NYU

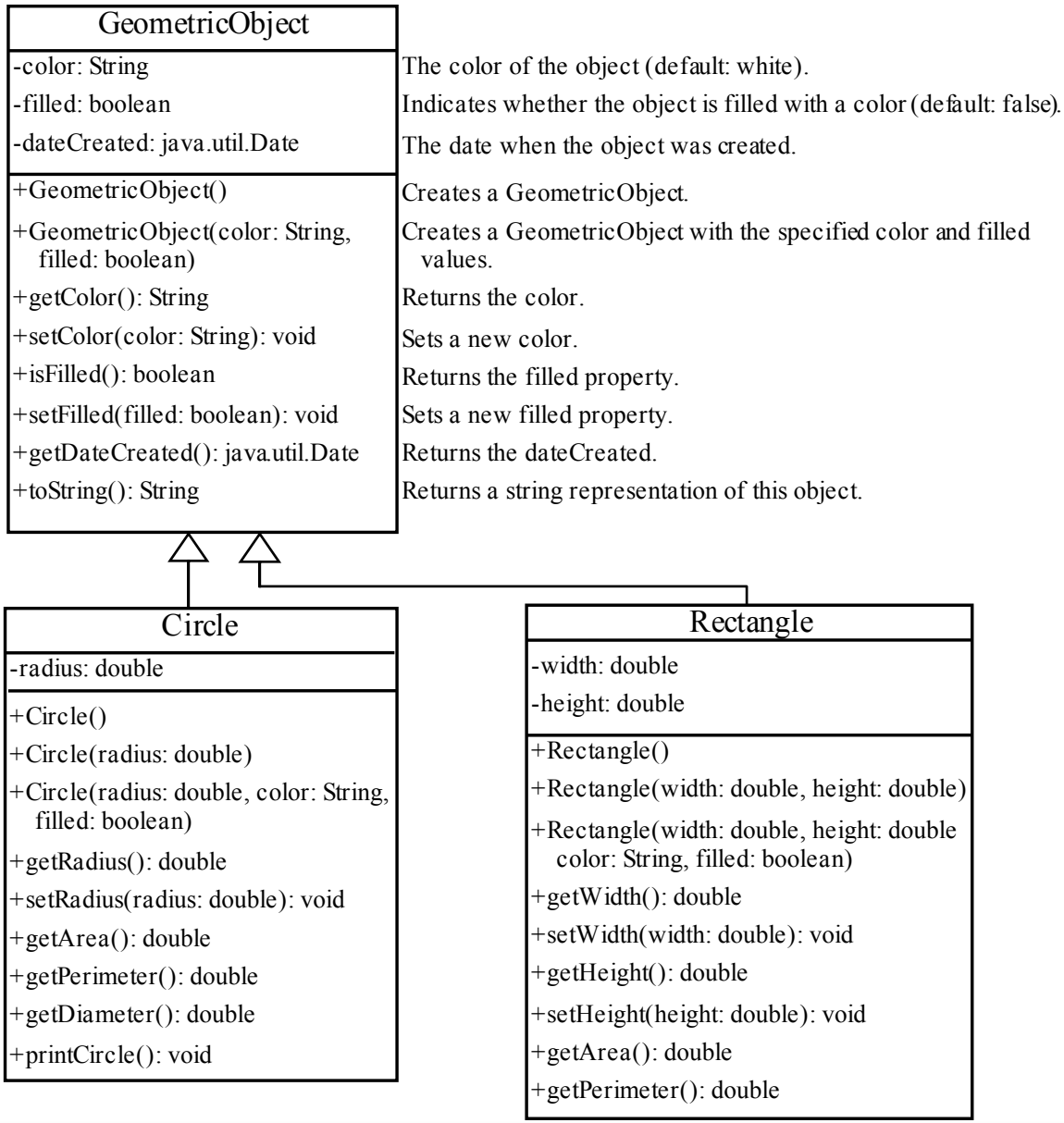
# Lecture 16

Inheritance and Polymorphism

# Motivations

- Suppose you will define classes to model circles, rectangles, and triangles. These classes have many common features. What is the best way to design these classes so to avoid redundancy? The answer is to use inheritance.

