CSC 321: Data Structures

Fall 2018

- Java review (or What I Expect You to Know from 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
  - ➢ searching and sorting, algorithm efficiency, recursion
  - ➢ interfaces, 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 7/22/18
 */
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

- 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 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 d1 = new Die();
      Die d2 = new Die();

      int roll = d1.roll() + d2.roll();

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

- to avoid confusion, a class should either be an *object-generator* (fields & non-static methods) or a *driver* (main & possibly static helper methods)

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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

```
int num;             double x = 5.8;        char ch = '?';
num = 0;                                    boolean flag = false;
```

object types are those defined by classes

```
Die d8 = new Die(8);                 String str1 = "foo";
int result = d8.roll();              String str2 = new String("foo");
```

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Class composition

fields can be

✓ primitive types

✓ instances of other classes

✓ `static` (shared by the class)

✓ `final` (cannot be changed)

control statements

- if statement
- while loop
- for loop

mathematical ops:

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

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

relational ops:

`> >= < <= == !=`

logical connectives: `&&, ||, !`

```
public class PigGame {
    private final static int GOAL_POINTS = 100;

    private Die roller = new Die();
    private int threshold;

    public PigGame(int cutoff) {
        this.threshold = cutoff;
        this.roller = new Die();
    }

    public int playTurn() {
        int turnPoints = 0;

        while (turnPoints < this.threshold) {
            int roll = this.roller.roll();
            //System.out.println(roll);
            if (roll == 1) {
                return 0;
            }
            else {
                turnPoints += roll;
            }
        }
        return turnPoints;
    }

    public int playGame() {
        int totalPoints = 0;
        int turn = 0;
        while (totalPoints < PigGame.GOAL_POINTS) {
            totalPoints += this.playTurn();
            //System.out.println(totalPoints);
            turn++;
        }
        return turn;
    }
}
```

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Pig driver

`Scanner` provides for basic keyboard input

- next(), nextLine(), nextInt(), nextDouble(), …
- hasNext(), hasNextLine(), hasNextInt(), …

use constants (final static) for "magic" numbers that only rarely change

```
import java.util.Scanner;

public class PigStats {
    public final static int NUM_GAMES = 1000000;

    public static void main(String[] args) {
        System.out.print("Enter the Pig cutoff: ");
        Scanner input = new Scanner(System.in);
        int cutoff = input.nextInt();

        PigGame game = new PigGame(cutoff);

        int totalRounds = 0;
        for (int i = 0; i < PigStats.NUM_GAMES; i++) {
            totalRounds += game.playGame();
        }
        double avgLength =
                 (double)totalRounds/PigStats.NUM_GAMES;

        System.out.println("Average length of " +
                           PigStats.NUM_GAMES +
                           " games with a cutoff of " +
                           cutoff + ": " + avgLength);
    }
}
```

```
Enter the Pig cutoff: 20
Average length of 1000000 games with a cutoff of 20: 13.32565
```

```
Enter the Pig cutoff: 30
Average length of 1000000 games with a cutoff of 30: 16.521772
```

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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.)

```
    . . .

    /**
     * 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;
    }
}
```

`java.lang.Math` contains many useful static fields & methods

- Math.PI, Math.E
- Math.abs, Math.sqrt, Math.random

Boolean operators use short-circuit evaluation

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

Example: Interactive VolleyballStats

```
import java.util.Scanner;

/**
 * Performs a large number of volleyball game simulations and displays statistics.
 *   @author Dave Reed
 *   @version 7/22/18
 */
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 + "%");
    }
}
```

the `Scanner` class contains methods for reading from the console or a file

- next, hasNext, nextLine, hasNextLine
- nextInt, hasNextInt, nextDouble, hasNextDouble

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 via 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()`	returns copy of String with all letters uppercase
`String toLowerCase()`	returns copy of String with all letters lowercase
`bool equals(String other)`	returns true if other String has same value
`int compareTo(String other)`	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 word) {
      int firstVowel = this.findVowel(word);

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

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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 DiceStats1 {
   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) + "%)");
      }
   }
}
```

```
2: 259  (2.59%)
3: 567  (5.67%)
4: 806  (8.06%)
5: 1123  (11.23%)
6: 1413  (14.13%)
7: 1634  (16.34%)
8: 1391  (13.91%)
9: 1145  (11.45%)
10: 809  (8.09%)
11: 595  (5.95%)
12: 258  (2.58%)
```

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Java ArrayLists

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

- must specify content type when declare, capacity 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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ArrayLists & primitives

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

```
import java.util.ArrayList;

public class DiceStats2 {
   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.size(); i++) {
         System.out.println(i + ": " + counts.get(i) + "   ("
                              + (100.0*counts.get(i)/NUM_ROLLS) + "%)");
      }
   }
}
```

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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.add(nextWord);
            }
        }
        catch (java.io.FileNotFoundException e) {
            System.out.println("FILE NOT FOUND");
        }
    }

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

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

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

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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`, its methods will be called
- if choose to instantiate with a `LinkedList`, its methods will be called

this style leads to more general-purpose code

```
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.add(nextWord);
            }
        }
        catch (java.io.FileNotFoundException e) {
            System.out.println("FILE NOT FOUND");
        }
    }

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

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

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

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>();
…
Collections.sort(words);

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

Searching a List

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 algorithms 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 (ignoring 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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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 ancestors 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 -left - 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 (ignoring 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
  . . .

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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 (~328 million) using binary search?

to search a phone book of the world (7.5 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 static <T extends Comparable<? super T>>
              void selectionSort(ArrayList<T> items) {
    for (int i = 0; i < items.size()-1; i++) {
        int indexOfSmallest = Sorts.findSmallestStartingAt(items, i);
        Collections.swap(items, i, indexOfSmallest);
    }
}

private static <T extends Comparable<? super T>>
               int findSmallestStartingAt(ArrayList<T> items, int startIndex) {
    int indexOfMin = startIndex;
    for (int i = startIndex+1; i < items.size(); i++) {
        if (items.get(i).compareTo(items.get(indexOfMin)) < 0) {
             indexOfMin = i;
        }
    }
    return indexOfMin;
}
```

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 static <T extends Comparable<? super T>>
              void mergeSort(ArrayList<T> items) {
    mergeSort(items, 0, items.size()-1);
}

private static <T extends Comparable<? super T>>
               void mergeSort(ArrayList<T> 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

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Recursion

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

- functional recursion: a method directly or indirectly calls itself

```
private static <T extends Comparable<? super T>> void
               mergeSort(ArrayList<T> 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);
    }
}
```

key to understanding recursion:

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

interesting aside:

- Collections.sort uses merge sort
- Arrays.sort uses merge sort (when objects are stored)
  quick sort (when primitives are stored)

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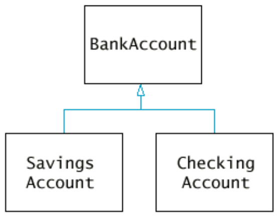
Inheritance

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;
      }
  }
}
```

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;
  }
}
```

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);
```