Object Oriented Programming

- Encapsulation and Data Hiding
- Classes and Instances
- Constructors
- Objects and References
- Standard Java Classes
- The String Class

OO Design Principles

- **Abstraction**: capture concepts in design
  - Promotes reuse and versatility of software
- **Encapsulation**: classes define data that belongs together
  - Presents coherent view of an object
- **Data Hiding**: users of an object should not need to know the implementation details of the class
  - Users should see just the methods that the class author chooses to make visible
- Java provides language constructs to allow code to adhere to these principles
  - **Class** definition
  - Visibility modifiers
Abstraction

Why the fuss about objects, classes, and methods?

As a driver, you don’t need to know how the engine works to be able to drive a car
- You understand the abstract concept of a car and the necessary interfaces (accelerator, steering, etc.)
- You can drive many different models of cars – you don’t have to learn how to drive all over again for each car model

As an engineer at Ford, you don’t have to understand how every single component of every car works
- You only need to know the component you work on and how it interacts with other components
- You can design a standard component that can be used in different places in a car, and in different models

An abstraction hides the right details at the right time

- For example, we don’t have to know how the println method works in order to call it
- println is an example of procedural abstraction

A human being can manage only a few pieces of information at one time
- But if we group information into chunks (such as objects) we can deal with many complicated pieces at once

In Object Oriented design and programming, the emphasis of abstraction is on the data
- An object is abstract in that we don’t have to think about its internal details in order to use it
- Classes and objects help us write complex software
Objects

- An object models a real world entity or abstraction
  - An object has a state, which is modeled in the data
  - An object has behavior, which is modeled in methods
- For example, a gift card is an entity that can be modeled in software
  - The state could consist of the card owner's name, the current balance, and the account number
  - The behavior could consist of methods to add value to the card, make purchases, and check the balance
  - The class definition for a card would encapsulate the data and methods
  - Then we could create a single card object rather than having separate, loosely connected variables for the name, balance, and number

Examples of Objects

- The players in a game
  - State of each player includes position, strength, team, weapons
  - Weapons could be objects themselves with ammunition, range, accuracy, power as their state
- Desktop on a computer populated with items
  - Each item could be an object with various properties
  - Behavior could include how item repaints and resizes itself
- Files on the disk could be objects
- A music player, each song, albums

- Fundamental idea of OO is that data that belongs together should be encapsulated and "know" how to take care of itself
Using Classes

- We use classes by creating objects of the class type and calling methods for that object.
- Objects are created with the keyword `new` and the class name, followed by parentheses.
  - Using `new` means that an object is created by using a special constructor method of the class.
  - The constructor performs any initialization necessary for the object to work correctly.
  - The constructor may allow parameter values to be passed to affect the way initialization is done.
- Once an object is created, methods may be called.
  - Syntax is the object variable, a dot, the method name and any parameters.
  - We have seen all of this with the Scanner class.

Libraries and Packages

- Java has many useful classes coded in libraries that are part of the Java environment.
  - Classes are organized in packages - groups of classes that go together.
  - Library classes can be used more easily by importing them.
  - E.g., be able to create Scanner objects for getting input:
    ```java
    import java.util.Scanner;
    ```
  - E.g., be able to create NumberFormat objects for formatting numbers:
    ```java
    import java.text.NumberFormat;
    ```
  - The full path name for a class could be used and no import statement would be needed.
    - But this is more cumbersome:
      ```java
      java.util.Scanner scan = new java.util.Scanner(System.in);
      ```
  - May also use wildcards to get all classes in a package:
    ```java
    import java.util.*;
    ```
Date and Calendar classes

- System independent date/time operations
- Date objects are created for a specific date/time
  - Time measured in milliseconds since "epoch"
- `import java.util.*;`
- Default Date constructor uses current time
- Calendar objects permit breakdown in days, hours, etc.
  - Calendars set from Dates
  - Fields of calendars can be manipulated
  - New date can be extracted from Calendar
- [Date API page](#)
- [GregorianCalendar API page](#)

BigInteger

- Built-in Java primitive types `int` or `long` have limits
  - Cannot be used for numbers larger than $2^{32}$ or $2^{64}$
  - Good enough for lots of things, but not everything
- BigInteger objects created from string representation of number
  - Constructor is given String argument
- BigInteger has methods for all arithmetic operations
  - Function syntax – not as nice as built in operators
- But no limit on size of values
  - Eventually machine could run out of resources
  - But calculations will be correct up to that point
- `import java.math.BigInteger;`
- Also BigDecimal for precision values
- [BigInteger API page](#)

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BigInteger Example

- Contest problem:
  - Given a number, find the smallest multiple of that number which consists of just ‘1’ digits
  - E.g., 111 is a multiple of 3
  - The original number must not be divisible by 2 or 5 (or there won’t be a multiple consisting just of 1’s)

- Strategy:
  - Use BigIntegers
  - Start with 1, then 11, then 111, etc.

