CSE 331

Review of Object-Oriented Programming and Java

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also based on course materials by Stuart Reges
http://www.cs.washington.edu/331/
Summary

• These slides contain material about objects, classes, and object-oriented programming in Java.

• We won't be covering these slides in lecture, but they contain material you are expected to remember from CSE 142 and 143.

• For additional review material, consult Ch. 1-6 of Core Java.
Primitives vs. objects; value and reference semantics
A swap method?

- Does the following `swap` method work? Why or why not?

```java
public static void main(String[] args) {
    int a = 7;
    int b = 35;

    // swap a with b?
    swap(a, b);
    System.out.println(a + " " + b);
}

public static void swap(int a, int b) {
    int temp = a;
    a = b;
    b = temp;
}
```
Value semantics

- **value semantics**: Behavior where values are copied when assigned, passed as parameters, or returned.
  - All primitive types in Java use value semantics.
  - When one variable is assigned to another, its value is copied.
  - Modifying the value of one variable does not affect others.

```java
int x = 5;
int y = x;  // x = 5, y = 5
y = 17;    // x = 5, y = 17
x = 8;     // x = 8, y = 17
```
**Reference semantics (objects)**

- **reference semantics**: Behavior where variables actually store the address of an object in memory.
  - When one variable is assigned to another, the object is *not* copied; both variables refer to the *same object*.
  - Modifying the value of one variable *will* affect others.

```java
int[] a1 = {4, 15, 8};
int[] a2 = a1;  // refer to same array as a1
a2[0] = 7;
System.out.println(Arrays.toString(a1));  // [7, 15, 8]
```
References and objects

- Arrays and objects use reference semantics. Why?
  - *efficiency*. Copying large objects slows down a program.
  - *sharing*. It's useful to share an object's data among methods.

```java
DrawingPanel panel1 = new DrawingPanel(80, 50);
DrawingPanel panel2 = panel1;  // same window
panel2.setBackground(Color.CYAN);
```

![Diagram showing references between panel1 and panel2](image)
Objects as parameters

- When an object is passed as a parameter, the object is *not* copied. The parameter refers to the same object.
  - If the parameter is modified, it *will* affect the original object.

```java
public static void main(String[] args) {
    DrawingPanel window = new DrawingPanel(80, 50);
    window.setBackground(Color.YELLOW);
    example(window);
}

public static void example(DrawingPanel panel) {
    panel.setBackground(Color.CYAN);
    ...
}
```
Arrays as parameters

• Arrays are also passed as parameters by reference.
  ▪ Changes made in the method are also seen by the caller.

```java
class ArrayExample {
    public static void main(String[] args) {
        int[] iq = {126, 167, 95};
        increase(iq);
        System.out.println(Arrays.toString(iq));
    }

    public static void increase(int[] a) {
        for (int i = 0; i < a.length; i++) {
            a[i] = a[i] * 2;
        }
    }

    // Output:
    [252, 334, 190]
}
```

Output:

```
[252, 334, 190]
```
Arrays pass by reference

- Arrays are also passed as parameters by reference.
  - Changes made in the method are also seen by the caller.

```java
public static void main(String[] args) {
    int[] iq = {126, 167, 95};
    increase(iq);
    System.out.println(Arrays.toString(iq));
}
```

```java
public static void increase(int[] a) {
    for (int i = 0; i < a.length; i++) {
        a[i] = a[i] * 2;
    }
}
```

- Output:
  - `[252, 334, 190]`
Classes and Objects
**Objects**

- **object**: An entity that encapsulates data and behavior.
  - **data**: variables inside the object
  - **behavior**: methods inside the object
    - You interact with the methods; the data is hidden in the object.

- Constructing (creating) an object:
  
  ```
  Type objectName = new Type(parameters);
  ```

- Calling an object's method:
  
  ```
  objectName . methodName (parameters);
  ```
Classes

• **class**: A program entity that represents either:
  1. A program / module, or
  2. A template for a new type of objects.

– **object-oriented programming (OOP)**: Programs that perform their behavior as interactions between objects.
  
  – **abstraction**: Separation between concepts and details. Objects and classes provide abstraction in programming.
Blueprint analogy

**iPod blueprint**

**state:**
current song
volume
battery life

**behavior:**
power on/off
change station/song
change volume
choose random song

creates

**iPod #1**

**state:**
song = "1,000,000 Miles"
volume = 17
battery life = 2.5 hrs

**behavior:**
power on/off
change station/song
change volume
choose random song

**iPod #2**

**state:**
song = "Letting You"
volume = 9
battery life = 3.41 hrs

**behavior:**
power on/off
change station/song
change volume
choose random song

**iPod #3**

**state:**
song = "Discipline"
volume = 24
battery life = 1.8 hrs

**behavior:**
power on/off
change station/song
change volume
choose random song
**Point objects**

```java
import java.awt.*;
...
Point p1 = new Point(5, -2);
Point p2 = new Point(); // origin (0, 0)
```

**Data:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>the point's x-coordinate</td>
</tr>
<tr>
<td>y</td>
<td>the point's y-coordinate</td>
</tr>
</tbody>
</table>

**Methods:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>setLocation(x, y)</td>
<td>sets the point's x and y to the given values</td>
</tr>
<tr>
<td>translate(dx, dy)</td>
<td>adjusts the point's x and y by the given amounts</td>
</tr>
<tr>
<td>distance(p)</td>
<td>how far away the point is from point p</td>
</tr>
</tbody>
</table>
The class (blueprint) describes how to create objects.

- Each object contains its own data and methods.
  - The methods operate on that object's data.
Clients of objects

- **client program**: A program that uses objects.
  
  - **Example**: Bomb is a client of DrawingPanel and Graphics.

```java
// Bomb.java (client program)
public class Bomb {
    public static void main(String[] args) {
        new DrawingPanel(...);
        new DrawingPanel(...);
        ...
    }
}

// DrawingPanel.java (class)
public class DrawingPanel {
    ...
}
```
Fields

• **field**: A variable inside an object that is part of its state.
  – Each object has *its own copy* of each field.

