COMP30820
Java Programming (Conv)

Michael O'Mahony

Chapter 9 Objects and Classes

Introduction

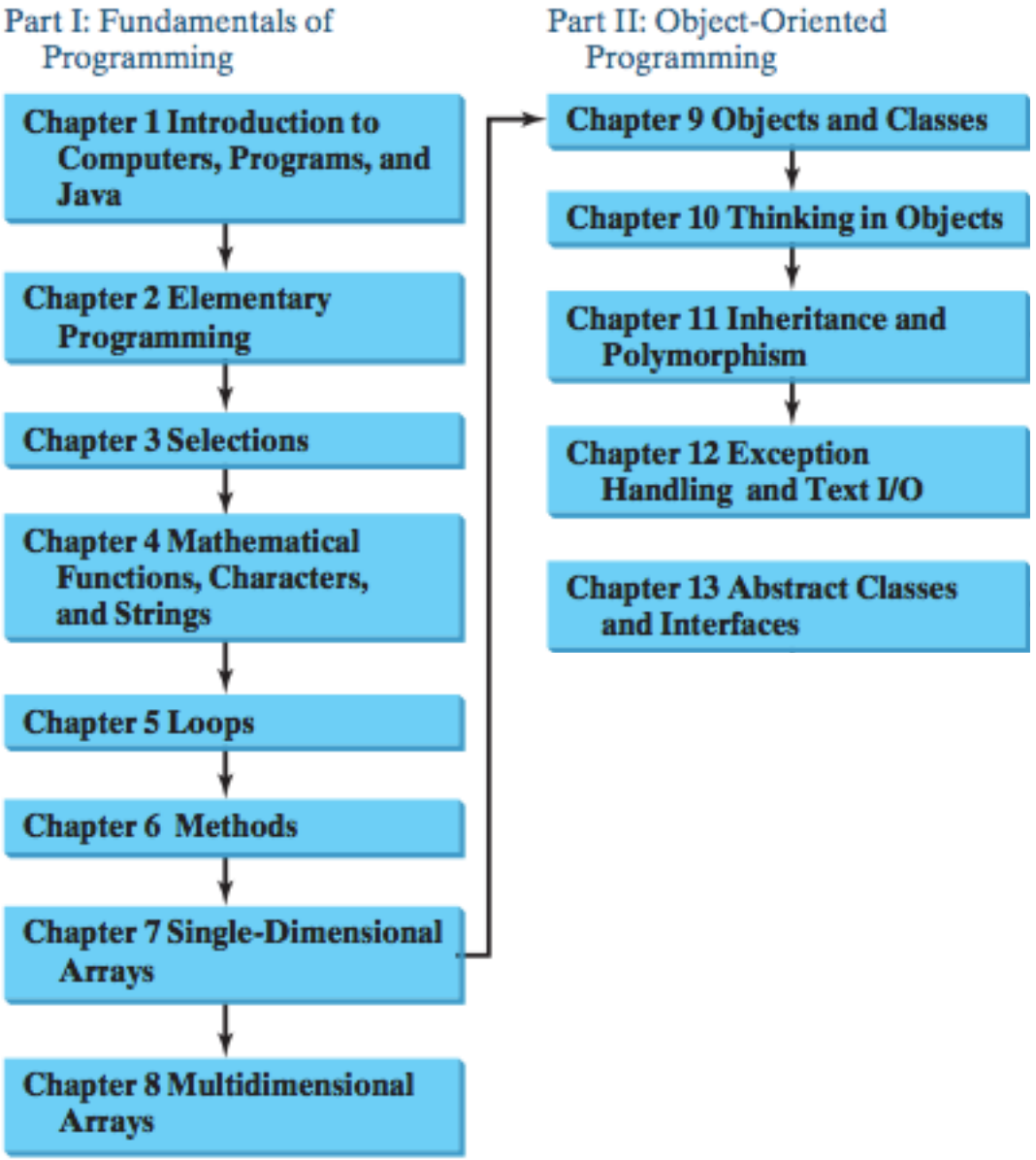
Previously, solved programming problems using selections, loops, arrays, methods…

This and subsequent lectures will focus on object-oriented programming.

