Topic 3
Encapsulation - Implementing Classes

"And so, from Europe, we get things such as ... object-oriented analysis and design (a clever way of breaking up software programming instructions and data into small, reusable objects, based on certain abstraction principles and design hierarchies.)"

-Michael A. Cusumano, The Business Of Software

Object Oriented Programming

- Creating large programs that work turns out to be very difficult
  - [DIA Automated baggage handling system]
  - [Ariane 5 Flight 501]
  - [More]
- Object oriented programming is one way of *managing the complexity* of programming and software projects
- Break up big problems into smaller, more manageable problems

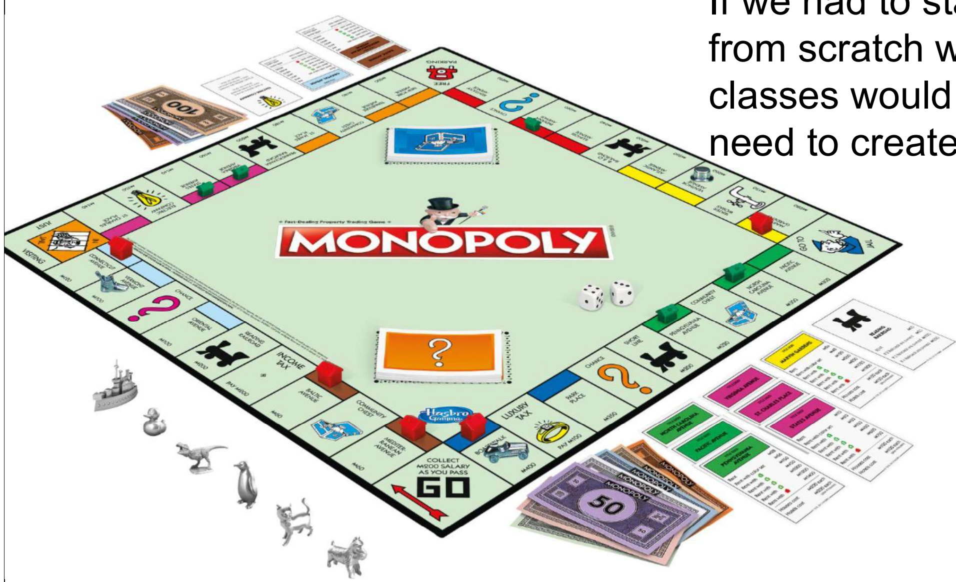
Object Oriented Programming

- "Object-oriented programming is a method of programming based on a hierarchy of classes, and well-defined and cooperating objects. "
- What is a class?
- "A class is a structure that defines the data and the methods to work on that data. When you write programs in the Java language, all program data is wrapped in a class, whether it is a class you write or a class you use from the Java platform API libraries."
  - a new data type

Object Oriented Programming

- In other words break the problem up based on the things / data types that are part of the problem
- Not the only way
- One of many different kinds of strategies or *paradigms* for software development
  - functional, procedural, event driven, data flow, formal methods, agile or extreme, ...
- In 314 we will do a lot of *object based* programming

Example - Monopoly



If we had to start from scratch what classes would we need to create?

Encapsulation

- One of the features of object oriented languages
- Allows programmers to define **new data types**
- Hide the data of an object (variable)
- Group operations and data together into a new data type
- Usually easier to ***use*** something than understand ***exactly how it works***
  – microwave, car, computer, software, mp3 player

Data Structures

- A data structure is a variable that stores other variables. (overly simplified definition)
  – aka Collection, Container
- May be ordered or unordered (from client's perspective)
  – Order a first element, second element,…
  – Lists are ordered, sets are typically unordered
- May allow duplicate values or not
  – Lists allow duplicates, sets typically do not

The IntList Class

- We will develop a class that models a list of ints
  – initially a pale imitation of the Java ArrayList class
- Improvement on an array of ints
  – resize automatically
  – insert easily
  – remove easily
- A list - our first *data structure*
  – a variable that stores other variables
- Lists maintain elements in a definite order and duplicates are allowed

```
 0   1  2   3   4  <- indices / positions
[5, 12, 5, 17, -5] <- elements
```

Clicker 1

Our `IntList` class has an array of ints instance variable (`int[] container`). What should the length of this internal array be?