• Declaration syntax:

  ```java
  private type name;
  ```

  – Example:

    ```java
    public class Point {
      private int x;
      private int y;

      ...
    }
    ```
Encapsulation

- **encapsulation**: Hiding implementation details from clients.
  - Encapsulation enforces *abstraction*.
    - separates external view (behavior) from internal view (state)
    - protects the integrity of an object's data
Benefits of encapsulation

• Abstraction between object and clients

• Protects object from unwanted access
  ▪ Example: Can't fraudulently increase an Account's balance.

• Can change the class implementation later
  ▪ Example: Point could be rewritten in polar coordinates \((r, \theta)\) with the same methods.

• Can constrain objects' state (invariants)
  ▪ Example: Only allow Accounts with non-negative balance.
  ▪ Example: Only allow Dates with a month from 1-12.
Instance methods

- **instance method (or object method):** Exists inside each object of a class and gives behavior to each object.

  ```java
  public type name(parameters) {
    statements;
  }
  ```

  - same syntax as static methods, but without `static` keyword

Example:

```java
public void translate(int dx, int dy) {
  x += dx;
  y += dy;
}
```
The implicit parameter

- implicit parameter:
The object on which an instance method is being called.

  - If we have a `Point` object `p1` and call `p1.translate(5, 3);` the object referred to by `p1` is the implicit parameter.

  - If we have a `Point` object `p2` and call `p2.translate(4, 1);` the object referred to by `p2` is the implicit parameter.

- The instance method can refer to that object's fields.
  - We say that it executes in the context of a particular object.
  - `translate` can refer to the `x` and `y` of the object it was called on.
Categories of methods

- **accessor**: A method that lets clients examine object state.
  - Examples: `distance, distanceFromOrigin`
  - Often has a non-`void` return type

- **mutator**: A method that modifies an object's state.
  - Examples: `setLocation, translate`

- **helper**: Assists some other method in performing its task.
  - Often declared as private so outside clients cannot call it
The `toString` method

tells Java how to convert an object into a `String` for printing

```java
public String toString() {
    code that returns a String representing this object;
}
```

- Method name, return, and parameters must match exactly.

- Example:

  ```java
  // Returns a String representing this Point.
  public String toString() {
      return "(" + x + ", " + y + ")";
  }
  ```
Constructors

- **constructor**: Initializes the state of new objects.

```java
public type(parameters) {
    statements;
}
```

- runs when the client uses the `new` keyword
- no return type is specified; implicitly "returns" the new object

```java
public class Point {
    private int x;
    private int y;

    public Point(int initialX, int initialY) {
        x = initialX;
        y = initialY;
    }
}
```
Multiple constructors

- A class can have multiple constructors.
  - Each one must accept a unique set of parameters.

- **Example:** A `Point` constructor with no parameters that initializes the point to (0, 0).

```java
// Constructs a new point at (0, 0).
public Point() {
    x = 0;
    y = 0;
}
```
The keyword **this**

- **this**: Refers to the implicit parameter inside your class. *(a variable that stores the object on which a method is called)*

- Refer to a field: `this.field`

- Call a method: `this.method(parameters);`

- One constructor `this(parameters);` can call another:
public class Point {
    private int x;
    private int y;

    public Point() {
        this(0, 0);
    }

    public Point(int x, int y) {
        this.x = x;
        this.y = y;
    }

    ...
}

• Avoids redundancy between constructors
• Only a constructor (not a method) can call another constructor
Comparing objects for equality and ordering
Comparing objects

• The `==` operator does not work well with objects.
  
  `==` compares references to objects, not their state.

  It only produces `true` when you compare an object to itself.

Point `p1` = new `Point(5, 3)`;
Point `p2` = new `Point(5, 3)`;
Point `p3` = `p2`;

// `p1 == p2` is false;
// `p1 == p3` is false;
// `p2 == p3` is true
The `equals` method

- The `equals` method compares the state of objects.

```java
if (str1.equals(str2)) {
    System.out.println("the strings are equal");
}
```

- But if you write a class, its `equals` method behaves like `==`

```java
if (p1.equals(p2)) { // false :-(
    System.out.println("equal");
}
```

- This is the default behavior we receive from class `Object`.
- Java doesn't understand how to compare new classes by default.
The `compareTo` method (10.2)

- The standard way for a Java class to define a comparison function for its objects is to define a `compareTo` method.
  - Example: in the `String` class, there is a method:
    ```java
    public int compareTo(String other)
    ```

- A call of `A.compareTo(B)` will return:
  - a value < 0 if `A` comes "before" `B` in the ordering,
  - a value > 0 if `A` comes "after" `B` in the ordering,
  - or 0 if `A` and `B` are considered "equal" in the ordering.
Using compareTo

• `compareTo` can be used as a test in an `if` statement.

```java
String a = "alice";
String b = "bob";
if (a.compareTo(b) < 0) { // true
    ...
}
```

<table>
<thead>
<tr>
<th>Primitives</th>
<th>Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>if (a &lt; b) { ...</td>
<td>if (a.compareTo(b) &lt; 0) { ...</td>
</tr>
<tr>
<td>if (a &lt;= b) { ...</td>
<td>if (a.compareTo(b) &lt;= 0) { ...</td>
</tr>
<tr>
<td>if (a == b) { ...</td>
<td>if (a.compareTo(b) == 0) { ...</td>
</tr>
<tr>
<td>if (a != b) { ...</td>
<td>if (a.compareTo(b) != 0) { ...</td>
</tr>
<tr>
<td>if (a &gt;= b) { ...</td>
<td>if (a.compareTo(b) &gt;= 0) { ...</td>
</tr>
<tr>
<td>if (a &gt; b) { ...</td>
<td>if (a.compareTo(b) &gt; 0) { ...</td>
</tr>
</tbody>
</table>
compareTo and collections

- You can use an array or list of strings with Java's included binary search method because it calls `compareTo` internally.

```java
String[] a = {"al", "bob", "cari", "dan", "mike"};
int index = Arrays.binarySearch(a, "dan"); // 3
```

- Java's `TreeSet/Map` use `compareTo` internally for ordering.

```java
Set<String> set = new TreeSet<String>();
for (String s : a) {
    set.add(s);
}
System.out.println(s);
// [al, bob, cari, dan, mike]
```
public interface Comparable<E> {
    public int compareTo(E other);
}

- A class can implement the Comparable interface to define a natural ordering function for its objects.