This lecture – introduce classes and objects.

Next lectures – focus on inheritance, polymorphism, abstract classes and interfaces etc.

Introduction



Objectives

- To describe objects and classes, and use classes to model objects (§9.2).
- To demonstrate how to define classes and create objects (§9.3).
- To create objects using constructors (§9.4).
- To access objects via object reference variables (§9.5).
- To access an object's data and methods using the object member access operator (**.**) (§9.5.2).
- To define data fields of reference types and assign default values for an object's data fields (§9.5.3).
- To distinguish between object reference variables and primitive data type variables (§9.5.4).
- To distinguish between instance and static variables and methods (§9.7).
- To define private data fields with appropriate **get** and **set** methods (§9.8).
- To encapsulate data fields to make classes easy to maintain (§9.9).
- To develop methods with object arguments and differentiate between primitive-type arguments and object-type arguments (§9.10).
- To use the keyword `this` to refer to the calling object itself (§9.14).
- To store and process objects in arrays (§9.11).

OO Programming Concepts

Object-oriented programming (OOP) involves programming using objects.

An *object* represents an entity in the real world that can be distinctly identified:

- For example, a student, a desk, a circle, a button, a loan, a car, a house etc. can all be viewed as objects.

An object has both *state* and *behaviour*. The *state* defines the object, and the *behaviour* defines what the object does.

OO Programming Concepts

The *state* of an object consists of a set of *data fields* (aka *data members* aka *properties*) with their current values. For example:

- A circle object has a data field `radius`, a property that characterizes a circle.
- A rectangle object has the data fields `width` and `height`, properties that characterize a rectangle.

The *behaviour* of an object is defined by methods. To *invoke* a method on an object is to ask the object to perform an action:

- For example, methods named `getArea()` and `getPerimeter()` can be defined for circle objects.
- Then a circle object may invoke `getArea()` to return its area and `getPerimeter()` to return its perimeter.

Classes

Objects of the same type are defined using a common *class*.

A class is a template (or blueprint) for creating objects. It defines what an object's data fields and methods will be.

An object is an *instance* of a class:

- Many instances of a class can be created.
- Creating an instance is referred to as *instantiation*.

The relationship between classes and objects is analogous to that between, for example, an apple-pie recipe and apple pies:

- You can make as many apple pies as you want from a single recipe...

Classes

A Java class uses variables to define data fields (*state*) and methods to define actions (*behaviour*).

Additionally, a class provides methods of a special type, known as *constructors*, which are invoked in order to create a new object (a new instance of a class).

Constructors are typically designed to perform initializing actions, such as initializing the data fields of objects.