Designing Classes

- A class definition is a blueprint for creating objects
  - It describes the state and behavior that each object of the class must have
  - A class is really a type definition, much like int or double, but more complex

- A TunesCard class could specify that all music purchase card objects have:
  - A current balance, kept as a double
  - An account number, kept as an int
  - An owner's name, kept as a String
  - Methods addValue, debit, and getBalance

- Once we have a class definition, we can create objects of that class type
  - All such objects will have the same form, but their data values (state) will be specific to the object
  - Objects of the class type are called instances
  - Creating objects is called instantiation
Classes and Objects

Class name: TunesCard
Data Fields: owner is ______
cardNo is ______
balance is ______
Methods: addValue, debit, getBalance

TunesCard objects

First TunesCard object
Data: name is John Doe
cardNo is 1234
balance is $25.00

Second TunesCard object
Data: name is Mary Smith
cardNo is 9876
balance is $32.81

Third TunesCard object
Data: name is Lee White
cardNo is 9999
balance is $35.12

Coding Classes in Java

- Java is an Object Oriented language
- A program in Java consists of **class** definitions
- A class definition contains
  - **Data** definitions
  - **Method** definitions
- One "main" class in the program contains a definition of the static **main** method
  - Execution of the program begins with **main**
  - Typically, **main** instantiates one or more objects and calls their methods (which may create more objects and call their methods ...)
  - The Java standard library defines hundreds of classes that can be used
Java Class Syntax

```java
public class TunesCard {
    private int cardNo;
    private double balance;
    private String owner;

    // Add given amount - adjust balance and return
    public double addValue(double amount) {
        balance = balance + amount;
        return balance;
    }

    // Returns current balance in the account
    public double getBalance() {
        return balance;
    }
}
```

Notes about Class code

- A class definition should be in a file named for the class and should be `public`
  - E.g., class TunesCard is defined in TunesCard.java
  - May have other class definitions in the file, but only one can be public (the one the file is named after)
- Data definitions are like variable declarations and are typically `private`
  - Also called class variables or instance variables
- Method definitions may use the class variables
  - Can be used as if they were local variables
- More about public and private later
Object Types

- Java has a handful of built-in primitive types
  - Numerical types, Boolean, single character
- Objects are more interesting types
  - A class defines a new object type
  - Objects have methods to perform operations, obtain data values, etc.
  - Objects can be very simple or very complicated
- Thousands of object types are defined in the Java library
  - Graphical objects: Buttons, Windows, ScrollBars, etc.
  - Computation objects: BigInteger, Date, etc.
- String is an object type, not a primitive
  - Method to get number of chars: `message.length()` is 12
  - Method to get a particular char: `message.charAt(1)` is ‘e’
  - The String type allows a set of characters to be treated as one entity
  - String is a special object type in Java

Initialization

- How does an object of the class type come into existence?
  - Objects are created with the `new` operator
  - For example
    ```java
    TunesCard myCard = new TunesCard();
    ```
  - This creates a variable named `myCard` whose type is a TunesCard object – it is an instance of the TunesCard class
- What are the initial data values in an object?
  - Same as for local variables: zeroes
- Seems like we should be able to control the initial values
  - We can, with special methods called `constructors`
Coding Constructors

- Constructors are special methods defined in a class to perform initialization
  - A constructor is called **automatically** when object is created with `new`
  - The constructor is never called explicitly
  - The name of the constructor method is the name of the class
  - The constructor has no return type (not void, just no type at all)
- A constructor typically sets data values for the class variables
  - Values may be determined from parameters passed to the constructor
  - The parameter values are provided with the `new` operator
  - Overloading allows multiple constructors for different ways to initialize
  - The parameters to `new` must match a defined constructor
- If no constructors are defined, then Java defines a "void" constructor that takes no arguments and has no statements