- A call to your compareTo method should return:
  a value < 0 if this object comes "before" the other object,
  a value > 0 if this object comes "after" the other object,
  or 0 if this object is considered "equal" to the other.

- If you want multiple orderings, use a Comparator instead (see Ch. 13.1)
Comparable template

public class name implements Comparable<name> {

    ...

    public int compareTo(name other) {
        ...
    }
}
Comparable example

```java
public class Point implements Comparable<Point> {
    private int x;
    private int y;
    ...

    // sort by x and break ties by y
    public int compareTo(Point other) {
        if (x < other.x) {
            return -1;
        } else if (x > other.x) {
            return 1;
        } else if (y < other.y) {
            return -1;  // same x, smaller y
        } else if (y > other.y) {
            return 1;  // same x, larger y
        } else {
            return 0;  // same x and same y
        }
    }
}
```
compareTo tricks

• *subtraction trick* - Subtracting related numeric values produces the right result for what you want `compareTo` to return:

```java
// sort by x and break ties by y
public int compareTo(Point other) {
    if (x != other.x) {
        return x - other.x;  // different x
    } else {
        return y - other.y;  // same x; compare y
    }
}
```

- The idea:
  - if `x > other.x`, then `x - other.x > 0`
  - if `x < other.x`, then `x - other.x < 0`
  - if `x == other.x`, then `x - other.x == 0`

- NOTE: This trick doesn't work for *doubles* (but see `Math.signum`)
**compareTo tricks 2**

- **delegation trick** - If your object's fields are comparable (such as strings), use their `compareTo` results to help you:

```java
// sort by employee name, e.g. "Jim" < "Susan"
public int compareTo(Employee other) {
    return name.compareTo(other.getName());
}
```

- **toString trick** - If your object's `toString` representation is related to the ordering, use that to help you:

```java
// sort by date, e.g. "09/19" > "04/01"
public int compareTo(Date other) {
    return toString().compareTo(other.toString());
}
```
Inheritance
Inheritance

- **inheritance**: Forming new classes based on existing ones.
  - a way to share/reuse code between two or more classes
  - **superclass**: Parent class being extended.
  - **subclass**: Child class that inherits behavior from superclass.
    - gets a copy of every field and method from superclass
  - **is-a relationship**: Each object of the subclass also "is a(n)" object of the superclass and can be treated as one.
public class name extends superclass {

- Example:

  public class Lawyer extends Employee {
      ...
  }

  By extending Employee, each Lawyer object now:
  - receives a copy of each method from Employee automatically
  - can be treated as an Employee by client code

- Lawyer can also replace ("override") behavior from Employee.
Overriding Methods

• **override**: To write a new version of a method in a subclass that replaces the superclass's version.
  - No special syntax required to override a superclass method. Just write a new version of it in the subclass.

```java
public class Lawyer extends Employee {
    // overrides getVacationForm in Employee class
    public String getVacationForm() {
        return "pink";
    }
    ...
}
```
The super keyword

- A subclass can call its parent's method/constructor:

```
super.method(parameters) // method
super(parameters); // constructor
```

```
public class Lawyer extends Employee {
    public Lawyer(String name) {
        super(name);
    }

    // give Lawyers a $5K raise (better)
    public double getSalary() {
        double baseSalary = super.getSalary();
        return baseSalary + 5000.00;
    }
}
```
Subclasses and fields

public class Employee {
    private double salary;
    ...
}

public class Lawyer extends Employee {
    ...
    public void giveRaise(double amount) {
        salary += amount; // error; salary is private
    }
}

• Inherited private fields/methods cannot be directly accessed by subclasses. (The subclass has the field, but it can't touch it.)
  ▪ How can we allow a subclass to access/modify these fields?
protected type name;    // field
protected type name(type name, ...., type name) {
    statement(s);        // method
}

• A **protected field** or **method** can be seen/called only by:
  ▪ the class itself, and its subclasses
  ▪ also by other classes in the same "package" (discussed later)
  ▪ useful for allowing selective access to inner class implementation

public class Employee {
    protected double salary;
    ...
}
Inheritance and constructors

• If we add a constructor to the `Employee` class, our subclasses do not compile. The error:

```
Lawyer.java:2: cannot find symbol
  symbol : constructor Employee()
location: class Employee
public class Lawyer extends Employee {
  ^
```

- The short explanation: Once we write a constructor (that requires parameters) in the superclass, we must now write constructors for our employee subclasses as well.
Inheritance and constructors

- Constructors are not inherited.
  - Subclasses don't inherit the `Employee(int)` constructor.
  - Subclasses receive a default constructor that contains:
    
    ```java
    public Lawyer() {
        super();  // calls Employee() constructor
    }
    ```

- But our `Employee(int)` replaces the default `Employee()`.
  - The subclasses' default constructors are now trying to call a non-existent default `Employee` constructor.
Calling superclass constructor

super(parameters);

- Example:
  public class Lawyer extends Employee {
      public Lawyer(int years) {
          super(years); // calls Employee c'tor
      }
      ...
  }

- The super call must be the first statement in the constructor.
Polymorphism
Polymorphism

- **polymorphism**: Ability for the same code to be used with different types of objects and behave differently with each.

