general approach is to have a separate "driver" class

- if a class has a "public static void main" method, it will automatically be executed
- a `static` method belongs to the entire class, you don't have to create an object in order to call the method

```
public class DiceRoller {
   public static void main(String[] args) {
      Die d6 = new Die();

      int roll = d6.roll() + d6.roll();

      System.out.println("You rolled a " + roll);
   }
}
```

- you can have a `public static void main` method in any class – makes it executable (good for testing purposes)

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Java variables

variable names consist of letters, digits, and underscores

- must start with a letter (can use underscore, but don't)

naming conventions:

- class names start with a capital letter
  - e.g., `Die`, `String`
- methods, fields, parameters, and local variables start with a lowercase letter
  - e.g., `roll`, `getNumberOfRolls`, `numRolls`, `numSides`, `sides`, `i`
- constants (i.e., `final` values) are in all capitals
  - e.g., `MAX_SCORE`, `DEFAULT_SIZE`

primitive types are predefined in Java, e.g., `int`, `double`, `boolean`, `char`

```
int num;            double x = 5.8;
num = 0;
```

object types are those defined by classes, e.g., `Die`, `String`

```
Die d8 = new Die(8);
int result = d8.roll();
```

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Class composition

fields of a class can be instances of other classes

- consider a Dot class, to be used in dot race simulations

predefined mathematical ops:

+, -, *, /, %, ++, --

arithmetic assignments:

+=, -=, *=, /=, %=

when applied to Strings, '+' concatenates

```
public class Dot {

    private Die die;
    private String dotColor;
    private int dotPosition;

    public Dot(String color, int maxStep) {
        this.die = new Die(maxStep);
        this.dotColor = color;
        this.dotPosition= 0;
    }

    public int getPosition() {
        return this.dotPosition;
    }

    public void step() {
        this.dotPosition += this.die.roll();
    }

    public void reset() {
        this.dotPosition = 0;
    }

    public void showPosition() {
        System.out.println(this.dotColor + ": " +
                           this.dotPosition);
    }
}
```

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DotRace class

`final` denotes a *constant* variable

- once assigned a value, it cannot be changed

`static` denotes a class variable

- belongs to the class, is shared by all instances

```
public class DotRace {

   public final static int GOAL = 20;
   public final static int MAX_STEP = 3;

   public static void main(String[] args) {
      Dot redDot = new Dot("RED", MAX_STEP);
      Dot blueDot = new Dot("BLUE", MAX_STEP);

      while (redDot.getPosition() < GOAL && blueDot.getPosition() < GOAL) {
         redDot.step();
         blueDot.step();

         redDot.showPosition();
         blueDot.showPosition();
      }

      if (redDot.getPosition() >= GOAL && blueDot.getPosition() >= GOAL) {
         System.out.println("It is a tie");
      }
      else if (redDot.getPosition() >= GOAL) {
         System.out.println("RED wins!");
      }
      else {
         System.out.println("BLUE wins!");
      }
   }
}
```

if statement (w/ optional else) defines conditional execution

while loop defines conditional repetition

- both driven by a boolean test
- can use relational ops: `>` `>=` `<` `<=` `==` `!=`
- can use logical connectives: `&&` (and), `||` (or), `!` (not)

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Example: VolleyballSimulator

consider a volleyball simulation in which each team's power ranking determines their likelihood of winning a point

```
public class VolleyballSimulator {

    private Die roller;       // Die for simulating points
    private int ranking1;     // power ranking of team 1
    private int ranking2;     // power ranking of team 2

    /**
     * Constructs a volleyball game simulator.
     *   @param team1Ranking the power ranking (0-100) of team 1, the team that serves first
     *   @param team2Ranking the power ranking (0-100) of team 2, the receiving team
     */
    public VolleyBallSimulator(int team1Ranking, int team2Ranking) {
        this.roller = new Die(team1Ranking+team2Ranking);
        this.ranking1 = team1Ranking;
        this.ranking2 = team2Ranking;
    }

    /**
     * Simulates a single rally between the two teams.
     *   @return the winner of the rally (either "team 1" or "team 2")
     */
    public String playRally() {
        if (this.roller.roll() <= this.ranking1) {
            return "team 1";
        }
        else {
            return "team 2";
        }
    }

    . . .
```

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Example: VolleyballSimulator (cont.)

