Java classes can be arranged in a large program in different ways. Classes can be in packages, local to methods, or members of other classes. This type of program organization is an important part of developing a large program.

There is another important, but completely different, way of organizing classes. It is possible to organize classes by the behavior of their instances. It is possible to take advantage of common behavior in objects in a program. By organizing classes in the class hierarchy one can increase flexibility and code reuse.
All Java classes are organized structurally in a hierarchy or tree with the class `Object` (cf the API) as the ancestor or root of all classes.
The relationship between two classes is thought of as being

“is a”

— as in a pencil is a kind of writing instrument.

The wider more general concept (writing instrument) contains all of the more specialized items (all pencils) plus potentially a lot more (fountain pens, chalk, and so on).
Organization of Classes

Any number of levels in the hierarchy. And no cycles.
Each class has one superclass; but any number of subclasses can have the same superclass.
Example: Biological Classification

- Animalia
  - Insecta
  - Mammalia
    - Rodentia
    - Primates
      - Lemuridae
      - Hominidae
    - Lepidoptera
Hierarchical Organization
Hierarchical Organization

- **Indo-European**
  - **Indo-Iranian**
    - **Indic**
      - Hindi
    - **Iranian**
      - Persian
      - Pasto
  - **Italic**
    - Spanish
    - French
  - **Balto-Slavic**
    - Slavic
      - Russian
Example: Hierarchical Organization from Java API

- JObjectComponent
  - AbstractButton
    - JButton
  - JLabel
  - JTextComponent
    - JTextArea
    - JTextField
Example: Hierarchical Organization

Object
  /   
Number Faculty
 /     /  
BigDecimal Integer Float
Hierarchical Organization

Point

Rectangle  Circle
The Java class hierarchy is a tree. A *tree* is a kind of structure with a root and the other elements are organized so that each element has one branch connecting it to the root.

1. Every class descends from the class `Object` (the root of the tree).
2. Every class has exactly one superclass (except the class `Object`).
3. No class can descend directly or indirectly from itself.
In Java, the relation or organization of classes is created explicitly by the programmer.

```java
class X extends Y {
}
```

The class X is declared a subclass of the class Y using the `extends` keyword. The `extends` clause is optional and if omitted then a class is declared to be a direct subclass of `Object`. 

Hierarchical Organization

class IndoEuropean { // ...  
class IndoIranian extends IndoEuropean { // ...  
class Indic extends IndoIranian { // ...  
class Hindi extends Indic { // ...  
class Bengali extends Indic { // ...  
class Iranian extends IndoIranian { // ...  
class Persian extends Iranian { // ...  
class Pasto extends Iranian { // ...  
class Italic extends IndoEuropean { // ...  
class Spanish extends Italic { // ...  
class French extends Italic { // ...  
class BaltoSlavic extends IndoEuropean { // ...  
class Slavic extends BaltoSlavic { // ...  
class Russian extends Slavic { // ...
No Multiple Inheritance

// Not syntactically correct!
class X extends Y, Z {
}

This is not allowed because of the conflicts it causes—like having two bosses that require you to do two different things. (Java interfaces – discussed later – can be used to create a kind of multiple superclasses.)
No Cyclic Structure

// Not semantically correct!
class X extends Y {
}

class Y extends X {
}
Hierarchical Organization

Sometimes the problem domain is naturally organized in a tree-like hierarchy. Sometimes the problem domain is not naturally organized like that.
In object-oriented programming we eventually learn the idioms or design patterns to solve different problems using this organization. Note that each class forms an interface, a suite of facilities or methods.
Interface. In general, an interface is the boundary between distinct systems. Specifically, the specification or protocol governing their interaction.
Note that Java uses the keyword interface and has a construct called an interface.
What is the advantage of organizing classes in a tree structure?
What is the advantage of organizing classes in a tree structure?

The answer is flexibility which we call subclass polymorphism. (Polymorphism is a word meaning *many forms.*) An object or instance of a class can be viewed as having more than one type (form).
Subclass Polymorphism

Any object can be viewed as being a kind of Object. (Since Object is at the top of the hierarchy.) This means it has the collection of methods or interface as does any Object.
Object Is A Special Class
The Top of the Hierarchy

class Object {
    public String toString ();
    public boolean equals (Object obj);
    protected Object clone ();   // copy
    public Class<? > getClass (); // meta information
    public void notify ();        // synchronization
    public void wait ();          // synchronization
}
For example, assignment