  - `System.out.println` can print any type of object.
    - Each one displays in its own way on the console.

  - `CritterMain` can interact with any type of critter.
    - Each one moves, fights, etc. in its own way.
Coding with polymorphism

• A variable of type $T$ can hold an object of any subclass of $T$.

```java
Employee ed = new Lawyer();
```

- You can call any methods from the Employee class on `ed`.

• When a method is called on `ed`, it behaves as a Lawyer.

```java
System.out.println(ed.getSalary()); // 50000.0
System.out.println(ed.getVacationForm()); // pink
```
Polymorphic parameters

- You can pass any subtype of a parameter's type.

```java
public static void main(String[] args) {
    Lawyer lisa = new Lawyer();
    Secretary steve = new Secretary();
    printInfo(lisa);
    printInfo(steve);
}

public static void printInfo(Employee e) {
    System.out.println("pay : " + e.getSalary());
    System.out.println("vdays: " + e.getVacationDays());
    System.out.println("vform: " + e.getVacationForm());
    System.out.println();
}
```

OUTPUT:

```
pay : 50000.0 pay : 50000.0
vdays: 15 vdays: 10
vform: pink vform: yellow
```
Polymorphism and arrays

- Arrays of superclass types can store any subtype as elements.

```java
public static void main(String[] args) {
    Employee[] e = {new Lawyer(), new Secretary(),
                    new Marketer(), new LegalSecretary()};

    for (int i = 0; i < e.length; i++) {
        System.out.println("pay : " + e[i].getSalary());
        System.out.println("vdays: " + i].getVacationDays());
        System.out.println();
    }
}
```

Output:

```
pay : 50000.0     pay : 60000.0
vdays: 15        vdays: 10
pay : 50000.0     pay : 55000.0
vdays: 10        vdays: 10
```
Casting references

- A variable can only call that type's methods, not a subtype's.

```java
Employee ed = new Lawyer();
int hours = ed.getHours();  // ok; in Employee
ed.sue();  // compiler error
```

- The compiler's reasoning is, variable `ed` could store any kind of employee, and not all kinds know how to `sue`.

- To use `Lawyer` methods on `ed`, we can type-cast it.

```java
Lawyer theRealEd = (Lawyer) ed;
theRealEd.sue();  // ok
((Lawyer) ed).sue();  // shorter version
```
More about casting

• The code crashes if you cast an object too far down the tree.

```java
Employee eric = new Secretary();
((Secretary) eric).takeDictation("hi"); // ok
((LegalSecretary) eric).fileLegalBriefs(); // error
// (Secretary doesn't know how to file briefs)
```

• You can cast only up and down the tree, not sideways.

```java
Lawyer linda = new Lawyer();
((Secretary) linda).takeDictation("hi"); // error
```

• Casting doesn't actually change the object's behavior. It just gets the code to compile/run.

```java
((Employee) linda).getVacationForm() // pink
```
Interfaces
Shapes example

- Consider the task of writing classes to represent 2D shapes such as Circle, Rectangle, and Triangle.

- Certain operations are common to all shapes:
  - perimeter: distance around the outside of the shape
  - area: amount of 2D space occupied by the shape

  - Every shape has these, but each computes them differently.
Shape area and perimeter

- Circle (as defined by radius $r$):
  
  area $= \pi r^2$
  
  perimeter $= 2 \pi r$

- Rectangle (as defined by width $w$ and height $h$):
  
  area $= w \times h$
  
  perimeter $= 2w + 2h$

- Triangle (as defined by side lengths $a$, $b$, and $c$):
  
  area $= \sqrt{s(s-a)(s-b)(s-c)}$
  
  where $s = \frac{1}{2} (a + b + c)$
  
  perimeter $= a + b + c$
Common behavior

• Suppose we have 3 classes Circle, Rectangle, Triangle.
  ▪ Each has the methods perimeter and area.

• We'd like our client code to be able to treat different kinds of shapes in the same way:
  ▪ Write a method that prints any shape's area and perimeter.
  ▪ Create an array to hold a mixture of the various shape objects.
  ▪ Write a method that could return a rectangle, a circle, a triangle, or any other kind of shape.
  ▪ Make a DrawingPanel display many shapes on screen.
Interfaces

- **interface**: A list of methods that a class can promise to implement.
  - Inheritance gives you an is-a relationship *and* code sharing.
    - A *Lawyer* can be treated as an *Employee* and inherits its code.
  - Interfaces give you an is-a relationship *without* code sharing.
    - A *Rectangle* object can be treated as a *Shape* but inherits no code.
  - Analogous to non-programming idea of roles or certifications:
    - "I'm certified as a CPA accountant. This assures you I know how to do taxes, audits, and consulting."
    - "I'm 'certified' as a Shape, because I implement the Shape interface. This assures you I know how to compute my area and perimeter."
public interface name {
    public type name(type name, ..., type name);
    public type name(type name, ..., type name);
    ...
    public type name(type name, ..., type name);
}

Example:
public interface Vehicle {
    public int getSpeed();
    public void setDirection(int direction);
}
Shape interface

// Describes features common to all shapes.
public interface Shape {
    public double area();
    public double perimeter();
}

- Saved as Shape.java

- abstract method: A header without an implementation.
  - The actual bodies are not specified, because we want to allow each class to implement the behavior in its own way.
Implementing an interface

```java
public class name implements interface {
    ...
}
```

- A class can declare that it "implements" an interface.
  - The class promises to contain each method in that interface.
    (Otherwise it will fail to compile.)

- Example:
  ```java
  public class Bicycle implements Vehicle {
      ...
  }
  ```
If we write a class that claims to be a **Shape** but doesn't implement **area** and **perimeter** methods, it will not compile.