`java.lang.Math` contains many useful static fields & methods
- Math.PI, Math.E
- Math.abs, Math.sqrt, Math.random

```
    . . .

    /**
     * Simulates an entire game using the rally scoring system.
     *   @param winningPoints the number of points needed to win the game (winningPoints > 0)
     *   @return the winner of the game (either "team 1" or "team 2")
     */
    public String playGame(int winningPoints) {
        int score1 = 0;
        int score2 = 0;
        String winner = "";

        while ((score1 < winningPoints && score2 < winningPoints)
                || (Math.abs(score1 - score2) <= 1)) {
            winner = this.playRally();
            if (winner.equals("team 1")) {
                score1++;
            }
            else {
                score2++;
            }

            System.out.println(winner + " wins the point (" + score1 + "-" + score2 + ")");
        }
        return winner;
    }
}
```

note: always use `equals` to compare objects, not ==

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Example: Interactive VolleyballStats

```
import java.util.Scanner;

/**
 * Performs a large number of volleyball game simulations and displays statistics.
 *   @author Dave Reed
 *   @version 8/25/11
 */
public class VolleyballStats {

    public final static int WINNING_POINTS = 15;
    public final static int NUM_GAMES = 10000;

    public static void main(String[] args) {
        Scanner input = new Scanner(System.in);

        System.out.print("What is the ranking for team 1? ");
        int ranking1 = input.nextInt();
        System.out.print("What is the ranking for team 2? ");
        int ranking2 = input.nextInt();

        VolleyballSimulator sim = new VolleyballSimulator(ranking1, ranking2);
        int team1Wins = 0;
        for (int game = 0; game < NUM_GAMES; game++) {
            if (sim.playGame(WINNING_POINTS).equals("team 1")) {
                team1Wins++;
            }
        }

        System.out.println("Out of " + NUM_GAMES + " games to " + WINNING_POINTS +
                           ", team 1 (" + ranking1 + "-" + ranking2 + ") won: " +
                           100.0*team1Wins/NUM_GAMES + "%");
    }
}
```

Java 5.0 introduced the `Scanner` class
- simple console or file input

for loop: neater version of while, for deterministic loops

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Design issues

cohesion describes how well a unit of code maps to an entity or behavior

in a highly cohesive system:

- each class maps to a single, well-defined entity – encapsulating all of its internal state and external behaviors
- each method of the class maps to a single, well-defined behavior
- leads to code that is easier to read and reuse

coupling describes the interconnectedness of classes

in a loosely coupled system:

- each class is largely independent and communicates with other classes vi a small, well-defined interface
- leads to code that is easier to develop and modify

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Java Strings

the `String` class includes many useful methods (in addition to '+')

`int length()`	returns number of chars in String
`char charAt(int index)`	returns the character at the specified index
`int indexOf(char ch)` `int indexOf(String str)`	returns index where the specified char/substring first occurs in the String (-1 if not found)
`String substring(int start, int end)`	returns the substring from indices start to (end-1)
`String toUpperCase()` `String toLowerCase()`	returns copy of String with all letters uppercase returns copy of String with all letters lowercase
`bool equals(String other)` `int compareTo(String other)`	returns true if other String has same value returns *neg* if < other; 0 if = other; *pos* if > other

ALSO, from the `Character` class:

`char Character.toLowerCase(char ch)`	returns lowercase copy of ch
`char Character.toUpperCase(char ch)`	returns uppercase copy of ch
`boolean Character.isLetter(char ch)`	returns true if ch is a letter
`boolean Character.isLowerCase(char ch)`	returns true if lowercase letter
`boolean Character.isUpperCase(char ch)`	returns true if uppercase letter