# Superclasses and Subclasses



# Defining a Subclass

- A subclass inherits from a superclass. You can also:
  - Add new properties
  - Add new methods
  - Override the methods of the superclass

# Example

```
//Superclass
public class GeometricObject
{
   public int x, y;
   public String getDateCreated() { ... }
   public double area() { ... }
}
//Subclass
public class Circle extends GeometricObject {
   public double radius;

   public double getDiameter() { ... }
   public void printCircle() { ... }
}
```

# Using the Keyword super

- The keyword `super` refers to the superclass of the class in which `super` appears.

- This keyword can be used in two ways:
  - To call a superclass constructor
  - To call a superclass method

# Calling Superclass Methods

- You could implemente the `printCircle()` method in the `Circle` class as follows:

```
public void printCircle() {
   System.out.println(
     "The circle is created " +
     super.getDateCreated() +
     " and the radius is " + radius);
}
```

# Overriding Methods in the Superclass

- A subclass inherits methods from a superclass.
- Sometimes it is necessary for the subclass to modify the implementation of a method defined in the superclass.
- This is referred to as ***method overriding***.

```
public class Circle extends GeometricObject {
  // Other methods are omitted


  /** Override the area method defined in GeometricObject */
  public double area() {
    return radius*radius*Math.Pi();
  }
}
```

# Overriding vs. Overloading

```
public class Test {
public static void
main(String[] args) {
    A a = new A();
    a.p(10);
    a.p(10.0);
  }
}

class B {
  public void p(double i) {
    System.out.println(i * 2);
  }
}

class A extends B {
  // overrides the method in B
  public void p(double i) {
    System.out.println(i);
  }
}
```

```
public class Test {
  public static void
main(String[] args) {
    A a = new A();
    a.p(10);
    a.p(10.0);
  }
}

class B {
  public void p(double i) {
    System.out.println(i * 2);
  }
}

class A extends B {
  // overloads the method in B
  public void p(int i) {
    System.out.println(i);
  }
}
```

# Note

- An instance method can be overridden only if it is accessible.
- Thus a **private** method cannot be overridden, because it is not accessible outside its own class.
- If a method defined in a subclass is private in its superclass, the two methods are completely unrelated.

# Note

- Like an instance method, a static method can be inherited.
- However, a **static method cannot be overridden**.
- If a static method defined in the superclass is redefined in a subclass, the method defined in the superclass is hidden.

# The protected Modifier

- The **protected** modifier can be applied on data and methods in a class.
- A protected data or a protected method in a public class can be accessed by any class in the same package or its subclasses, even if the subclasses are in a different package.