Banana.java:1: Banana is not abstract and does not override abstract method area() in Shape
public class Banana implements Shape {
  // haha, no methods! pwned
}
Interfaces + polymorphism

- Interfaces benefit the *client code* author the most.
  - they allow **polymorphism**
    (the same code can work with different types of objects)

```java
public static void printInfo(Shape s) {
    System.out.println("The shape: " + s);
    System.out.println("area: " + s.area());
    System.out.println("perim: " + s.perimeter());
    System.out.println();
}

Circle circ = new Circle(12.0);
Triangle tri = new Triangle(5, 12, 13);
printInfo(circ);
printInfo(tri);
```
Abstract Classes
Suppose we have implemented the following two list classes:

- **ArrayList**

<table>
<thead>
<tr>
<th>index</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>value</td>
<td>42</td>
<td>-3</td>
<td>17</td>
</tr>
</tbody>
</table>

- **LinkedList**

We have a `List` interface to indicate that both implement a List ADT.

**Problem:**
- Some of their methods are implemented the same way (redundancy).
• Notice that some of the methods are implemented the same way in both the array and linked list classes.
  - add(value)
  - contains
  - isEmpty

• Should we change our interface to a class? Why / why not?
  - How can we capture this common behavior?
Abstract classes (9.6)

- **abstract class**: A hybrid between an interface and a class.
  - defines a superclass type that can contain method declarations (like an interface) and/or method bodies (like a class)
  - like interfaces, abstract classes that cannot be instantiated (cannot use `new` to create any objects of their type)

- What goes in an abstract class?
  - implementation of common state and behavior that will be inherited by subclasses (parent class role)
  - declare generic behaviors that subclasses implement (interface role)
Abstract class syntax

// declaring an abstract class
public abstract class name {
    ...

    // declaring an abstract method
    // (any subclass must implement it)
    public abstract type name(parameters);
}

- A class can be abstract even if it has no abstract methods
- You can create variables (but not objects) of the abstract type
Abstract and interfaces

- Normal classes that claim to implement an interface must implement all methods of that interface:
  
  ```java
  public class Empty implements List {}
  // error
  ```

- Abstract classes can claim to implement an interface without writing its methods; subclasses must implement the methods.
  
  ```java
  public abstract class Empty implements List {}
  // ok

  public class Child extends Empty {}
  // error
  ```
An abstract list class

// Superclass with common code for a list of integers.
public abstract class AbstractList implements List {
    public void add(int value) {
        add(size(), value);
    }

    public boolean contains(int value) {
        return indexOf(value) >= 0;
    }

    public boolean isEmpty() {
        return size() == 0;
    }
}

public class ArrayList extends AbstractList {
    ...
}

public class LinkedList extends AbstractList {
    ...
}
Abstract class vs. interface

- Why do both interfaces and abstract classes exist in Java?
  - An abstract class can do everything an interface can do and more.
  - So why would someone ever use an interface?

- Answer: Java has single inheritance.
  - can extend only one superclass
  - can implement many interfaces
  - Having interfaces allows a class to be part of a hierarchy (polymorphism) without using up its inheritance relationship.
Inner Classes
Inner classes

- **inner class**: A class defined inside of another class.
  - can be created as `static` or non-static
  - we will focus on standard non-static ("nested") inner classes

- usefulness:
  - inner classes are hidden from other classes (encapsulated)
  - inner objects can access/modify the fields of the outer object
// outer (enclosing) class
public class name {
  ...

  // inner (nested) class
  private class name {
    ...
  }
}

- Only this file can see the inner class or make objects of it.
- Each inner object is associated with the outer object that created it, so it can access/modify that outer object's methods/fields.
  - If necessary, can refer to outer object as OuterClassName.this
Example: Array list iterator

```java
public class ArrayList extends AbstractList {
    ...
    // not perfect; doesn't forbid multiple removes in a row
    private class ArrayIterator implements Iterator<Integer> {
        private int index; // current position in list
        public ArrayIterator() {
            index = 0;
        }
        public boolean hasNext() {
            return index < size();
        }
        public E next() {
            index++;
            return get(index - 1);
        }
        public void remove() {
            ArrayList.this.remove(index - 1);
            index--;
        }
    }
}
```
Collections
Collections

- **collection**: an object that stores data; a.k.a. "data structure"
  - the objects stored are called **elements**
  - some collections maintain an ordering; some allow duplicates
  - typical operations: *add, remove, clear, contains* (search), *size*

- examples found in the Java class libraries:
  - `ArrayList`, `LinkedList`, `HashMap`, `TreeSet`, `PriorityQueue`

- all collections are in the `java.util` package
  
  ```java
  import java.util.*;
  ```
Java collection framework
Lists

- **list**: a collection storing an ordered sequence of elements
  - each element is accessible by a 0-based **index**
  - a list has a **size** (number of elements that have been added)
  - elements can be added to the front, back, or elsewhere
  - in Java, a list can be represented as an **ArrayList** object
Idea of a list

• Rather than creating an array of boxes, create an object that represents a "list" of items. (initially an empty list.)

  []

• You can add items to the list.
  ▪ The default behavior is to add to the end of the list.