A. less than the size of the list
B. equal to the size of the list
C. greater than or equal to the size of the list
D. some fixed amount that never changes
E. 0

Array length less than the number of elements in the list?!?

- What if most elements are all the same value? Only store the elements (and their position) not equal to the default? Sparse List

Clicker 2

When adding a new element to a list, where should the new element be added by default?

A. The beginning
B. The end
C. The middle
D. A random location
E. Don't bother to actually add

IntList Design

- Create a new, empty IntList

```
new IntList -> []
```

- The above is not code. It is a notation that shows what the results of operations. `[]` is an empty list.
- add to a list.

```
[].add(1) -> [1]
[1].add(5) -> [1, 5]
[1, 5].add(4) -> [1, 5, 4]
```

- elements in a list have a definite order and a position.
  - zero based position or 1 based positioning?

```
IntList aList = new IntList();
aList.add(42);
aList.add(12);
aList.add(37);
```

Abstract view of list of integers

0 1 2
[42, 12, 37]

The wall of abstraction.

Instance Variables

- Internal data
  – also called instance variables because every instance (object) of this class has its own copy of these
  – something to store the elements of the list
  – size of internal storage container?
  – if not what else is needed
- Must be clear on the difference between the internal data of an IntList object and the IntList that is being represented
- Why make internal data private?

Constructors

- For initialization of objects
- IntList constructors
  – default
  – initial capacity?
- redirecting to another constructor

```
this(10);
```

- class constants
  – what `static` means

Default add method

- where to add?
- what if not enough space?

```
[].add(3) -> [3]
[3].add(5) -> [3, 5]
[3, 5].add(3) -> [3, 5, 3]
```

- Testing, testing, testing!
  – a `toString` method would be useful

The IntList Class

- instance variables
- constructors
  - default
  - initial capacity
    - preconditions, exceptions, postconditions, assert
  - meaning of static
- add method
- get method
- size method

toString method

- return a Java String of list
- empty list -> `[]`
- one element -> `[12]`
- multiple elements -> `[12, 0, 5, 4]`

Clicker 3 - Timing Experiment

- Add N elements to an initially empty IntList then call toString. Time both events. How does the time to add compare to the time to complete toString?

```
IntList list = new IntList();
for (int i = 0; i < N; i++)
    list.add(i); // resize, cap * 2
String s = list.toString();
```

A. time to add << time for toString()
B. time to add < time for toString()
C. time to add ~= time for toString()
D. time to add > time for toString()
E. time to add >> time for toString()

The IntList Class

- testing!!!
- toString
  - "beware the performance of String concatenation" – Joshua Bloch
- insert method `(int pos, int value)`
- remove method `(int pos)`
- insertAll method `(int pos, IntList other)`
  - queens and kings of all the IntLists!!!

Clicker Question 4

What is output by the following code?

```
IntList list
list = new IntList(25);
System.out.println(list.size());
```

A. `25`

B. `0`

C. `-1`

D. unknown

E. No output due to runtime error.

get and size methods

- get
  - access element from list
  - preconditions?

`[3, 5, 2].get(0)` returns `3`

`[3, 5, 2].get(1)` returns `5`

- size
  - number of elements in the list
  - Do not confuse with the capacity of the internal storage container
  - The array is not the list!

`[4, 5, 2].size()` returns `3`

insert method

- add at someplace besides the end

`[3, 5].insert(1, 4) -> [3, 4, 5]`

where what

`[3, 4, 5].insert(0, 4) -> [4, 3, 4, 5]`

- preconditions?
- overload add?
- chance for internal loose coupling

Clicker 5

What is output by the following code?

```
IntList list = new IntList();
list.add(3);
list.insert(0, 4); // position, value
list.insert(1, 1);
list.add(5);
list.insert(2, 9);
System.out.println(list);
```