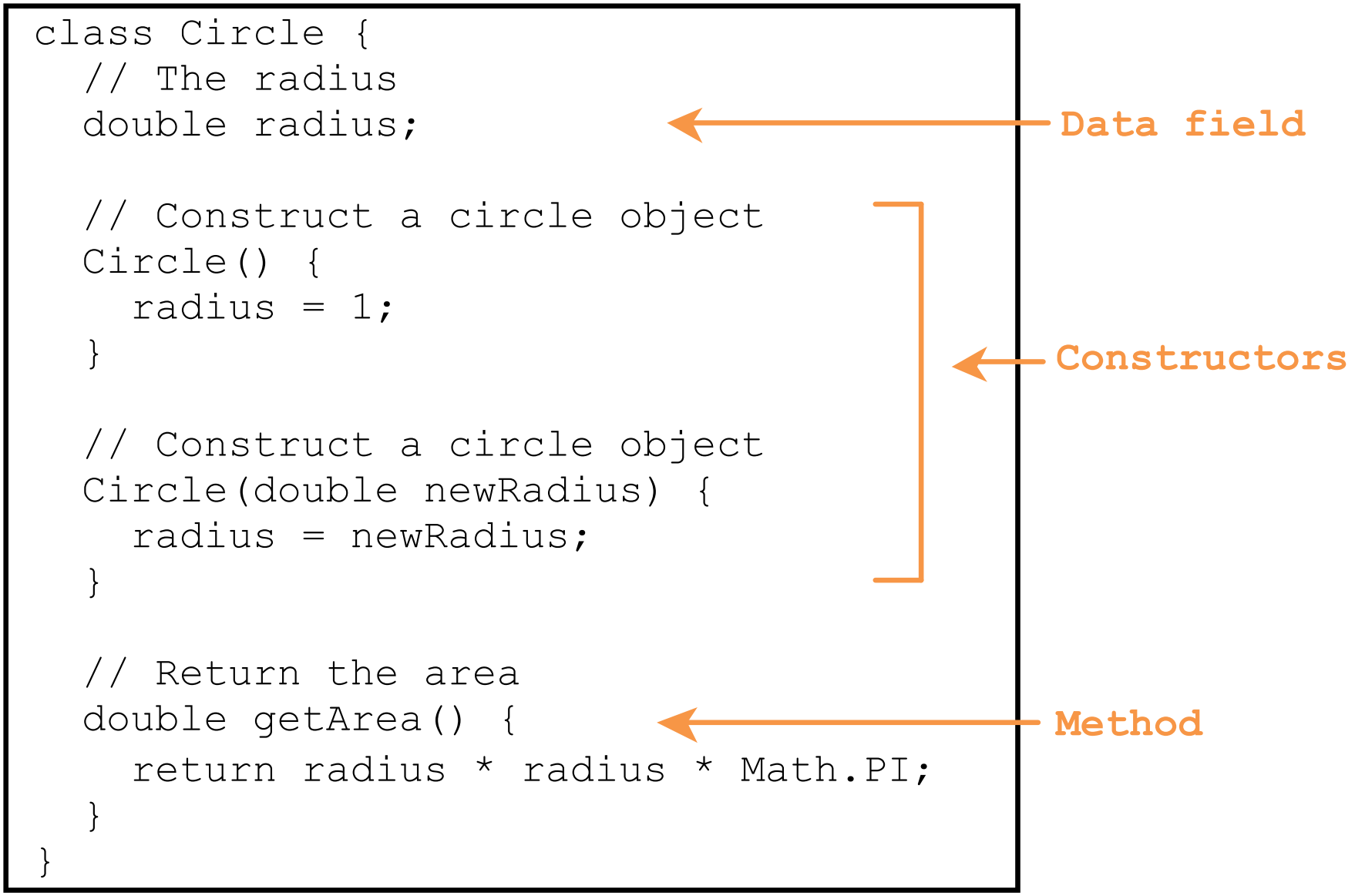
Example Class: `Circle`

```
class Circle {
  // The radius
  double radius;

  // Construct a circle object
  Circle() {
    radius = 1;
  }

  // Construct a circle object
  Circle(double newRadius) {
    radius = newRadius;
  }

  // Return the area
  double getArea() {
    return radius * radius * Math.PI;
  }
}
```



Constructors

Constructors are a special kind of method that are invoked to construct objects:

- Constructors must have the same name as the class itself.
- Constructors do not have a return type (not even `void`).
- A constructor with no parameters is referred to as a *no-arg (no-argument) constructor*.

A class may be defined without constructors:

- In this case, a no-arg constructor with an empty body is implicitly defined in the class.
- This constructor, called *a default constructor*, is provided automatically *only if no constructors are explicitly defined in the class*.

Constructors are invoked using the `new` operator when an object is created. Constructors play the role of initializing objects.

Creating Objects Using Constructors

Examples of constructors:

```
Circle() {
  radius = 1;
}
```

```
Circle(double newRadius) {
  radius = newRadius;
}
```

Creating objects using constructors:

- General syntax: `new ClassName();`
- Examples:
  - `new Circle();`
  - `new Circle(5.0);`

Declaring Object Reference Variables

To reference an object, assign the object to a reference variable.