    [hello, ABC, goodbye, okay]

• The list object keeps track of the element values that have been added to it, their order, indexes, and its total size.
  ▪ Think of an "array list" as an automatically resizing array object.
  ▪ Internally, the list is implemented using an array and a size field.
## ArrayList methods (10.1)

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>add(value)</code></td>
<td>appends value at end of list</td>
</tr>
<tr>
<td><code>add(index, value)</code></td>
<td>inserts given value just before the given index, shifting subsequent values to the right</td>
</tr>
<tr>
<td><code>clear()</code></td>
<td>removes all elements of the list</td>
</tr>
<tr>
<td><code>indexOf(value)</code></td>
<td>returns first index where given value is found in list (-1 if not found)</td>
</tr>
<tr>
<td><code>get(index)</code></td>
<td>returns the value at given index</td>
</tr>
<tr>
<td><code>remove(index)</code></td>
<td>removes/returns value at given index, shifting subsequent values to the left</td>
</tr>
<tr>
<td><code>set(index, value)</code></td>
<td>replaces value at given index with given value</td>
</tr>
<tr>
<td><code>size()</code></td>
<td>returns the number of elements in list</td>
</tr>
<tr>
<td><code>toString()</code></td>
<td>returns a string representation of the list such as &quot;[3, 42, -7, 15]&quot;</td>
</tr>
</tbody>
</table>
# ArrayList methods 2

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>addAll(list)</code></td>
<td>adds all elements from the given list to this list (at the end of the list, or inserts them at the given index)</td>
</tr>
<tr>
<td><code>addAll(index, list)</code></td>
<td></td>
</tr>
<tr>
<td><code>contains(value)</code></td>
<td>returns true if given value is found somewhere in this list</td>
</tr>
<tr>
<td><code>containsAll(list)</code></td>
<td>returns true if this list contains every element from given list</td>
</tr>
<tr>
<td><code>equals(list)</code></td>
<td>returns true if given other list contains the same elements</td>
</tr>
<tr>
<td><code>iterator()</code></td>
<td>returns an object used to examine the contents of the list</td>
</tr>
<tr>
<td><code>listIterator()</code></td>
<td></td>
</tr>
<tr>
<td><code>lastIndexOf(value)</code></td>
<td>returns last index value is found in list (-1 if not found)</td>
</tr>
<tr>
<td><code>remove(value)</code></td>
<td>finds and removes the given value from this list</td>
</tr>
<tr>
<td><code>removeAll(list)</code></td>
<td>removes any elements found in the given list from this list</td>
</tr>
<tr>
<td><code>retainAll(list)</code></td>
<td>removes any elements <em>not</em> found in given list from this list</td>
</tr>
<tr>
<td><code>subList(from, to)</code></td>
<td>returns the sub-portion of the list between indexes <em>from</em> (inclusive) and <em>to</em> (exclusive)</td>
</tr>
<tr>
<td><code>toArray()</code></td>
<td>returns the elements in this list as an array</td>
</tr>
</tbody>
</table>
List<Type> name = new ArrayList<Type>();

• When constructing an ArrayList, you must specify the type of elements it will contain between < and >.
  ▪ This is called a type parameter or a generic class.
  ▪ Allows the same ArrayList class to store lists of different types.

List<String> names = new ArrayList<String>();
names.add("Marty Stepp");
names.add("Stuart Reges");
Stacks and queues

- Sometimes it is good to have a collection that is less powerful, but is optimized to perform certain operations very quickly.

- Two specialty collections:
  - **stack**: Retrieves elements in the reverse of the order they were added.
  - **queue**: Retrieves elements in the same order they were added.
Stacks

- **stack**: A collection based on the principle of adding elements and retrieving them in the opposite order.
  - Last-In, First-Out ("LIFO")
  - The elements are stored in order of insertion, but we do not think of them as having indexes.
  - The client can only add/remove/examine the last element added (the "top").

- basic stack operations:
  - **push**: Add an element to the top.
  - **pop**: Remove the top element.
  - **peek**: Examine the top element.
Class Stack

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack&lt;\texttt{E}&gt;()</td>
<td>constructs a new stack with elements of type \texttt{E}</td>
</tr>
<tr>
<td>\texttt{push(value)}</td>
<td>places given value on top of stack</td>
</tr>
<tr>
<td>\texttt{pop()}</td>
<td>removes top value from stack and returns it; \texttt{throws EmptyStackException} if stack is empty</td>
</tr>
<tr>
<td>\texttt{peek()}</td>
<td>returns top value from stack without removing it; \texttt{throws EmptyStackException} if stack is empty</td>
</tr>
<tr>
<td>\texttt{size()}</td>
<td>returns number of elements in stack</td>
</tr>
<tr>
<td>\texttt{isEmpty()}</td>
<td>returns true if stack has no elements</td>
</tr>
</tbody>
</table>

Stack<\texttt{Integer}> s = new Stack<\texttt{Integer}>();
s.push(42);
s.push(-3);
s.push(17);    // bottom [42, -3, 17] top
System.out.println(s.pop());    // 17

- Stack has other methods, but you should not use them.
Queues

- **queue**: Retrieves elements in the order they were added.
  - First-In, First-Out ("FIFO")
  - Elements are stored in order of insertion but don't have indexes.
  - Client can only add to the end of the queue, and can only examine/remove the front of the queue.

- **basic queue operations**:
  - **add** (enqueue): Add an element to the back.
  - **remove** (dequeue): Remove the front element.
  - **peek**: Examine the front element.
## Programming with Queues

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>add(value)</code></td>
<td>places given value at back of queue</td>
</tr>
<tr>
<td><code>remove()</code></td>
<td>removes value from front of queue and returns it; throws a NoSuchElementException if queue is empty</td>
</tr>
<tr>
<td><code>peek()</code></td>
<td>returns front value from queue without removing it; returns null if queue is empty</td>
</tr>
<tr>
<td><code>size()</code></td>
<td>returns number of elements in queue</td>
</tr>
<tr>
<td><code>isEmpty()</code></td>
<td>returns true if queue has no elements</td>
</tr>
</tbody>
</table>

```java
Queue<Integer> q = new LinkedList<Integer>();
q.add(42);
qu.add(-3);
qu.add(17); // front [42, -3, 17] back
System.out.println(q.remove()); // 42
```

- **IMPORTANT**: When constructing a queue you must use a new LinkedList object instead of a new Queue object.
Queue idioms

• As with stacks, must pull contents out of queue to view them.