A. `[4, 1, 3, 9, 5]`

B. `[3, 4, 1, 5, 9]`

C. `[4, 1, 9, 3, 5]`

D. `[3, 1, 4, 9, 5]`

E. Something else

remove method

- remove an element from the list based on location

`[3, 4, 5].remove(0) -> [4, 5]`

`[3, 5, 6, 1, 2].remove(2) ->`

`[3, 5, 1, 2]`

- preconditions?
- return value?
  - accessor methods, mutator methods, and mutator methods that return a value

Clicker Question 6

What is output by the following code?

```
IntList list = new IntList();
list.add(12);
list.add(15);
list.add(12);
list.add(17);
list.remove(1);
System.out.println(list);
```

A. `[15, 17]`
B. `[12, 17]`
C. `[12, 0, 12, 17]`
D. `[12, 12, 17]`
E. `[15, 12, 17]`

insertAll method

- add all elements of one list to another starting at a specified location

`[5, 3, 7].insertAll(2, [2, 3]) ->`

`[5, 3, ` **`2, 3,`** ` 7]`

The parameter `[2, 3]` would be unchanged.

- Working with other objects of the same type
  - `this`?
  - where is private private?
  - loose coupling vs. performance
  - queens and kings of all the IntLists!!!

Clicker 7 - InsertAll First Version

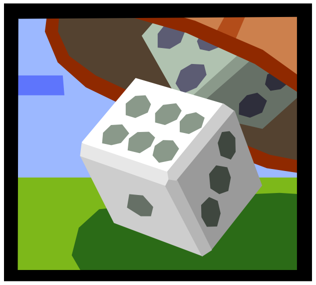
- What is the order of the first version of InsertAll? Assume both lists have N elements and that the insert position is halfway through the calling list.

A. O(1)
B. O(logN)
C. O($N^{0.5}$)
D. O(N)
E. O(N^2)

Class Design and Implementation – Another Example

This example will not be covered in class.

The Die Class



- Consider a class used to model a die
- What is the interface? What actions should a die be able to perform?
- The methods or behaviors can be broken up into constructors, mutators, accessors

The Die Class Interface

- Constructors (used in creation of objects)
  - default, single int parameter to specify the number of sides, int and boolean to determine if should roll
- Mutators (change state of objects)
  - roll
- Accessors (do not change state of objects)
  - getResult, getNumSides, toString
- Public constants
  - DEFAULT_SIDES

Visibility Modifiers

- All parts of a *class* have visibility modifiers
  - Java keywords
  - **public**, protected, **private,** (no modifier means package access)
  - do not use these modifiers on local variables (syntax error)
- **public** means that constructor, method, or field may be accessed outside of the class.
  - part of the interface
  - constructors and methods are generally public
- **private** means that part of the class is hidden and inaccessible by code outside of the class
  - part of the implementation
  - data fields are generally private

The Die Class Implementation

- Implementation is made up of constructor code, method code, and private data members of the class.
- scope of data members / instance variables
  - *private data members may be used in any of the constructors or methods of a class*
- Implementation is hidden from users of a class and can be changed without changing the interface or affecting clients (other classes that use this class)
  - Example: Previous version of Die class, DieVersion1.java
- Once Die class completed can be used in anything requiring a Die or situation requiring random numbers between 1 and N
  - DieTester class. What does it do?

DieTester method

```
public static void main(String[] args) {
       final int NUM_ROLLS = 50;
       final int TEN_SIDED = 10;
       Die d1 = new Die();
       Die d2 = new Die();
       Die d3 = new Die(TEN_SIDED);
       final int MAX_ROLL = d1.getNumSides() +
              d2.getNumSides() + d3.getNumSides();

       for(int i = 0; i < NUM_ROLLS; i++)
       {      d1.roll();
              d2.roll();
              System.out.println("d1: " + d1.getResult()
                     + " d2: " + d2.getResult() + " Total: "
                     + (d1.getResult() + d2.getResult() ) );
       }
```


DieTester continued

```
int total = 0;
int numRolls = 0;
do
{      d1.roll();
       d2.roll();
       d3.roll();
       total = d1.getResult() + d2.getResult()
              + d3.getResult();
       numRolls++;
}
while(total != MAX_ROLL);

System.out.println("\n\nNumber of rolls to get "
       + MAX_ROLL + " was " + numRolls);
```