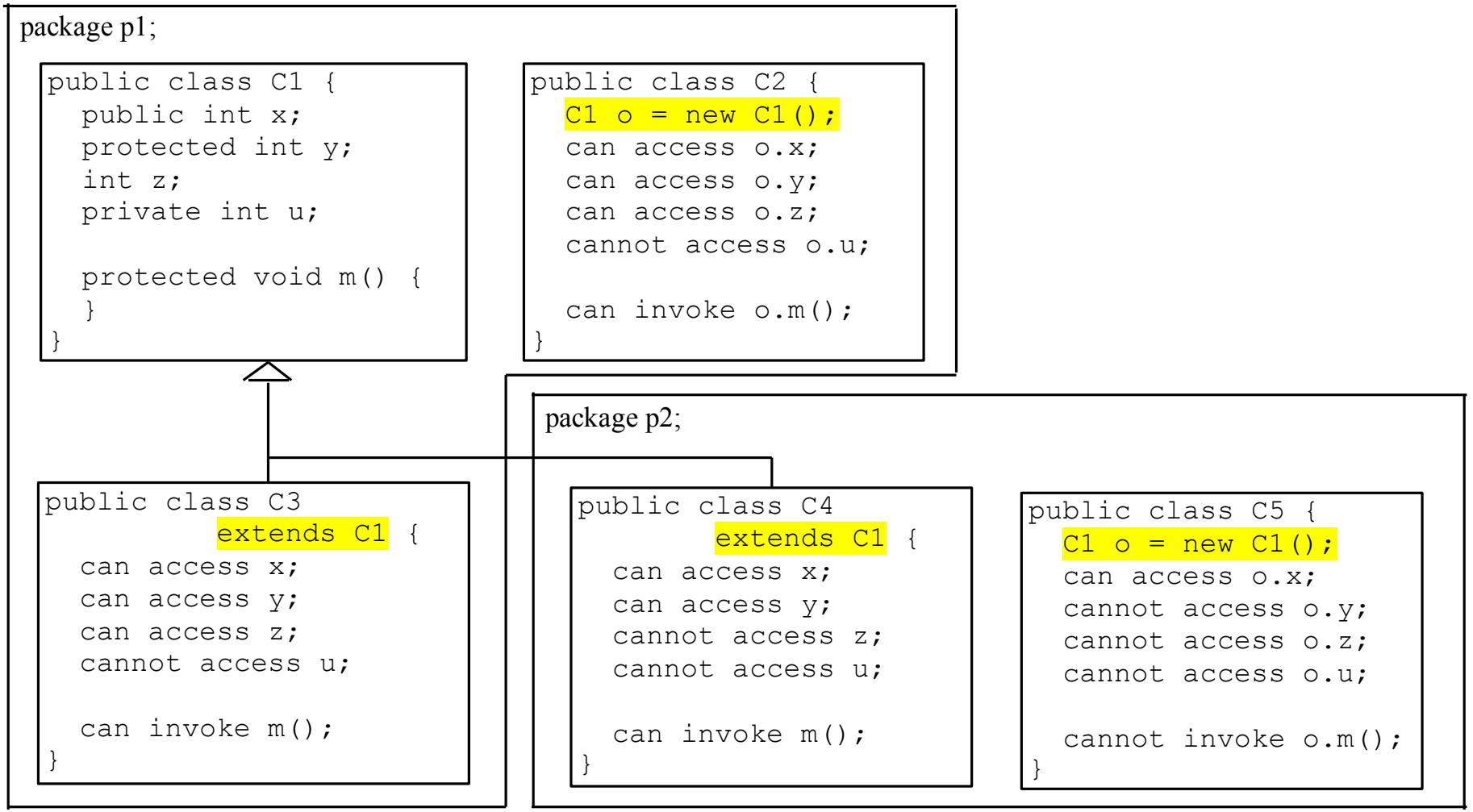
- private, default, protected, public

Visibility increases

# Accessibility Summary

| Modifier on members in a class | Accessed from the same class | Accessed from the same package | Accessed from a subclass | Accessed from a different package |
|---|---|---|---|---|
| public | ✓ | ✓ | ✓ | ✓ |
| protected | ✓ | ✓ | ✓ | – |
| default | ✓ | ✓ | – | – |
| private | ✓ | – | – | – |

# Visibility Modifiers



# Accessibility Weakening

- A subclass may override a protected method in its superclass and change its visibility to public.
- However, a **subclass cannot weaken the accessibility of a method defined in the superclass**.
- For example, if a method is defined as public in the superclass, it must be defined as public in the subclass.

# Note

- The modifiers are used on classes and class members (data and methods),
- Except that the **final** modifier can also be used on local variables in a method.
- A final local variable is a constant inside a method.

# The final Modifier

- The final class cannot be extended:

```
final class Math {
   ...
}
```

- The final variable is a constant:

```
final static double PI = 3.14159;
```

- The final method cannot be overridden by its subclasses.

# The Object Class and Its Methods

- Every class in Java is descended from the `java.lang.Object` class.

- If no inheritance is specified when a class is defined, the superclass of the class is Object.

```
public class Circle {
    ...
}
```

equivalent

```
public class Circle extends Object {
    ...
}
```

# The toString() method in Object

- The `toString()` method returns a string representation of the object.
- The default implementation returns a string consisting of
  - a class name of which the object is an instance,
  - the at sign (@), and
  - a number representing this object.

- Example

```
Circle circle = new Circle();
System.out.println(circle.toString());
```

The code displays something like Circle@15037e5.

# The toString() method in Object

- This message is not very helpful or informative.
- Usually you should override the `toString` method so that it returns a digestible string representation of the object.

```
public String toString() {
  return
     "The circle is created " +
     super.getDateCreated() +
     " and the radius is " + radius);
}
```

# The equals Method

- The `equals()` method compares the contents of two objects.
- The default implementation of the equals method in the Object class is as follows:

```
public boolean equals(Object obj) {
  return this == obj;
}
```

- Better

```
public boolean equals(Object o) {
  if (o instanceof Circle) {
    return radius == ((Circle)o).radius;
  }
  else
    return false;
}
```

# Note

- The == comparison operator is used for comparing
  - two primitive data type values or
  - for determining whether two objects have the same references.