To declare a reference variable:

- General syntax: `ClassName objectRefVar;`
- Example: `Circle myCircle;`

Declaring/Creating Objects in a Single Step:

- General syntax: `ClassName objectRefVar = new ClassName();`

Declaring Object Reference Variables

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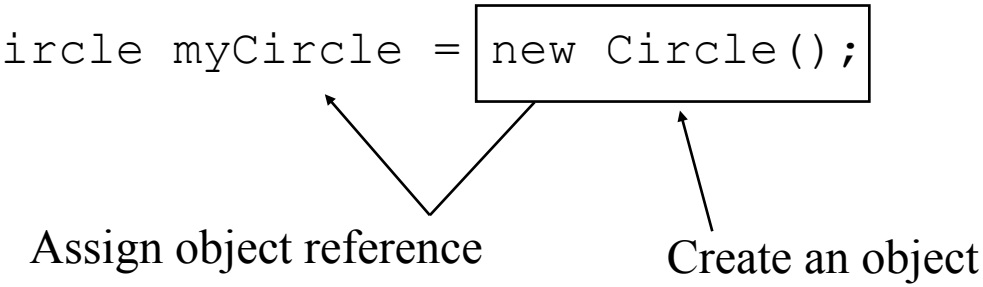

Accessing Object's Members

In OOP terminology, an object's *member* refers to its data fields and methods.

After an object is created, use the *dot operator* (.) to access its data fields and to invoke its methods.

To reference the data fields of an object:

- General syntax: `objectRefVar.dataField`
- Example: `myCircle.radius`

To invoke the methods of an object:

- General syntax: `objectRefVar.methodName(arguments)`
- Example: `myCircle.getArea()`

animation

Trace Code

```
Circle myCircle = new Circle(5.0);

Circle yourCircle = new Circle();

yourCircle.radius = 100;
```

animation

Trace Code

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Circle myCircle = new Circle(5.0);