Correctness Sidetrack

- When creating the public interface of a class give careful thought and consideration to the *contract* you are creating between yourself and users (other programmers) of your class
- Use *preconditions* to state what you assume to be true before a method is called
  - caller of the method is responsible for making sure these are true
- Use post*conditions* to state what you guarantee to be true after the method is done if the preconditions are met
  - implementer of the method is responsible for making sure these are true

Precondition and Postcondition Example

```
/* pre: numSides > 1
  post: getResult() = 1, getNumSides() = sides
*/
 public Die(int numSides)
 {  assert (numSides > 1) : “Violation of precondition: Die(int)”;
     iMyNumSides = numSides;
     iMyResult = 1;
     assert getResult() == 1 && getNumSides() == numSides;
 }
```

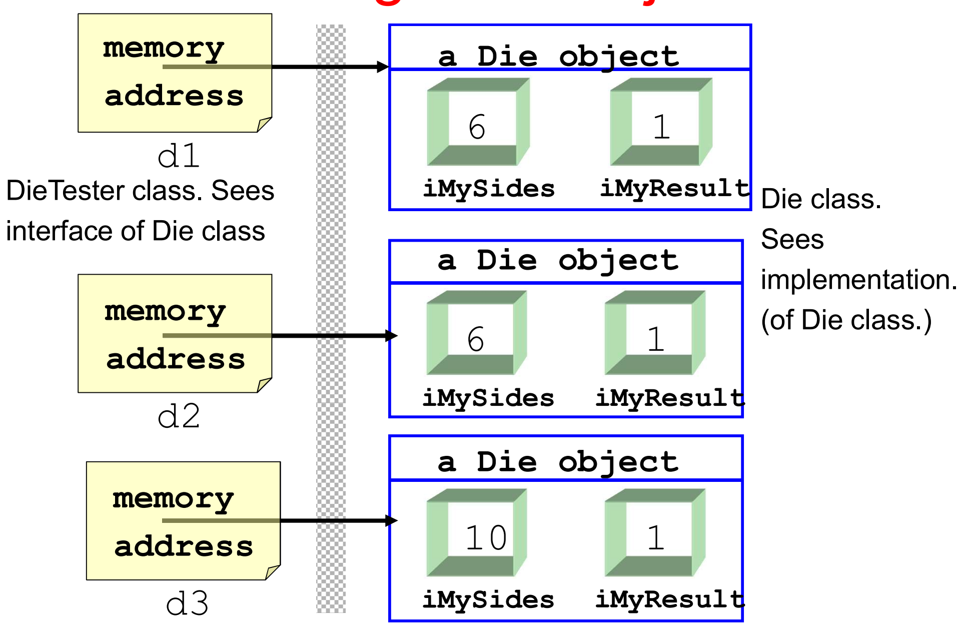

Object Behavior - Instantiation

- Consider the DieTester class

```
Die d1 = new Die();
Die d2 = new Die();
Die d3 = new Die(10);
```

- When the new operator is invoked control is transferred to the Die class and the specified constructor is executed, based on parameter matching
- Space(memory) is set aside for the new object's fields
- The memory address of the new object is passed back and stored in the object variable (pointer)
- After creating the object, methods may be called on it.

Creating Dice Objects



Objects

- Every Die object created has its own instance of the variables declared in the class blueprint

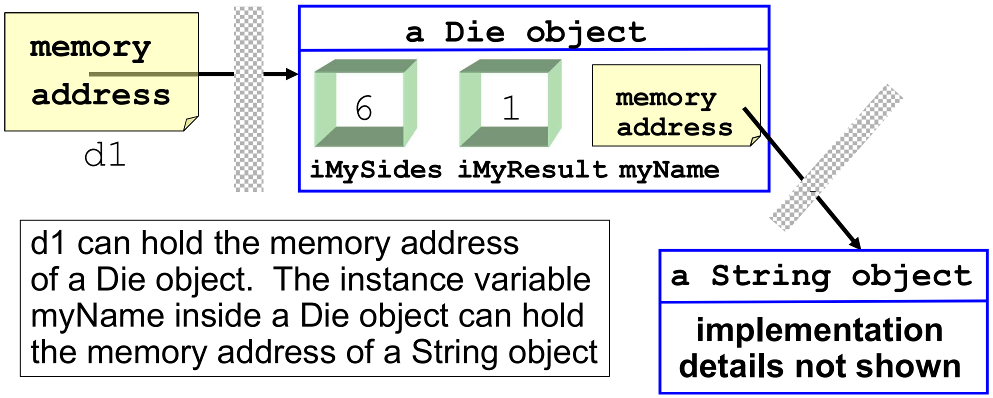
```
private int iMySides;
private int iMyResult;
```