- The **equals method** is intended to test whether two objects have the **same contents**, provided that the method is modified in the defining class of the objects.
- The == operator is stronger than the equals method, in that the == operator checks whether the two reference variables refer to the same object.

# Polymorphism

- Polymorphism means that a variable of a supertype can refer to a subtype object.

- A class defines a type.
- A type defined by a subclass is called a *subtype*, and a type defined by its superclass is called a *supertype*.

- Therefore, you can say that **Circle** is a subtype of **GeometricObject** and **GeometricObject** is a supertype for **Circle**.

# Example

```
public class PolymorphismDemo {
  public static void main(String[] args) {
    m(new GraduateStudent());
    m(new Student());
    m(new Person());
    m(new Object());
  }

  public static void m(Object x) {
    System.out.println(x.toString());
  }
}

class GraduateStudent extends Student {
}

class Student extends Person {
  public String toString() {
    return "Student";
  }
}

class Person extends Object {
  public String toString() {
    return "Person";
  }
}
```

Method `m` takes a parameter of the Object type. You can invoke it with any object.

An object of a subtype can be used wherever its supertype value is required. This feature is known as ***polymorphism***.

# Example

- When the method `m(Object x)` is executed, the argument `x`'s `toString` method is invoked.
- x may be an instance of `GraduateStudent`, `Student`, `Person`, or `Object`.
- Classes `GraduateStudent`, `Student`, `Person`, and `Object` have their own implementation of the `toString` method.
- Which implementation is used will be determined **dynamically** by the Java Virtual Machine at runtime.

- This capability is known as dynamic binding.

# Dynamic Binding

- Suppose an object `o` is an instance of classes `C1`, `C2`, ..., and `Cn`
- `C1` is a subclass of `C2`, `C2` is a subclass of `C3`, ..., and `Cn-1` is a subclass of `Cn` (`Cn` is the most general class, and `C1` is the most specific class).
- In Java, `Cn` is the Object class.
- If `o` invokes a method `p`, the JVM searches the implementation for the method `p` in `C1`, `C2`, ..., `Cn`, in **this order**, until it is found.
- Once an implementation is found, the search stops and the first-found implementation is invoked.

# Method Matching vs. Binding

- Matching a method signature and binding a method implementation are two issues.
- The compiler finds a matching method according to parameter type, number of parameters, and order of the parameters at compilation time.
- A method may be implemented in several subclasses.

- The Java Virtual Machine dynamically binds the implementation of the method at runtime.

# Generic Programming

```
public class PolymorphismDemo {
  public static void main(String[] args) {
    m(new GraduateStudent());
    m(new Student());
    m(new Person());
    m(new Object());
  }

  public static void m(Object x) {
    System.out.println(x.toString());
  }
}

class GraduateStudent extends Student {
}

class Student extends Person {
  public String toString() {
    return "Student";
  }
}

class Person extends Object {
  public String toString() {
    return "Person";
  }
}
```

# Generic Programming

- Polymorphism allows methods to be used generically for a wide range of object arguments.
- This is known as generic programming.
- If a method's parameter type is a superclass (e.g., `Object`), you may pass an object to this method of any of the parameter's subclasses (e.g., `Student` or `String`).
- When an object (e.g., a `Student` object or a `String` object) is used in the method, the particular implementation of the method of the object that is invoked (e.g., `toString`) is determined dynamically.

# Casting Objects

- We have already used the casting operator to convert variables of one primitive type to another.
- Casting can also be used to convert an object of one class type to another within an inheritance hierarchy.
- Example:

```
Object o = new Student(); // Implicit casting
m(o);
```

- This statement, known as implicit casting, is legal because an instance of `Student` is automatically an instance of `Object`.

# Why Casting Is Necessary?

```
Object o = new Student()
```

- Suppose you want to assign the object reference `o` to a variable of the Student type using the following statement:

```
Student b = o;
```

- A compile error would occur.

- Why does the statement `Object o = new Student()` work and the statement Student b = o doesn't?

# Why Casting Is Necessary?

- This is because a `Student` object is **always** an instance of `Object`, but an `Object` **is not necessarily** an instance of `Student`.
- Even though you can see that `o` is really a `Student` object, the compiler is not so clever to know it.