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Example: Pig Latin

```
  . . .

  public String pigLatin(String str) {
      int firstVowel = this.findVowel(str);

      if (firstVowel <= 0) {
          return str + "way";
      }
      else {
          return str.substring(firstVowel, str.length()) +
                 str.substring(0, firstVowel) + "ay";
      }
  }

  private boolean isVowel(char ch) {
      String VOWELS = "aeiouAEIOU";
      return (VOWELS.indexOf(ch) != -1);
  }

  private int findVowel(String str) {
      for (int i = 0; i < str.length(); i++) {
          if (this.isVowel(str.charAt(i))) {
              return i;
          }
      }
      return -1;
  }
```


Java arrays

arrays are simple lists

- stored contiguously, with each item accessible via an index
- must specify content type when declare, size when create
- once created, the size cannot be changed (without copying entire contents)

```
public class DiceStats {
   public final static int DIE_SIDES = 6;
   public final static int NUM_ROLLS = 10000;

   public static void main(String[] args) {
      int[] counts = new int[2*DIE_SIDES+1];

      Die die = new Die(DIE_SIDES);
      for (int i = 0; i < NUM_ROLLS; i++) {
         counts[die.roll() + die.roll()]++;
      }

      for (int i = 2; i < counts.length; i++) {
         System.out.println(i + ": " + counts[i] + "  ("
                             + (100.0*counts[i]/NUM_ROLLS) + "%)");
      }
   }
}
```

Java ArrayLists

an `ArrayList` is a more robust, general purpose list of objects

- must specify content type when declare, size is optional (default is 0)
- can be dynamically expanded/reduced; can easily add/remove from middle

common methods:

`T get(int index)`	returns object at specified index
`T add(Object obj)`	adds obj to the end of the list
`T add(int index, T obj)`	adds obj at index (shifts to right)
`T remove(int index)`	removes object at index (shifts to left)
`int size()`	removes number of entries in list
`boolean contains(T obj)`	returns true if obj is in the list

other useful methods:

`T set(int index, T obj)`	sets entry at index to be obj
`int indexOf(T obj)`	returns index of obj in the list (assumes obj has an `equals` method)
`String toString()`	returns a String representation of the list e.g., "[foo, bar, biz, baz]"

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Example: Dictionary

one constructor can call another via `this()`

a `Scanner` object can be used to read from a file

- must create a `File` object
- in case the file isn't there, the code is required to catch `FileNotFoundException`

```
try {
  // CODE TO TRY
}
catch (ExceptionType e) {
  // CODE IN CASE IT OCCURS
}
```

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

public class Dictionary {
    private ArrayList<String> words;

    public Dictionary() {
        this.words = new ArrayList<String>();
    }

    public Dictionary(String filename) {
        this();

        try {
            Scanner infile = new Scanner(new File(filename));
            while (infile.hasNext()) {
                String nextWord = infile.next();
                this.words.add(nextWord.toLowerCase());
            }
        }
        catch (java.io.FileNotFoundException e) {
            System.out.println("FILE NOT FOUND");
        }
    }

    public void add(String newWord) {
        this.words.add(newWord.toLowerCase());
    }

    public void remove(String oldWord) {
        this.words.remove(oldWord.toLowerCase());
    }

    public boolean contains(String testWord) {
        return this.words.contains(testWord.toLowerCase());
    }
}
```

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Arraylists & primitives

ArrayLists can only store objects, but Java 5.0 (and above) will automatically box and unbox primitives into *wrapper classes* (Integer, Double, Character, …)

```
import java.util.ArrayList;

public class DiceStats {
   public final static int DIE_SIDES = 6;
   public final static int NUM_ROLLS = 10000;

   public static void main(String[] args) {
      ArrayList<Integer> counts = new ArrayList<Integer>();
      for (int i = 0; i <= 2*DIE_SIDES; i++) {
         counts.add(0);
      }