Object obj;
Number num;

obj = new String (); // string "is-a" object
obj = new Integer (4);
obj = new Float (4.0f);
obj = new ArrayList < String >(); // ArrayList "is-a" object
obj = new int [4]; // int array "is-a" object

num = new Integer (4);
num = new Float (4.0f); // Float "is-a" Number
num = new BigDecimal (4.0d);
num = new Double (7.0d); // Double "is-a" Number
num = 4.0d; // double is sorta a Number (auto-boxing)
Polymorphism

Number num;

num = new String ();  // a string is NOT a Number
num = new ArrayList<String>(); // an ArrayList is NOT a Number
num = new int [4];     // an int array is NOT a Number
num = new Object ();   // an object is NOT a Number

Compile-time, semantic error

incompatible types
Subclass Polymorphism

*Substitution Principle.* A variable of a given type may be assigned a value of any subtype of that type, and a method with a parameter of a given type may be invoked with an argument of any subtype of that type.
Subclass Polymorphism

The flexibility only works one way.

```
Object o = new Integer (4); // OK
Integer i = new Object ();   // Semantic Error: in
```

And remember, primitive types are not technically classes. Yet:

```
Object o = 4;    // autoboxing
Integer i = 4;  // autoboxing
Number n = 4;   // autoboxing
int i = new Integer (4); // auto-unboxing
int i = new Object (); // compilation error
```
Another Example

An instance of a subclass “is-a” instance of the superclass.

class Main {
    public static void Main (String[] args) {
        IndoEuropean[] languages = new IndoEuropean[100];
        languages[0] = new Hindi();
        languages[1] = new Persian();
        languages[2] = new Spanish();
        languages[3] = new French();
        languages[4] = new Russian();
    }
}

Another Example

```java
import java.math.BigDecimal;

public class NumberMain {

    public static long add(Number n1, Number n2) {
        return n1.longValue() + n2.longValue();
    }

    public static void main(String[] args) {
        // BigDecimal and Long are each a Number.
        System.out.println(add(new BigDecimal("32.1"), 34L));
    }
}
```
extend. To make a new class that inherits the members of an existing class.

superclass. The parent or base class. “Super” in the sense of “above” not “more.”

subclass. The child or derived class that inherits or extends a superclass. It represents a sub-part of the universe of things that make up the superclass.

inheritance. A subclass implicitly has the member fields and methods of a class by virtue of extending that class.

Important terms coming up: overriding, and dynamic dispatch.
How do you extend another class in Java?

class SubClass extends SuperClass {
    // additional fields ...
    // constructors ...
    // additional methods ...
}

If the *extends* clause is omitted from a class, then it is as if you have extended the class `Object`. 
Conundrum: how can one class also be another class at the same time?

Answer: the interface of the superclass must also be included in the interface of the subclass. Every thing the superclass can do, the subclass can do as well. If the superclass has a member field $x$, then the subclass must also have member field $x$. If the superclass has a method `int getX()`, then the subclass must also have method `int getX()`.

Therefore: the subclass inherits all the member methods and fields of the superclass.
Inheriting Member Fields

An instance of a subclass “is-a” instance of the superclass.

class SuperClass { int x; }
class SubClass extends SuperClass { }

class Main {
    public static void main (String[] args) {
        SuperClass[] a = new SuperClass[2];
        a[0] = new SuperClass();
        a[1] = new SubClass();
        for (SuperClass c: a) {
            System.out.println(c.x);
        }
    }
}

Inheriting Member Methods

An instance of a subclass “is-a” instance of the superclass.

```java
class Dog {
    void bark () {
        System.out.println('bark');
    }
}
class Poodle extends Dog {
}

class Main {
    public static void main (String[] args) {
        Dog[] dogs = new Dog [2];
dogs[0] = new Dog();
dogs[1] = new Poodle();
        for (Dog d: dogs) {
            System.out.println(d.bark());
        }
    }
}
```
Extend

Since,

class SubClass {
    // ...
}

is the same as:

class SubClass extends Object {
    // ...
}

It follows, that every class has:

public String toString ();
public boolean equals (Object obj);
protected Object clone ();   // copy
public Class<?> getClass (); // meta information
public void notify ();       // synchronization
public void wait ();          // synchronization
Inheriting the `toString()` method

*Every* object has a `toString()` method!

```java
class SuperC { int x; }
class SubClass extends SuperC { }
class Main {
    public static void main (String[] args) {
        Object[] a={new Object(), new SuperC(), new SubClass()};
        for (int i=0; i<a.length; i++) {
            System.out.println(a[i].toString());
        }
    }
}
```

By the way, the output is not very specific:

```java
java.lang.Object@16930e2
SuperC@108786b
SubClass@119c082
```
Overloaded print()