- To tell the compiler that o is a Student object, use an explicit casting.
- The syntax is similar to the one used for casting among primitive data types.

```
Student b = (Student)o; // Explicit casting
```

# Casting from Superclass to Subclass

- Explicit casting must be used when casting an object from a superclass to a subclass.

- This type of casting may not always succeed.

  - `Apple x = (Apple)fruit;`
  - `Orange x = (Orange)fruit;`

# The instanceof Operator

- Use the `instanceof` operator to test whether an object is an instance of a class:

```
Object myObject = new Circle();
    ... // Some lines of code


// Cast if myObject is an instance of Circle
   if (myObject instanceof Circle) {
     System.out.println(
         "The circle diameter is " +
       ((Circle)myObject).getDiameter());
     ...
   }
```

# Tip

- To help understand casting, you may also consider the analogy of fruit, apple, and orange with the Fruit class as the superclass for Apple and Orange.

- An apple is a fruit, so you can always safely assign an instance of Apple to a variable for Fruit.

- However, a fruit is not necessarily an apple, so you have to use explicit casting to assign an instance of Fruit to a variable of Apple.

# Example

- Create two geometric objects:
  - a circle, and
  - a rectangle

- Create the `displayGeometricObject` method to display the objects.

- The `displayGeometricObject` displays
  - the area and diameter if the object is a circle,
  - area if the object is a rectangle.

# Superclass Constructor Inherited

- No. They are **not** inherited.
- They are invoked explicitly or implicitly.
- Explicitly using the `super` keyword.

- A constructor is used to construct an instance of a class.
- Unlike properties and methods, a superclass's constructors are not inherited in the subclass.
- They can only be invoked from the subclasses' constructors, using the keyword super.
- If the keyword `super` is not explicitly used, the superclass's no-arg constructor is automatically invoked.

# Superclass Constructor Invoked

- A constructor may invoke an overloaded constructor or its superclass's constructor.
- If none of them is invoked explicitly, the compiler puts `super()` as the first statement in the constructor.

```
public A() {
}
```

```
public A(double d) {
  // some statements
}
```

```
public A() {
   super();
}
```

```
public A(double d) {
  super();
  // some statements
}
```

# Caution

- You must use the keyword `super` to call the superclass constructor.

- Invoking a superclass constructor's name in a subclass causes a syntax error.
- Java requires that the statement that uses the keyword `super` appear first in the constructor.

# Constructor Chaining

- Constructing an instance of a class invokes all the superclasses' constructors along the inheritance chain. This is known as *constructor chaining*.

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
  }
}

class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee’s overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
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  public Employee() {
    this("(2) Invoke Employee's overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Start from the main method

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
  }
}

class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee's overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Invoke Faculty constructor

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
  }
}

class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee's overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Invoke Employee's no-arg constructor

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
  }
}

class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee's overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Invoke Employee(String) constructor

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg construct      invoked");
  }
}

class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee's overload    constructor");
    System.out.println("(3) Employee'    o-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Invoke Person() constructor

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is i      ");
  }
}

class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee's overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is in     ed");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Execute println

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
  }
}

class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee's overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Execute println

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
    new Faculty();
  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
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    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
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}
```

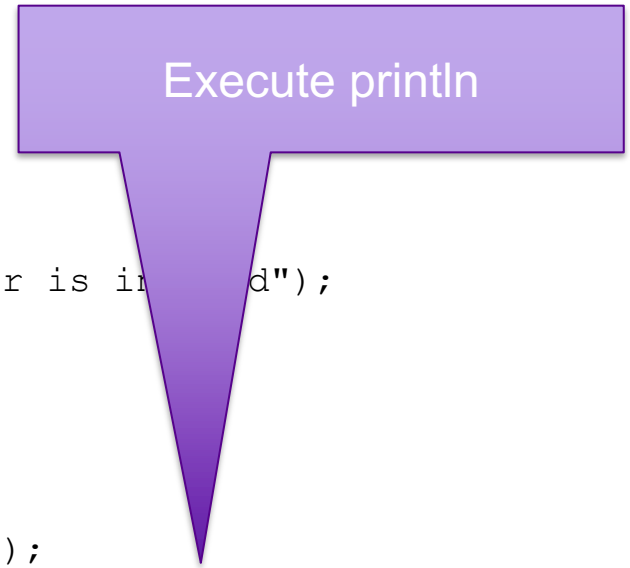

# Constructor Chaining