Constructor Example

- A constructor for the TunesCard class

```
public class TunesCard {
    // Constructor requires name on the card
    public TunesCard(String who) {
        owner = who;
        balance = 0;
    }
}
```

- Creating an account object with the constructor

```
public class TunesCardTest {
    public static void main(String[] args) {
        TunesCard hers = new TunesCard("Mary D");
        TunesCard his = new TunesCard("John S");
        ... ...
    }
}
```
Calling Instance Methods

- Recall that static methods for a class are called by using the **class name** and a dot
  - E.g., Math.random()
- Instance methods are called by using the **object variable name** and a dot
  - E.g., herCard.addValue(100);
  - Thus the code of the method deposit refers to the data of the object herCard
  - If an instance method of a class is called from another method of the same class, then the instance variable is not necessary – the same object is used
- Instance methods can only be called in the context of a particular object

Completing the example

- Notes
  - A "driver" program is often used to test a class
  - If a class provides a `toString` method, then the object may be passed as an argument to `System.out.println`

`TunesCard.java`
`TunesCardTest.java`
Objects, Memory and References

- The built in types are called **primitive** data types
  - int, long, float, double, char, byte, boolean
  - When we declare a variable of this type, appropriate space is reserved and initialized
  - E.g., for a local variable of type double, 8 bytes of the stack is used
- **Object** types are handled differently
  - When a variable of any object type is declared, space is only reserved for a reference to the object
  - Think of a reference as a "handle" - a memory address (4 bytes)
  - The reference is initially set to an invalid address (the null pointer)
  - Space for the object itself is only reserved when the new operation is performed
    - For Strings, initialization to a literal is shorthand for a new operation
  - The object will be in a separate memory pool called the heap

Objects and References

- If an object variable has not been associated with a valid object, then we cannot access methods or data through the variable

```java
StringBuffer x, y;
x.append("World");
y = new StringBuffer("Hello");
y.append("World");
```

- Remember – all objects must be created
  - Primitive types are automatically "created" by the declaration

`ObjectTest.java`
Objects and Assignment

- When we assign one **primitive** type variable to another, the value is copied from the one variable to the other.

  ```
  int a = 13;  a 13
  int b = 7;   b 7
  after b = a; a 13
  b 13
  ```

- What about when one **object** variable is assigned to another?
  - The reference to one object is reassigned.
  - This means there are now two variables referring to the **same** object.
  - There is only **one** object now.

  ```
  Card a = new Card("John");
  Card b = new Card("Mary");
  a John / 1234 / 0.0
  b Mary / 1235 / 0.0
  after b = a;
  a John / 1234 / 0.0
  b Mary / 1235 / 0.0
  ```

Object References

- Assignment of objects makes copies of the reference, not the object itself.
  - The assigned variable becomes an alias for the same object.

- Done implicitly when objects are passed to methods.
  - The method gets a reference to the same object.
  - If the object is mutable, the object's state may be changed during the method call.
  - Thus a method may produce side effects on the objects passed.