The implementation of the java.io.PrintStream class:

```java
void print (Object o) { print(o.toString());}
void print (boolean b) { print(String.valueOf(b));}
void print (char c) { print(String.valueOf(c));}
void print (int i) { print(String.valueOf(i));}
void print (long l) { print(String.valueOf(l));}
void print (float f) { print(String.valueOf(f));}
void print (double d) { print(String.valueOf(d));}

void print (String s) {
    // Do the real print work
}
```
Shapes Example

Suppose we want to write a program to compute with points, circles, and rectangles. There are different ways to define the data structure of each of the shapes. One possible framework of definitions which may prove useful is to think of shapes as having a reference point.
class Point {
    int x, y;
}

class Circle extends Point {
    int radius;
}

class Main {
    public static void Main (String[] args) {
        Circle c = new Circle();
        System.out.printf("%d,%d,%d%n", c.x, c.y, c.radius);
    }
}
class Point {
    int x, y;
    void move (int dx, int dy) { x += dx; y += dy; }
}
class Circle extends Point {
    int radius;
}
class Main {
    public static void Main (String[] args) {
        Circle c = new Circle ();
        c.move (2, 3);
        System.out.println (c.x +", "+ c.y +", "+ c.radius);
    }
}
class SuperClass {
    int x, y;
}

class SubClass extends SuperClass {
    int x, y;
}

The class SubClass has two fields named x and two fields named y. This is allowed because the author of the subclass should not have to know what names the author of the superclass might have picked. To forbid the class would enable the subclass author to “peek” inside the superclass.
class SuperClass {
    int x=2;
}

class SubClass extends SuperClass {
    int x=super.x+1;
}

class SubSubClass extends SubClass {
    int x=((SuperClass) this).x+3;
}

If the integer \(x\) in the class \(\text{SuperClass}\) is declared \texttt{private}, then access to it from a subclass causes a compile-time, semantic error.
Static Methods

You can use the name of the subclass to access static methods of the superclass. (Not so terribly important.)

class IndoEuropean {
    static void info () {
        System.out.println ("To find out more ... ")
    }
}

class German extends IndoEuropean {}
class Main {
    public static void Main (String[] args) {
        IndoEuropean.info ();
        German.info ();
    }
}

It might be better to always use the class name IndoEuropean when accessing the method info(), to show where to actually find the code.
Constructors *Not* Inherited

Constructors are not class members; they are not inherited.
Constructors and super

Default constructor. “If a class contains no constructor declarations, then a default constructor that takes no parameters is automatically provided.”

class Point {
    int x, y;
}

is equivalent to the declaration

class Point {
    int x, y;
    Point () { super (); }
}

“A compile-time error occurs if a default constructor is provided by the compiler but the superclass does not have an accessible constructor that takes no arguments.”
Java Language Rule: Each subclass constructor must implicitly or explicitly call one of its superclass’s constructors. This is used to properly initialize the superclass including its instance fields. This is important to the subclass which inherits and may depend on the superclass’s instance fields.

class Super {
    final int x;
    Super(int x) { this.x = x; }
    int sum() { return x; }
}
class Sub extends Super {
    final int y;
    Sub(int x, int y) { super(x); this.y = y; }
    @java.lang.Override
    int sum() { return x+y; }
}
class Super {
    final int x;
    Super (int x) { this.x = x; }
    int sum () { return x; }
}
class Sub extends Super {
    final int y;
    Sub (int x, int y) {this.y=y;} //Error
    @java.lang.Override
    int sum () { return x+y; }
}
Do not call instance (non-static) methods from constructors. Call either only private or final methods from inside constructors. The reason is that Java uses dynamic dispatch and this could result in a call a method on a half-initialized object.
Pitfall: Constructors and Subclasses

```java
class Super {
    final int i;
    Super (int i) { this.i = i; }
}

class Sub extends Super { }  // Illegal!
```
Methods Can Be Overridden

Sometimes the behavior of inherited methods is close, but not quite right for the subclass. In these cases it is appropriate to override the method.
A subclass overrides a method by defining a method of the same name and signature. For example,

```java
public String toString()
```

“A class type may contain a declaration for a method with the same name and the same signature as a method that would otherwise be inherited from a superclass. In this case, the method of the superclass is not inherited. The new declaration is said to override it.”
Overriding Example
Dynamic Dispatch

Dynamic dispatch (aka single dispatch, aka virtual function call) In most OO systems, the concrete function that is called from a function call in the code depends on the type of a single object at runtime.
Dynamic Dispatch

A simple example: class/Dispatch.java
The following is not so very important, but everyone asks. [Don’t ask because if you do, either:

▶ your OO design is bad,
▶ you don’t understand the subclass contract, or
▶ you have been looking at C++.]