```
public class Faculty extends Employee {
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class Employee extends Person {
  public Employee() {
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    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Execute println

# Constructor Chaining

```
public class Faculty extends Employee {
  public static void main(String[] args) {
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  }

  public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
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class Employee extends Person {
  public Employee() {
    this("(2) Invoke Employee's overloaded constructor");
    System.out.println("(3) Employee's no-arg constructor is invoked");
  }

  public Employee(String s) {
    System.out.println(s);
  }
}

class Person {
  public Person() {
    System.out.println("(1) Person's no-arg constructor is invoked");
  }
}
```

Done

# Superclass without no-arg Constructor

- Find out the errors in the program:

```
public class Apple extends Fruit {
}


class Fruit {
  public Fruit(String name) {
    System.out.println("Fruit's constructor is
  invoked");
  }
}
```

# The ArrayList Class

- You can create an array to store objects.
- But the array's size is fixed once the array is created.
- Java provides the `ArrayList` class that can be used to store an unlimited number of objects.

# The ArrayList Class

| java.util.ArrayList<E> | |
|---|---|
| +ArrayList() | Creates an empty list. |
| +add(o: E) : void | Appends a new element o at the end of this list. |
| +add(index: int, o: E) : void | Adds a new element o at the specified index in this list. |
| +clear(): void | Removes all the elements from this list. |
| +contains(o: Object): boolean | Returns true if this list contains the element o. |
| +get(index: int) : E | Returns the element from this list at the specified index. |
| +indexOf(o: Object) : int | Returns the index of the first matching element in this list. |
| +isEmpty(): boolean | Returns true if this list contains no elements. |
| +lastIndexOf(o: Object) : int | Returns the index of the last matching element in this list. |
| +remove(o: Object): boolean | Removes the element o from this list. |
| +size(): int | Returns the number of elements in this list. |
| +remove(index: int) : boolean | Removes the element at the specified index. |
| +set(index: int, o: E) : E | Sets the element at the specified index. |

# Generic Type

- ArrayList is known as a generic class with a generic type E.
- You can specify a concrete type to replace E when creating an ArrayList.
- For example, the following statement creates an ArrayList and assigns its reference to variable cities.
- This ArrayList object can be used to store strings.

```
ArrayList<String> cities = new
                           ArrayList<String>();
ArrayList<String> cities = new ArrayList<>();
```

# Arrays vs ArrayList

| Operation | Array | ArrayList |
|---|---|---|
| Creation | `String[] a = new String[10]` | `ArrayList<String> list = new ArrayList<>();` |
| Accessing an element | `a[index]` | `list.get(index);` |
| Updating an element | `a[index] = "String";` | `list.set(index, "String");` |
| Returning size | `a.length` | `list.size();` |
| Adding a new element | | `list.add("String");` |
| Inserting a new element | | `list.add(index, "String");` |
| Removing an element | | `list.remove(index);` |
| Removing an element | | `list.remove("String");` |
| Removing all elements | | `list.clear();` |

# Array Lists from/to Arrays

- Creating an ArrayList from an array of objects:

```
String[] array = {"red", "green", "blue"};
ArrayList<String> list =
      new ArrayList<>(Arrays.asList(array));
```

- Creating an array of objects from an `ArrayList`:

```
ArrayList<String> list = new ArrayList<>()
String[] array1 = new String[list.size()];
list.toArray(array1);
```

# max and min in an Array List

```
String[] array = {"red", "green", "blue"};

System.out.pritnln(
  java.util.Collections.max(
     new ArrayList<String>(
          Arrays.asList(array))));
```

```
String[] array = {"red", "green", "blue"};
System.out.pritnln(
  java.util.Collections.min(
     new ArrayList<String>(
          Arrays.asList(array))));
```

# Shuffling an Array List

```
Integer[] array =
        {3, 5, 95, 4, 15, 34, 3, 6, 5};

ArrayList<Integer> list =
  new ArrayList<>(Arrays.asList(array));

java.util.Collections.shuffle(list);
System.out.println(list);
```