- thus the term *instance variable*
- the instance vars are part of the hidden implementation and may be of *any* data type
  - unless they are public, which is almost always a bad idea if you follow the tenets of information hiding and encapsulation

Complex Objects

- What if one of the instance variables is itself an object?
- add to the Die class

```
private String myName;
```



d1 can hold the memory address of a Die object. The instance variable myName inside a Die object can hold the memory address of a String object

The Implicit Parameter

- Consider this code from the Die class

```
public void roll()
{   iMyResult =
        ourRandomNumGen.nextInt(iMySides) + 1;
}
```

- Taken in isolation this code is rather confusing.
- what is this iMyResult thing?
  - It's not a parameter or local variable
  - why does it exist?
  - *it belongs to the Die object that called this method*
  - if there are numerous Die objects in existence
  - Which one is used depends on which object called the method.

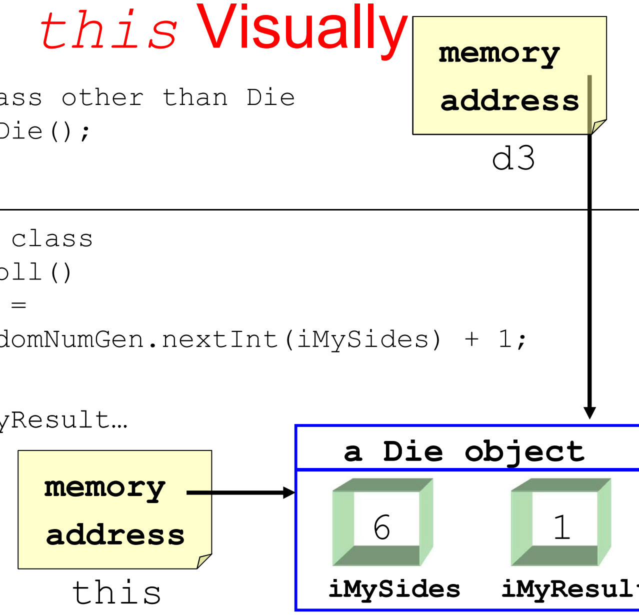
The `this` Keyword

- When a method is called it may be necessary for the calling object to be able to refer to itself
  - most likely so it can pass itself somewhere as a parameter
- when an object calls a method an implicit reference is assigned to the calling object
- the name of this implicit reference is `this`
- `this` is a reference to the current calling object and may be used as an object variable (may not declare it)

`this` Visually

```
// in some class other than Die
Die d3 = new Die();
d3.roll();
```

```
// in the Die class
public void roll()
{   iMyResult =
        ourRandomNumGen.nextInt(iMySides) + 1;
    /* OR
      this.iMyResult…
    */
}
```



An equals method

- working with objects of the same type in a class can be confusing
- write an equals method for the Die class. assume every Die has a myName instance variable as well as iMyNumber and iMySides

A Possible Equals Method

```
public boolean equals(Object otherObject)
{     Die other = (Die)otherObject;
      return iMySides == other.iMySides
             && iMyResult== other.iMyResult
             && myName.equals( other.myName );
}
```

- Declared Type of Parameter is Object not Die
- override (replace) the equals method instead of overload (present an alternate version)
  - easier to create generic code
- we will see the equals method is *inherited* from the Object class
- access to another object's private instance variables?