- What happens to the object no longer being referenced after an assignment between object variables?
  - The memory used by the object is reclaimed at some point by the JVM automatic garbage collection.
  - Otherwise memory would eventually run out.

```
Visibility Modifiers

- Class information is designed as **external** and **internal**

- **External information is the interface**
  - The information we must know to use the object
  - Generally, the interface just consists of methods
  - These methods must be declared as **public** to be able to be used by code outside of the class definition

- **Internal information is the implementation**
  - We do not need to know implementation details to use the object (e.g., variable names, types, internal methods)
  - Data and methods which are internal are declared as **private**
  - Generally, all data should be private
  - Goal is to keep public interface as small as possible

Visibility Modifiers

**public**

- **Provide services to clients**
- **Violate encapsulation**

**private**

- **Support other methods in the class**
- **Enforce encapsulation**

- Public methods/variables are accessible from any code in **any** class
  - The scope is everywhere (with the proper object/class qualifier)
- Private methods/variables are only accessible from the code **inside** the class itself
  - The scope is limited to the class code
Visibility Modifiers

- Proper use of public and private expresses design intent in code
  - The Java compiler can then enforce this design
  - Private data can not be accessed outside of the class code – it will produce a compiler error
- General rule of thumb: objects should take care of themselves
  - All data should be private, and changeable from the outside only by public methods
  - One exception is constants – since they are not changeable, it is safe to have public constants
- `public` and `private` support encapsulation and data hiding
  - In a good class design, the interface will be as large as it needs to be, but no larger
  - Encapsulation means the object is like a black box – as users, we only know the interface, not the inner workings

Scope and `this`

- Recall that a variable's `scope` is where it can be used
  - The scope of a local variable is the block in which it is declared
- The scope of a public class method is everywhere
  - But an object of the class type is needed to qualify the name
- The scope of a private class variable or method is the code of the class
- Within a class, no qualification of a name is necessary for public or private identifiers
  - The name implicitly refers to the current instance data
  - But the identifier can be qualified with `this` to make explicit
  - `this` is the "name" of the current object instance
Scope and this

- Suppose that in the TunesCard constructor we wanted to name the parameter owner instead of who
  ```java
  private String owner;
  ...
  public TunesCard(String owner) {
    owner = owner;
    balance = 0;
  }
  ```

- Use keyword this to qualify the data member so it is distinguished from the parameter
  ```java
  public TunesCard(String owner) {
    this.owner = owner;
    balance = 0;
  }
  ```

Oops! Both uses of owner refer to the parameter, so class data does not get changed

Static vs. Non-static

- Math class has static methods
  - No need for a Math object (can't actually create one anyway)
  - Static methods do not (can not) use instance data

- Non-static (instance) methods only make sense in context of a particular object
  - Can only be called with an explicit object (or implicitly from another instance method – same object)
  - Instance methods use the instance data

- What about static data?
  - Not associated with an object
  - Exists independently of the creation of any objects
  - This is per-class data, not per-object data
  - Useful for things like counters for the class, or even a count of the number of instances of objects of the class
Strings as Objects

- What’s wrong with this?

```java
String msg;
System.out.println(msg);
System.out.println(msg.length());
```
Null Pointer Exception since no String Object!

- A String object might look like

```java
String msg = "hello";
```

- When a String is created, memory is allocated for data
  - The characters
  - The length

Comparing Strings

- What does the following code do?

```java
s, t; . . .
if (s == t) . . .
```

**Scenario 1**

```
s = "hello";
t = s;
```

`s==t` is **true**

**Scenario 2**

```
s = "hello";
t = "world";
```

`s==t` is **false**

**Scenario 3**

```
s = "hello";
t = s.substring(0,4)+"o";
```

`s==t` is **false**

- The operator `==` asks if the variables refer to the *same object*, but that is not what we really want to know
  - We want to know if two strings match
  - I.e., are they equivalent - same letters in the same order
Comparing Strings

- String provides method `equals` to determine if Strings are the "same"
  - In OO fashion, Strings “know” when two Strings are equivalent
  - The method is given one argument - another String
  - `this` String compares itself to the other String
  ```java
  if ( s.equals(t) ) . . .
  ```
- In Scenarios 1 and 3, `s.equals(t)` is true, but false in Scenario 2
- String has `compareTo` to determine how two Strings are ordered
  - Returns 0 if the Strings are equal (as above)
  - Returns distance between first differing characters (as positive or negative)
  - This produces lexicographic ordering of Strings
- Most objects implement an `equals` method (default is `==`)
- Comparable objects implement a `compareTo` method

The toString Method

- Every object in Java has a method named `toString` with the signature:
  ```java
  public String toString()
  ```
- If an object does not define the method, the default behavior is to return a string with the object's location in memory
- A class can define the method to provide a meaningful string representation of the objects of that type
- This method will be used whenever an object is the argument for `println`
  - It may also be called explicitly
  - Also used when object is "added" to a String
Mutable vs. Immutable Objects

- Account objects have methods that change the state of the object
  - Deposit and withdraw methods change the balance field
- Do any methods of String change the String object?
  - length()? No concat()? No toLowerCase()? No equals()? No substring()? No
- None of the String methods change the state of the String object
  - String objects are immutable
  - Once created, the String object can never change
  - Other immutable classes: BigInteger
- Mutable objects may be changed by methods
  - Some methods are getters and don’t change data
  - Other methods are setters or otherwise change
  - Mutable classes: Scanner, Date, StringBuffer

A Note on String Efficiency

- Java has special treatment for the String class
  - Use of symbolic ‘+’ operator (and +=) for Strings
  - Shorthand for String object creation from literal without new
- Efficient treatment of constant literal Strings
  - Pool of constant strings
  - All uses of same literal share single instance
  - E.g., if "Go Ducks" appears in five places in the program, there will still be only one instance in memory
  - This is called an interned String
  - Possible since String objects are immutable

StringTest2.java