What if you want some particular method to be called. You don’t want the method in the subclass called, but the method somewhere up in the subclass hierarchy. *Casting does not help for methods*  

▶ class/AccessField.java – casts make a different  
▶ class/AccessMethod.java – casts make no difference
Object-Oriented Design

1. Identify the problem’s objects.
   1.1 If the object cannot be directly represented using the existing types, then design a class to do so.
   1.2 If two or more classes share common attributes, then design a hierarchy to store their common attributes

2. Identify the problem’s operations.
   2.1 Define a method to do the operations.
   2.2 Structure the method within the class hierarchy so as to take advantage of inheritance
   2.3 Where necessary, have subclasses override inherited definitions.

3. Solve the problem
Attribute or Method

If a value depends on parameter, then use a method. If a value needs to be computed (like with a random number generator), then use a method. If no behavioral variation, then use an attribute. Inherited attributes, might be private and given access through getter and setter methods.

```java
private int x;
protected int getX () { return x;}
protected void setX (int i) {x=i;}
```

This way the validity of any new value can be checked
Calling Procedure

- call P(a) – compiler looks up address of P and jumps to instruction
- call P(a) – (overloading) compiler chooses from among several procedures based on the static types of arguments
- o.P(a) – (dynamic dispatch) the runtime system chooses from among several procedures based on the subtype of object o

Note that static type checking is possible in all cases.
Casting

Upcast or widening — OK
Downcast or narrowing — dangerous
Narrowing often must be used in OO languages.
Narrowing

Coercions can be classified into those that preserve information (*widenings*) and those that lose information (*narrowings*). The coercion `int` to `long` is a widening; `int` to `short` is a narrowing. See the table of Java coercions at

/ ryan/java/language/java-data.html

The terms apply to the OO hierarchy as well. OO programming often requires narrowing which defeats the purpose of strong typing. See the Java program example:

misc/Points.java
class/Widening.java
class Mammal {}
class Dog extends Mammal {}
class Cat extends Mammal {}
Mammal m = (Math.random() < 0.5) ? new Mammal() : new Dog();
Dog spot = new Dog();
Cat felix = new Cat();

m = spot; m = felix; // Valid (no cast needed)
spot = m; // Compile-time error
spot = (Dog) m; // Valid at compile time; runtime check
felix = (Cat) m; // Valid at compile time; runtime check
felix = spot; // Compile-time error
felix = (Cat) spot; // Compile-time error
Wary programmer:

```java
if (m instanceof Cat) {
    felix = (Cat) m;
}
```

Runtime system:

```java
if (m instanceof Cat) {
    felix = (Cat) m;
} else {
    throw new ClassCastException();
}
```
Abstract Classes

An abstract class is a class that has some abstract methods. Abstract methods have a specification, but lack code/instructions/behavior. An abstract class cannot be created/instantiated (but can have constructors), It is used as superclass to define a subclass with the responsibility of implementing the missing behavior.
abstract

In a class hierarchy, if a method’s behavior depends on the class, it is natural to override it. But if some class has no special behavior for the method, then there are two choices.

1. Define a meaningless or generic default behavior and let subclass override it. (Think of `toString()` for `Object`.)

2. Declare the method `abstract`.

If you declare a method `abstract` in a class, then the class is `abstract`. Meaning that the class is not used for instantiation, but only for defining other classes.

**Subclass responsibility.** All (non-abstract) subclasses are given the requirement (not just the opportunity) that the method be overridden.
Compare the followings:

```java
class Object {
    public String toString () { return "Object"; }
}
class SubClass extends Object {
    int x;
    public String toString () { return Integer.toString(x); }
}

abstract class Object {
    abstract public String toString ();
}
class SubClass extends Object {
    int x;
    public String toString () { return Integer.toString(x); }
}
```
Abstract List

abstract class AbstractList implements List {
    // 1. Operations that are in common to all lists
    // 2. Operations that have different behavior, but common interface
}
abstract/Main.java
abstract/InheritV.java
An interface is a set of methods describing functionality common across several classes.

Interfaces are totally abstract classes.

Advantage: can implement as many of them as you like.

Disadvantage: can’t implement code.