Another equals Methods

```
public boolean equals(Object otherObject)
{     // dangerous! Not checking for null or type.
      Die other = (Die)otherObject;
      return this.iMySides == other.iMySides
             && this.iMyNumber == other.iMyNumber
             && this.myName.equals( other.myName );
}
```

Using the this keyword / reference to access the implicit parameters instance variables is unnecessary.
If a method within the same class is called within a method, the original calling object is still the calling object

A "Perfect" Equals Method

- From Cay Horstmann's *Core Java*

```
public boolean equals(Object otherObject)
{     // check if objects identical
      if( this == otherObject)
            return true;
      // must return false if explicit parameter null
      if(otherObject == null)
            return false;
      // if objects not of same type they cannot be equal
      if(getClass() != otherObject.getClass() )
            return false;
      // we know otherObject is a non null Die
      Die other = (Die)otherObject;
      return iMySides == other.iMySides
            && iMyNumber == other.iMyNumber
            && myName.equals( other.myName );
}
```

the instanceof Operator

- `instanceof` is a Java keyword.
- part of a boolean statement

```
public boolean equals(Object otherObj)
{  if otherObj instanceof Die
   {    //now go and cast
        // rest of equals method
   }
}
```

- Should not use instanceof in equals methods.
- `instanceof` has its uses but not in equals because of the contract of the equals method

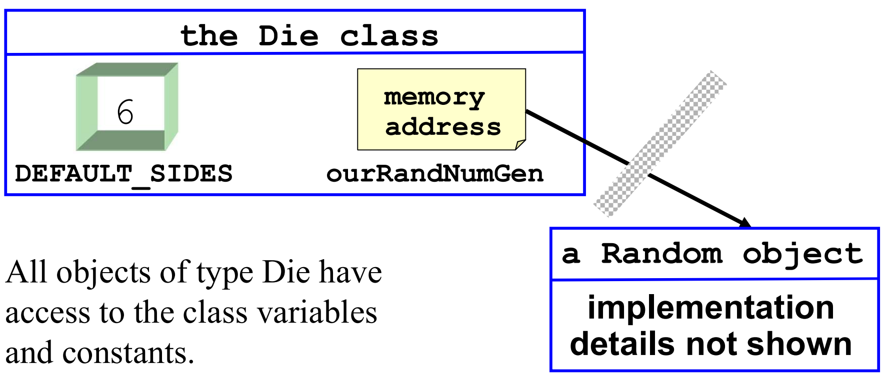
Class Variables and Class Methods

- Sometimes every object of a class does not need its own copy of a variable or constant
- The keyword `static` is used to specify class variables, constants, and methods

```
private static Random ourRandNumGen
   = new Random();
public static final int DEFAULT_SIDES = 6;
```

- The most prevalent use of static is for class constants.
  - if the value can't be changed why should every object have a copy of this non changing value

Class Variables and Constants



All objects of type Die have access to the class variables and constants.

A public class variable or constant may be referred to via the class name.

Syntax for Accessing Class Variables

```
public class UseDieStatic
{  public static void main(String[] args)
   {  System.out.println( "Die.DEFAULT_SIDES "
         + Die.DEFAULT_SIDES );
      // Any attempt to access Die.ourRandNumGen
      // would generate a syntax error

      Die d1 = new Die(10);

      System.out.println( "Die.DEFAULT_SIDES "
         + Die.DEFAULT_SIDES );
      System.out.println( "d1.DEFAULT_SIDES "
         + d1.DEFAULT_SIDES );

      // regardless of the number of Die objects in
      // existence, there is only one copy of DEFAULT_SIDES
      // in the Die class

   } // end of main method
} // end of UseDieStatic class
```

Static Methods

- `static` has a somewhat different meaning when used in a method declaration
- static methods may not manipulate any instance variables
- in non static methods, some object invokes the method

```
d3.roll();
```

- the object that makes the method call is an implicit parameter to the method

Static Methods Continued

- Since there is no implicit object parameter sent to the static method it does not have access to a copy of any objects instance variables
  - unless of course that object is sent as an explicit parameter
- Static methods are normally utility methods or used to manipulate static variables (class variables)
- The Math and System classes are nothing but static methods

static and this

- Why does this work (added to Die class)

```
public class Die
{
     public void outputSelf()
     { System.out.println( this );
     }
}
```

- but this doesn't?

```
public class StaticThis
{
     public static void main(String[] args)
     { System.out.println( this );
     }
}
```