      Die die = new Die(DIE_SIDES);
      for (int i = 0; i < NUM_ROLLS; i++) {
         int roll = die.roll() + die.roll();
         counts.set(roll, counts.get(roll)+1);
      }

      for (int i = 2; i < counts.length; i++) {
         System.out.println(i + ": " + counts.get(i) + "  ("
                           + (100.0*counts.get(i)/NUM_ROLLS) + "%)");
      }
   }
}
```

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List interface

an *interface* defines a generic template for a class

- specifies the methods that the class must implement
- but, does not specify fields nor method implementations

```
public interface List<T> {
    boolean add(T obj);
    boolean add(int index, T obj);
    void clear();
    boolean contains(Object obj);
    T get(int index);
    T remove(int index);
    boolean remove(T obj)
    T set(int index, T obj);
    int size();
    . . .
}
```

advantage: can define different implementations with different tradeoffs

```
public class ArrayList<T> implements List<T> { … }     // uses array, so direct access
                                                       // but must shift when add/remove

public class LinkedList<T> implements List<T> { … }    // uses doubly-linked list, so
                                                       // sequential access but easy
                                                       // add/remove
```

- so, can write generic code that works on a `List` → either implementation will work

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Example: Dictionary

polymorphism: the capability of objects to react differently to the same method call

here, can declare the field to be of type `List` (the more generic interface)

- if choose to instantiate with an `ArrayList`, it's methods will be called
- if choose to instantiate with a `LinkedList`, it's methods will be called

this style leads to more general-purpose code

```
import java.util.List;
import java.util.ArrayList;
import java.util.Scanner;
import java.io.File;

public class Dictionary {
    private List<String> words;

    public Dictionary() {
        this.words = new ArrayList<String>();
    }

    public Dictionary(String filename) {
        this();

        try {
            Scanner infile = new Scanner(new File(filename));
            while (infile.hasNext()) {
                String nextWord = infile.next();
                this.words.add(nextWord.toLowerCase());
            }
        }
        catch (java.io.FileNotFoundException e) {
            System.out.println("FILE NOT FOUND");
        }
    }

    public void add(String newWord) {
        this.words.add(newWord.toLowerCase());
    }

    public void remove(String oldWord) {
        this.words.remove(oldWord.toLowerCase());
    }

    public boolean contains(String testWord) {
        return this.words.contains(testWord.toLowerCase());
    }
}
```

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Collections class

`java.util.Collections` provides a variety of static methods on Lists

```
static int binarySearch(List<T> list, T key);   // where T is Comparable
static T max(List<T> list);                     // where T is Comparable
static T min(List<T> list);                     // where T is Comparable
static void reverse(List<T> list);
static void shuffle(List<T> list);
static void sort(List<T> list);                 // where T is Comparable
```

since the `List` interface is specified, can make use of polymorphism

- these methods can be called on both `ArrayLists` and `LinkedLists`

```
ArrayList<String> words = new ArrayList<String>();
…
sort(words);

LinkedList<Integer> nums = new LinkedList<Integer>();
…
sort(nums);
```

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Searching an ArrayList

sequential search traverses the list from beginning to end

- check each entry in the list
- if matches the desired entry, then FOUND (return its index)
- if traverse entire list and no match, then NOT FOUND (return -1)

recall: the `ArrayList` class has `indexOf`, `contains` methods

```
public int indexOf(T desired) {
    for(int k=0; k < this.size(); k++) {
        if (desired.equals(this.get(k))) {
            return k;
        }
    }
    return -1;
}

public boolean contains(T desired) {
    return this.indexOf(desired) != -1;
}
```

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Sequential search: Big-Oh analysis

to represent an algorithm's performance in relation to the size of the problem, computer scientists use *Big-Oh* notation

an algorithm is O(N) if the number of operations required to solve a problem is proportional to the size of the problem

sequential search on a list of N items requires *roughly* N checks (+ other constants)
➔ O(N)

<we will revisit the technical definition of Big-Oh later in the course>

for an O(N) algorithm, doubling the size of the problem requires double the amount of work (in the worst case)

- if it takes 1 second to search a list of 1,000 items, then
  it takes 2 seconds to search a list of 2,000 items
  it takes 4 seconds to search a list of 4,000 items
  it takes 8 seconds to search a list of 8,000 items
  . . .

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Quick quiz:

what is the Big-Oh complexity of the following method?