  // process (and destroy) an entire queue
  while (!q.isEmpty()) {
    do something with q.remove();
  }

  another idiom: Examining each element exactly once.

  int size = q.size();
  for (int i = 0; i < size; i++) {
    do something with q.remove();
    (including possibly re-adding it to the queue)
  }
Abstract data types (ADTs)

- **abstract data type (ADT):** A specification of a collection of data and the operations that can be performed on it.
  - Describes *what* a collection does, not *how* it does it

- We don't know exactly how a stack or queue is implemented, and we don't need to.
  - We just need to understand the idea of the collection and what operations it can perform.

(Stacks are usually implemented with arrays; queues are often implemented using another structure called a linked list.)
ADTs as interfaces (11.1)

- **abstract data type (ADT):** A specification of a collection of data and the operations that can be performed on it.
  - Describes *what* a collection does, not *how* it does it.

- Java's collection framework uses interfaces to describe ADTs:
  - Collection, Deque, List, Map, Queue, Set

- An ADT can be implemented in multiple ways by classes:
  - ArrayList and LinkedList implement List
  - HashSet and TreeSet implement Set
  - LinkedList, ArrayDeque, etc. implement Queue

- They messed up on Stack; there's no Stack interface, just a class.
Using ADT interfaces

When using Java's built-in collection classes:

• It is considered good practice to always declare collection variables using the corresponding ADT interface type:

  ```java
  List<String> list = new ArrayList<String>();
  ```

• Methods that accept a collection as a parameter should also declare the parameter using the ADT interface type:

  ```java
  public void stutter(List<String> list) {
      ...
  }
  ```
Why use ADTs?

• Why would we want more than one kind of list, queue, etc.?

• Answer: Each implementation is more efficient at certain tasks.
  
  ▪ **ArrayList** is faster for adding/removing at the end;
  ▪ **LinkedList** is faster for adding/removing at the front/middle.
  ▪ Etc.

• You choose the optimal implementation for your task, and if the rest of your code is written to use the ADT interfaces, it will work.
Sets

- **set**: A collection of unique values (no duplicates allowed) that can perform the following operations efficiently:
  - add, remove, search (contains)

- We don't think of a set as having indexes; we just add things to the set in general and don't worry about order.

```java
set.contains("to")  // true
set.contains("be")  // false
```
Set implementation

- in Java, sets are represented by `Set` interface in `java.util`

- `Set` is implemented by `HashSet` and `TreeSet` classes

  - `HashSet`: implemented using a "hash table" array; very fast: $O(1)$ for all operations; elements are stored in unpredictable order

  - `TreeSet`: implemented using a "binary search tree"; pretty fast: $O(\log N)$ for all operations; elements are stored in sorted order

  - `LinkedHashSet`: $O(1)$ but stores in order of insertion
Set methods

List<String> list = new ArrayList<String>();
...
Set<Integer> set = new TreeSet<Integer>(); // empty
Set<String> set2 = new HashSet<String>(list);

- can construct an empty set, or one based on a given collection

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>add(value)</td>
<td>adds the given value to the set</td>
</tr>
<tr>
<td>contains(value)</td>
<td>returns true if the given value is found in this set</td>
</tr>
<tr>
<td>remove(value)</td>
<td>removes the given value from the set</td>
</tr>
<tr>
<td>clear()</td>
<td>removes all elements of the set</td>
</tr>
<tr>
<td>size()</td>
<td>returns the number of elements in list</td>
</tr>
<tr>
<td>isEmpty()</td>
<td>returns true if the set's size is 0</td>
</tr>
<tr>
<td>toString()</td>
<td>returns a string such as &quot;[3, 42, -7, 15]&quot;</td>
</tr>
</tbody>
</table>
## Set operations

### Set Operations Table

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>addAll(collection)</code></td>
<td>Adds all elements from the given collection to this set</td>
</tr>
<tr>
<td><code>containsAll(coll)</code></td>
<td>Returns <code>true</code> if this set contains every element from given set</td>
</tr>
<tr>
<td><code>equals(set)</code></td>
<td>Returns <code>true</code> if given other set contains the same elements</td>
</tr>
<tr>
<td><code>iterator()</code></td>
<td>Returns an object used to examine set's contents <em>(seen later)</em></td>
</tr>
<tr>
<td><code>removeAll(coll)</code></td>
<td>Removes all elements in the given collection from this set</td>
</tr>
<tr>
<td><code>retainAll(coll)</code></td>
<td>Removes elements <em>not</em> found in given collection from this set</td>
</tr>
<tr>
<td><code>toArray()</code></td>
<td>Returns an array of the elements in this set</td>
</tr>
</tbody>
</table>

### Venn Diagrams

- **Union** (`A ∪ B`): All elements from set `A` and set `B`.
- **Intersection** (`A ∩ B`): Elements common to both sets.
- **Difference** (`A - B`): Elements in `A` but not in `B`.

### Examples

- **Union**: If set `A` = `{1, 2, 3}` and set `B` = `{3, 4, 5}`, then `A ∪ B` = `{1, 2, 3, 4, 5}`.
- **Intersection**: If set `A` = `{1, 2, 3}` and set `B` = `{3, 4, 5}`, then `A ∩ B` = `{3}`.
- **Difference**: If set `A` = `{1, 2, 3}` and set `B` = `{3, 4, 5}`, then `A - B` = `{1, 2}`.
Sets and ordering

- **HashSet**: elements are stored in an unpredictable order
  
  ```java
  Set<String> names = new HashSet<String>();
  names.add("Jake");
  names.add("Robert");
  names.add("Marisa");
  names.add("Kasey");
  System.out.println(names);
  // [Kasey, Robert, Jake, Marisa]
  ```

- **TreeSet**: elements are stored in their "natural" sorted order
  
  ```java
  Set<String> names = new TreeSet<String>();
  ...
  // [Jake, Kasey, Marisa, Robert]
  ```

- **LinkedHashSet**: elements stored in order of insertion
  
  ```java
  Set<String> names = new LinkedHashSet<String>();
  ...
  // [Jake, Robert, Marisa, Kasey]
  ```
The "for each" loop (7.1)

```java
for (type name : collection) {
    statements;
}
```