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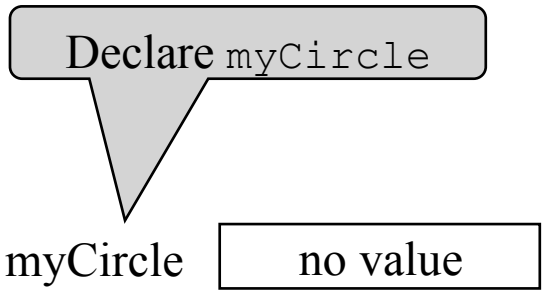
yourCircle.radius = 100;
```



animation

Trace Code, cont.

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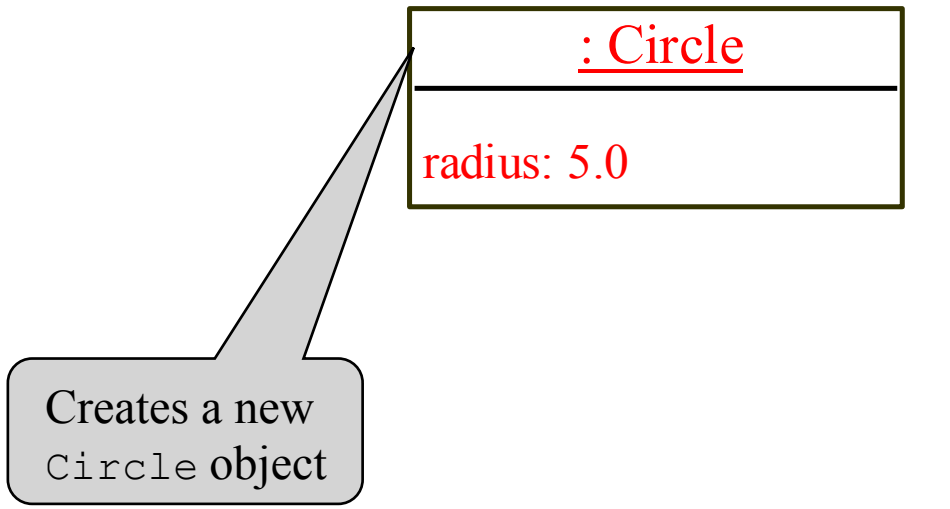

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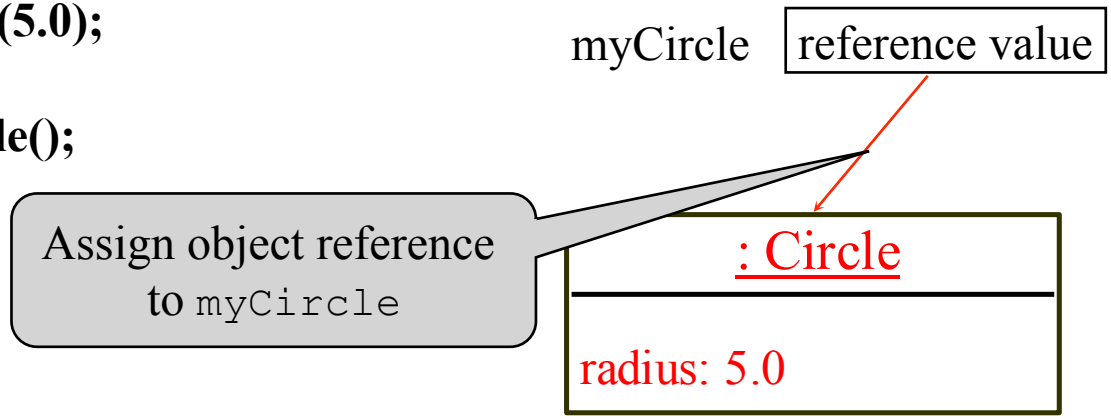