```
public int sumOfNums(List<Integer> numbers) {
    int sum = 0;
    for (int i = 0; i < numbers.size(); i++) {
        sum += numbers.get(i);
    }
    return sum;
}
```

does it matter if the method is passed an `ArrayList` or `LinkedList`?

alternative: iterator

```
Iterator<Integer> iter = numbers.iterator();
while (iter.hasNext()) {
    sum += iter.next();
}
```

the iterator executes an efficient traversal, regardless of the List type → O(N)

alternative: enhanced for loop

```
for (Integer n : numbers) {
    sum += n;
}
```

hides the underlying iterator → O(N)
note: can't be used if altering the list while traversing

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Binary search

the `Collections` utility class contains a `binarySearch` method

- `T extends Comparable<? super T>` is UGLY notation
  refers to the fact that the class must implement the `Comparable` interface, or if a derived class then one of its parents must

```
public static <T extends Comparable<? super T>> int binarySearch(List<T> items, T desired) {
    int left = 0;                    // initialize range where desired could be
    int right = items.length-1;

    while (left <= right) {
        int mid = (left+right)/2;        // get midpoint value and compare
        int comparison = desired.compareTo(items.get(mid));

        if (comparison == 0) {           // if desired at midpoint, then DONE
            return mid;
        }
        else if (comparison < 0) {       // if less than midpoint, focus on left half
            right = mid-1;
        }
        else {                           // otherwise, focus on right half
            left = mid + 1;
        }
    }
    return -1;                       // if reduced to empty range, NOT FOUND
}
```

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Binary search: Big-Oh analysis

an algorithm is O(log N) if the number of operations required to solve a problem is proportional to the logarithm of the size of the problem

binary search on a list of N items requires *roughly* $\log_2$ N checks (+ other constants)
➔ O(log N)

for an O(log N) algorithm, doubling the size of the problem adds only a constant amount of work

- if it takes 1 second to search a list of 1,000 items, then
  searching a list of 2,000 items will take time to check midpoint + 1 second
  searching a list of 4,000 items will take time for 2 checks + 1 second
  searching a list of 8,000 items will take time for 3 checks + 1 second
  . . .

Comparison: searching a phone book

Number of entries in phone book	Number of checks performed by sequential search	Number of checks performed by binary search
100	100	7
200	200	8
400	400	9
800	800	10
1,600	1,600	11
…	…	…
10,000	10,000	14
20,000	20,000	15
40,000	40,000	16
…	…	…
1,000,000	1,000,000	20

to search a phone book of the United States (~300 million) using binary search?

to search a phone book of the world (6.7 billion) using binary search?

$O(N^2)$ sorts

a variety of algorithms exist for sorting a list

- *insertion sort* takes one item at a time and inserts it into an auxiliary sorted list
- *selection sort* traverses to find the next smallest, then swaps it into place
- both are $O(N^2)$, so doubling the list size quadruples the amount of work

```
public void selectionSort(ArrayList<String> items) {
  for (int i = 0; i < items.size()-1; i++) {        // traverse the list to
    int indexOfMin = i;                             // find the index of the
    for (int j = i+1; j < items.size(); j++) {      // next smallest item
      if (items.get(j).compareTo(items.get(indexOfMin)) < 0) {
        indexOfMin = j;
      }
    }

    String temp = items.get(i);                     // swap the next smallest
    items.set(i, items.get(indexOfMin));            // item into its correct
    items.set(indexOfMin, temp);                    // position
  }
}
```


O(N log N) sorts

faster, but more complex sorts exist

- *quick sort* partitions the list around a pivot, then recursively sorts each partition
- *merge sort* recursively sorts each half of the list, then merges the sorted sublists
- both are O(N log N), so doubling the list size increases the work by a little more than double

```
public void mergeSort(ArrayList<String> items) {
    mergeSort(items, 0, items.size()-1);
}

private void mergeSort(ArrayList<String> items, int low, int high) {
    if (low < high) {
        int middle = (low + high)/2;
        mergeSort(items, low, middle);
        mergeSort(items, middle+1, high);
        merge(items, low, high);
    }
}