Used as (rather poor) enumeration types. Important in threads. Important as callbacks (especially in GUI code). Important in collection classes.
Interface

interface/Verbose.java
interface/List.java
interface/Example.java
interface/PointPack.java
misc/Reactive.java
Common Interfaces

- interface Comparable.
- interface Comparator.
- interface Iterator.
- interface Runnable.
- marker interface Serializable.
- marker interface Cloneable.

A marker interface has no methods; hence any class can “implement” it. It is used as a signal to the JVM. A class that implements such an interface is allowed to be serialized, cloned, etc.
Java 8: Functional Interfaces

Table 2-1. Important functional interfaces in Java

<table>
<thead>
<tr>
<th>Interface name</th>
<th>Arguments</th>
<th>Returns</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicate&lt;T&gt;</td>
<td>T</td>
<td>boolean</td>
<td>Has this album been released yet?</td>
</tr>
<tr>
<td>Consumer&lt;T&gt;</td>
<td>T</td>
<td>void</td>
<td>Printing out a value</td>
</tr>
<tr>
<td>Function&lt;T,R&gt;</td>
<td>T</td>
<td>R</td>
<td>Get the name from an Artist object</td>
</tr>
<tr>
<td>Supplier&lt;T&gt;</td>
<td>None</td>
<td>T</td>
<td>A factory method</td>
</tr>
<tr>
<td>UnaryOperator&lt;T&gt;</td>
<td>T</td>
<td>T</td>
<td>Logical not (!)</td>
</tr>
<tr>
<td>BinaryOperator&lt;T&gt;</td>
<td>(T, T)</td>
<td>T</td>
<td>Multiplying two numbers (*)</td>
</tr>
</tbody>
</table>
Nested Classes

inner/Nest.java
inner/Local.java
inner/Iter.java
misc/Anon.java
inner/Searcher.java
Equals

equals/Main.java
equals/Override.java
equals/Example.java
Clone

Why clone? Because assignment just copies references. This creates aliases and this leads to programming mistakes.

```java
BankAccount ba153 = new BankAccount (500);
BankAccount ba714 = ba153;  // sharing
ba153.deposit (25);         // both get deposit!
```

```java
BankAccount ba153 = new BankAccount (500);
BankAccount ba714 = ba153.clone(); // a copy
ba153.deposit (25);              // only one deposit
```
class(Clone.java)

Superclass does the work and even copies the added fields (x). The class must be marked Cloneable or the unchecked exception CloneNotSupportedException will be raised. The protected method clone is overridden with a public method. This is permitted. You can override with less restrictive access, but not more restrictive access.
- **private**—members declared private are only accessible within the class itself.
- **“package”**—members declared with no access modifier are accessible in classes in the same package.
- **protected**—members declared protected are accessible in subclasses (in the same package or not) and in the class itself.
- **public**—members declared public are accessible anywhere the class is accessible.

<table>
<thead>
<tr>
<th>access from</th>
<th>private</th>
<th>“package”</th>
<th>protected</th>
<th>public</th>
</tr>
</thead>
<tbody>
<tr>
<td>same class</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>in subclass, same package</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>non-subclass, same package</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>in subclass, out of package</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>non-subclass, out of package</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>
Display 7.9 Access Modifiers

package somePackage;

public class A {
    public int v1;
    protected int v2;
    int v3; //package
    //access
    private int v4;
}

public class B {
    can access v1.
    can access v2.
    can access v3.
    cannot access v4.
}

public class C extends A {
    can access v1.
    can access v2.
    can access v3.
    cannot access v4.
}

public class D extends A {
    can access v1.
    can access v2.
    cannot access v3.
    cannot access v4.
}

public class E {
    can access v1.
    cannot access v2.
    cannot access v3.
    cannot access v4.
}

In this diagram, "access" means access directly, that is, access by name.

A line from one class to another means the lower class is a derived class of the higher class.

If the instance variables are replaced by methods, the same access rules apply.
Overriding: same name, different classes, same signature, at least as much access (cf. §8.4.8.3 JLS 3rd).

```
private < “package” < protected < public

class Restrictive {
    // Semantic error!
    // "attempting to assign weaker access privileges"
    private boolean equals (Object x) {
        return false;
    }
    // OK. But, overloading not overriding!!
    private boolean equals (Restrictive x) {
        return true;
    }
}
```
Is-a versus Has-a

Design consideration.
It is easy to misuse inheritance. “is-a” or “has-a”. Aspects.

- aspect/Point.java
- aspect/SubPoint.java
- aspect/Aspect.java
Summary

- class hierarchy
- subtype polymorphism
- inheritance
- overriding
- dynamic dispatch
- Java’s abstract classes
- Java’s interfaces