- Provides a clean syntax for looping over the elements of a Set, List, array, or other collection

```java
Set<Double> grades = new HashSet<Double>();
...

for (double grade : grades) {
    System.out.println("Student's grade: " + grade);
}
```

- needed because sets have no indexes; can't get element i
The Map ADT

- **map**: Holds a set of unique keys and a collection of values, where each key is associated with one value.
  - a.k.a. "dictionary", "associative array", "hash"

- **basic map operations**:
  - **put**(key, value): Adds a mapping from a key to a value.
  - **get**(key): Retrieves the value mapped to the key.
  - **remove**(key): Removes the given key and its mapped value.

```java
myMap.get("Juliet") returns "Capulet"
```
Map concepts

- A map can be thought of as a generalization of a tallying array.
  - The "index" (key) doesn't have to be an int.

- Recall previous tallying examples from CSE 142.
  - Count digits: 22092310907
    - Index: 0 1 2 3 4 5 6 7 8 9
    - Value: 3 1 3 0 0 0 0 1 0 2

  // (M)cCain, (O)bama, (I)ndependent
  - Count votes: "MOOOOOOONMMMMO000000MOMMIMOMMIMOMMI0"

<table>
<thead>
<tr>
<th>Key</th>
<th>&quot;M&quot;</th>
<th>&quot;O&quot;</th>
<th>&quot;I&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>16</td>
<td>14</td>
<td>3</td>
</tr>
</tbody>
</table>
Map implementation

- in Java, maps are represented by `Map` interface in `java.util`

- `Map` is implemented by the `HashMap` and `TreeMap` classes
  - `HashMap`: implemented using an array called a "hash table"; extremely fast: $O(1)$; keys are stored in unpredictable order
  - `TreeMap`: implemented as a linked "binary tree" structure; very fast: $O(\log N)$; keys are stored in sorted order

- A map requires 2 type parameters: one for keys, one for values.

```java
// maps from String keys to Integer values
Map<String, Integer> votes = new HashMap<String, Integer>();
```
Map methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>put(key, value)</code></td>
<td>adds a mapping from the given key to the given value; if the key already exists, replaces its value with the given one</td>
</tr>
<tr>
<td><code>get(key)</code></td>
<td>returns the value mapped to the given key (null if not found)</td>
</tr>
<tr>
<td><code>containsKey(key)</code></td>
<td>returns true if the map contains a mapping for the given key</td>
</tr>
<tr>
<td><code>remove(key)</code></td>
<td>removes any existing mapping for the given key</td>
</tr>
<tr>
<td><code>clear()</code></td>
<td>removes all key/value pairs from the map</td>
</tr>
<tr>
<td><code>size()</code></td>
<td>returns the number of key/value pairs in the map</td>
</tr>
<tr>
<td><code>isEmpty()</code></td>
<td>returns true if the map's size is 0</td>
</tr>
<tr>
<td><code>toString()</code></td>
<td>returns a string such as &quot;{a=90, d=60, c=70}&quot;</td>
</tr>
<tr>
<td><code>keySet()</code></td>
<td>returns a set of all keys in the map</td>
</tr>
<tr>
<td><code>values()</code></td>
<td>returns a collection of all values in the map</td>
</tr>
<tr>
<td><code>putAll(map)</code></td>
<td>adds all key/value pairs from the given map to this map</td>
</tr>
<tr>
<td><code>equals(map)</code></td>
<td>returns true if given map has the same mappings as this one</td>
</tr>
</tbody>
</table>
Using maps

- A map allows you to get from one half of a pair to the other.
  - Remembers one piece of information about every index (key).

```java
// key     value
put("Joe", "206-685-2181")
```

- Later, we can supply only the key and get back the related value:

  Allows us to ask: *What is Joe's phone number?*

```java
get("Joe")
```

```
"206-685-2181"
```
Maps vs. sets

- A set is like a map from elements to boolean values.
  - Set: Is Joe found in the set? (true/false)
  - Map: What is Joe's phone number?

```
Set:  "Joe" -> true
Map:  "Joe" -> "206-685-2181"
```
keySet and values

- **keySet** method returns a Set of all keys in the map
  - can loop over the keys in a foreach loop
  - can get each key's associated value by calling `get` on the map

```java
Map<String, Integer> ages = new TreeMap<String, Integer>();
ages.put("Joe", 19);
ages.put("Geneva", 2);  // ages.keySet() returns Set<String>
ages.put("Vicki", 57);
for (String name : ages.keySet()) {
    int age = ages.get(name);
    System.out.println(name + " -> " + age);  // Geneva -> 2
}  // Joe -> 19
```  // Vicki -> 57

- **values** method returns a collection of all values in the map
  - can loop over the values in a foreach loop
  - no easy way to get from a value to its associated key(s)
Priority queue ADT

- **priority queue**: a collection of ordered elements that provides fast access to the minimum (or maximum) element
  - usually implemented using a tree structure called a *heap*

- **priority queue operations**:
  - `add`: adds in order; \( \text{O}(\log \, N) \) worst
  - `peek`: returns **minimum** value; \( \text{O}(1) \) always
  - `remove`: removes/returns **minimum** value; \( \text{O}(\log \, N) \) worst
  - `isEmpty`, `clear`, `size`, `iterator`: \( \text{O}(1) \) always
Java's PriorityQueue class

```java
public class PriorityQueue<E> implements Queue<E> {

    Queue<String> pq = new PriorityQueue<String>();
pq.add("Stuart");
pq.add("Marty");
...}
```
Priority queue ordering

- For a priority queue to work, elements must have an ordering
  - in Java, this means implementing the `Comparable` interface

- Reminder:

```java
public class Foo implements Comparable<Foo> {
    ...
    public int compareTo(Foo other) {
        // Return positive, zero, or negative number
    }
}
```