. . .
```

note: merging two lists of size N can be done in O(N) steps

Recursion

recursion is useful when a task can be broken down into smaller, similar tasks

- functional recursion: a method directly or indirectly calls itself
- structural recursion: an object contains a smaller version of itself as a field

```
private void mergeSort(ArrayList<String> items, int low, int high) {
    if (low < high) {
        int middle = (low + high)/2;
        mergeSort(items, low, middle);
        mergeSort(items, middle+1, high);
        merge(items, low, high);
    }
}


public class Node<Type> {
    private Type data;
    private Node<Type> next;

    …
}
```

key to understanding recursion:

don't think too hard – only 1 level deep!

Stacks & Queues

the `java.util.Stack` class defines the basic operations of a stack

```
public class Stack<T> {
    public Stack<T>() { … }
    T push(T obj) { … }
    T pop() { … }
    T peek() { … }
    boolean isEmpty() { … }
    …
}
```

the `java.util.Queue` interface defines the basic operations of a queue

- `LinkedList` implements the `Queue` interface

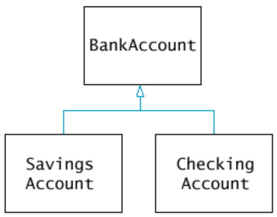
```
public interface Queue<T> {
    boolean add(T obj);
    T remove();
    T peek();
    boolean isEmpty();
    …
}

Queue<Integer> numQ = new LinkedList<Integer>();
```

Inheritance

inheritance is a mechanism for enhancing existing classes

- one of the most powerful techniques of object-oriented programming
- allows for large-scale code reuse



- here, a static field is used so that each account has a unique number

```
public class BankAccount {

  private double balance;
  private int accountNumber;
  private static int nextNumber = 1;

  public BankAccount() {
      this.balance = 0;
      this.accountNumber = this.nextNumber;
      this.nextNumber++;
  }

  public int getAccountNumber() {
      return this.accountNumber;
  }

  public double getBalance() {
      return this.balance;
  }

  public void deposit(double amount) {
      this.balance += amount;
  }

  public void withdraw(double amount) {
      if (amount >= this.balance) {
          this.balance -= amount;
      }
  }
}
```

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Derived classes

```
public class SavingsAccount extends BankAccount
{
  private double interestRate;

  public SavingsAccount(double rate)
  {
    this.interestRate = rate;
  }

  public void addInterest()
  {
    double interest =
      this.getBalance()*this.interestRate/100;
    this.deposit(interest);
  }
}
```

a derived class automatically inherits all fields and methods (but private fields are inaccessible)

- can override existing methods or add new fields/methods as needed

```
public class CheckingAccount extends BankAccount
{
  private int transCount;
  private static final int NUM_FREE = 3;
  private static final double TRANS_FEE = 2.0;

  public CheckingAccount()
  {
    this.transCount = 0;
  }

  public void deposit(double amount)
  {
    super.deposit(amount);
    this.transCount++;
  }

  public void withdraw(double amount)
  {
    super.withdraw(amount);
    this.transCount++;
  }

  public void deductFees()
  {
    if (this.transCount > NUM_FREE) {
      double fees =
        TRANS_FEE*(this.transCount - NUM_FREE);
      super.withdraw(fees);
    }
    this.transCount = 0;
  }
}
```

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Inheritance & polymorphism

polymorphism applies to classes in an inheritance hierarchy

- can pass a derived class wherever the parent class is expected
- the appropriate method for the class is called

```
public void showAccount(BankAccount acct) {
    System.out.println("Account " + acct.getAccountNumber() + ": $" +
                       acct.getBalance());
}


BankAccount acct1 = new BankAccount();
…
showAccount(acct1);

SavingsAccount acct2 = new SavingsAccount();
…
showAccount(acct2);

CheckingAccount acct3 = new CheckingAccount();
…
showAccount(acct3);
```