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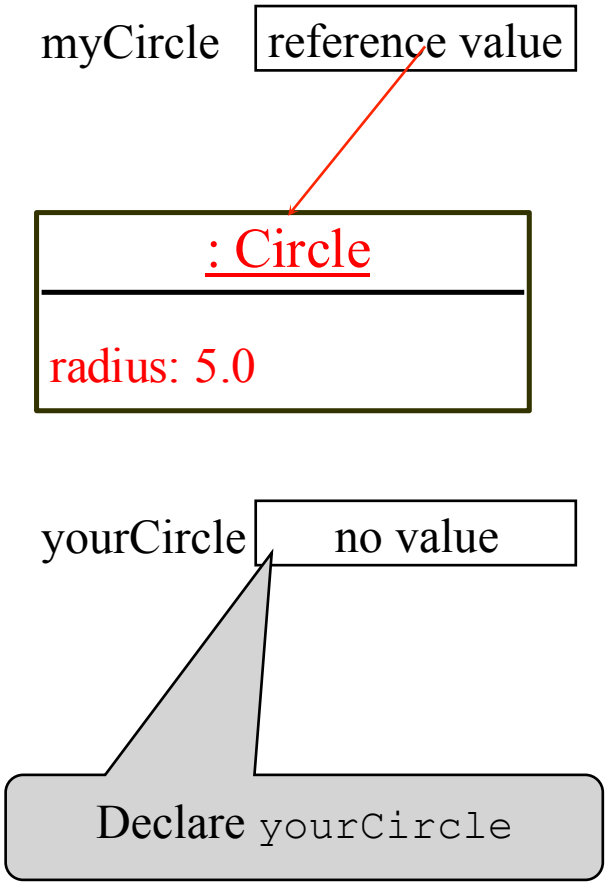

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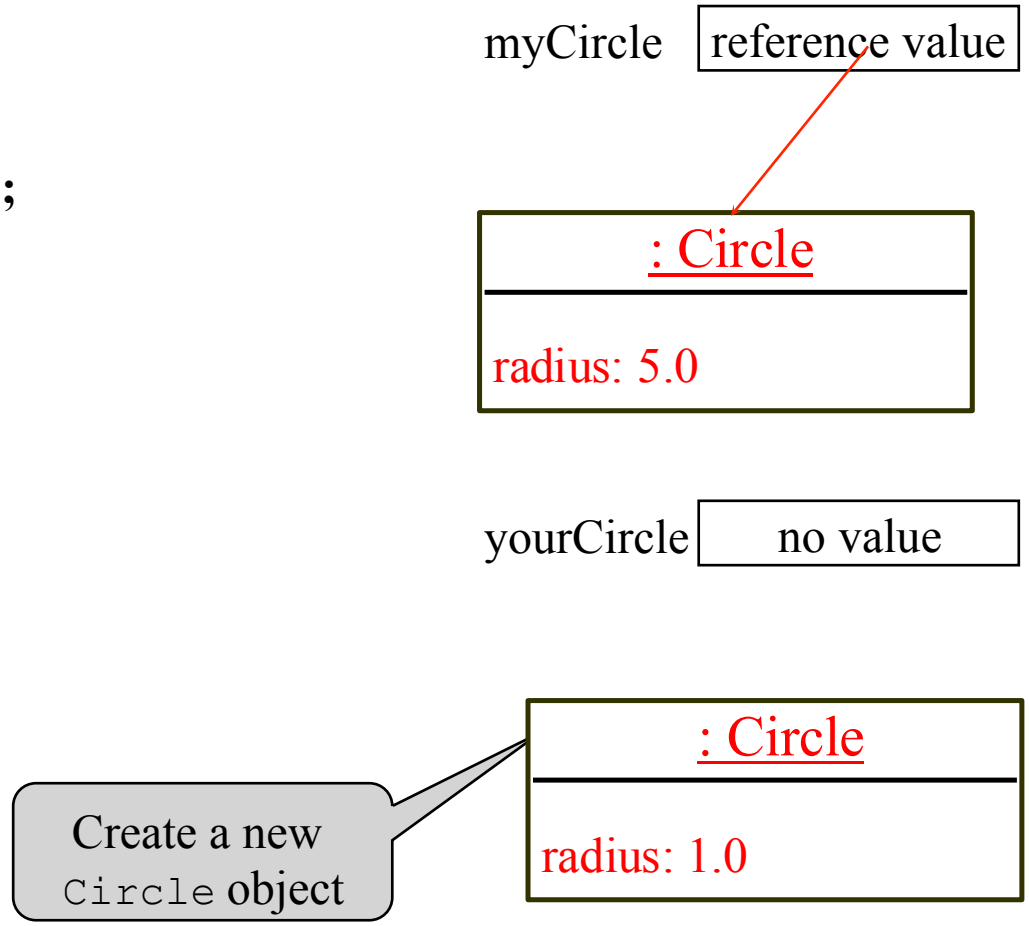

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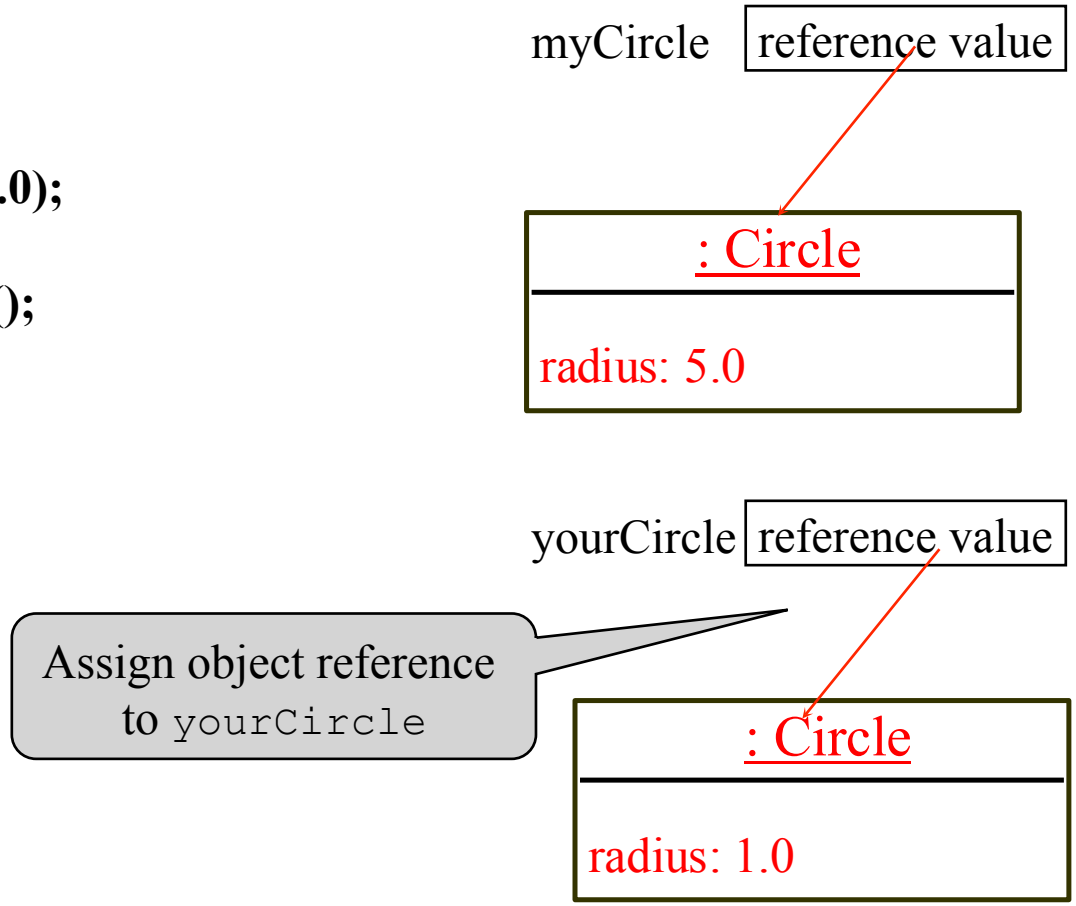

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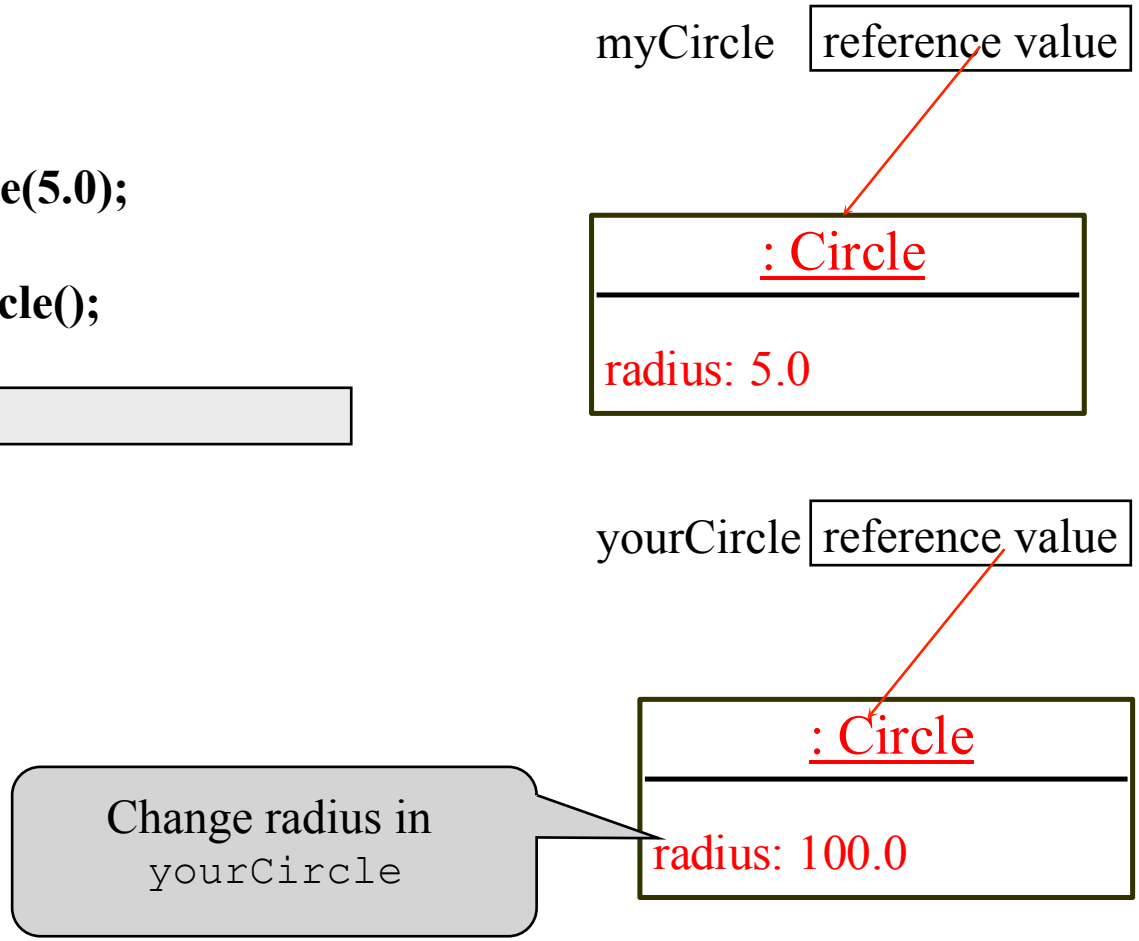

Data Fields and Default Values

Data fields can be primitive or reference types.

For example, the following `Student` class contains a data field `name` of the `String` type, a data field `age` of type `int` etc.

```
class Student {
   String name; // default value null
   int age; // default value 0
   boolean isScienceMajor; // default value false
   char gender; // default value '\u0000'
}
```

Data fields are assigned default values: `null` for reference types, 0 for numeric types, `false` for boolean types, and `'\u0000'` for char types:

- Note `null` is a literal for reference types just like, for example, `true` and `false` are literals for boolean types.

Default Values for Data Fields

What is the output of the following code?

```
public class Test {
  public static void main(String[] args) {
    Student student = new Student();
    System.out.println("name? " + student.name);
    System.out.println("age? " + student.age);
    System.out.println("isScienceMajor? " + student.isScienceMajor);
    System.out.println("gender? " + student.gender);
  }
}
```

Output:

Default Values for Data Fields

What is the output of the following code?

```
public class Test {
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    System.out.println("isScienceMajor? " + student.isScienceMajor);
    System.out.println("gender? " + student.gender);
  }
}
```

Output:

```
name? null
age? 0
isScienceMajor? false
gender?
```

Caution

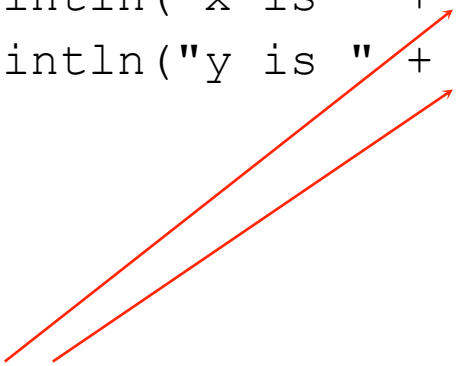
Java does not assign a default value to (local) variables inside a method...

```
public class Test {
  public static void main(String[] args) {
    int x;
    String y;
    System.out.println("x is " + x);
    System.out.println("y is " + y);
  }
}
```

Caution

Java does not assign a default value to (local) variables inside a method...

```
public class Test {
  public static void main(String[] args) {
    int x;
    String y;
    System.out.println("x is " + x);
    System.out.println("y is " + y);
  }
}
```



Compile error: variables not initialized

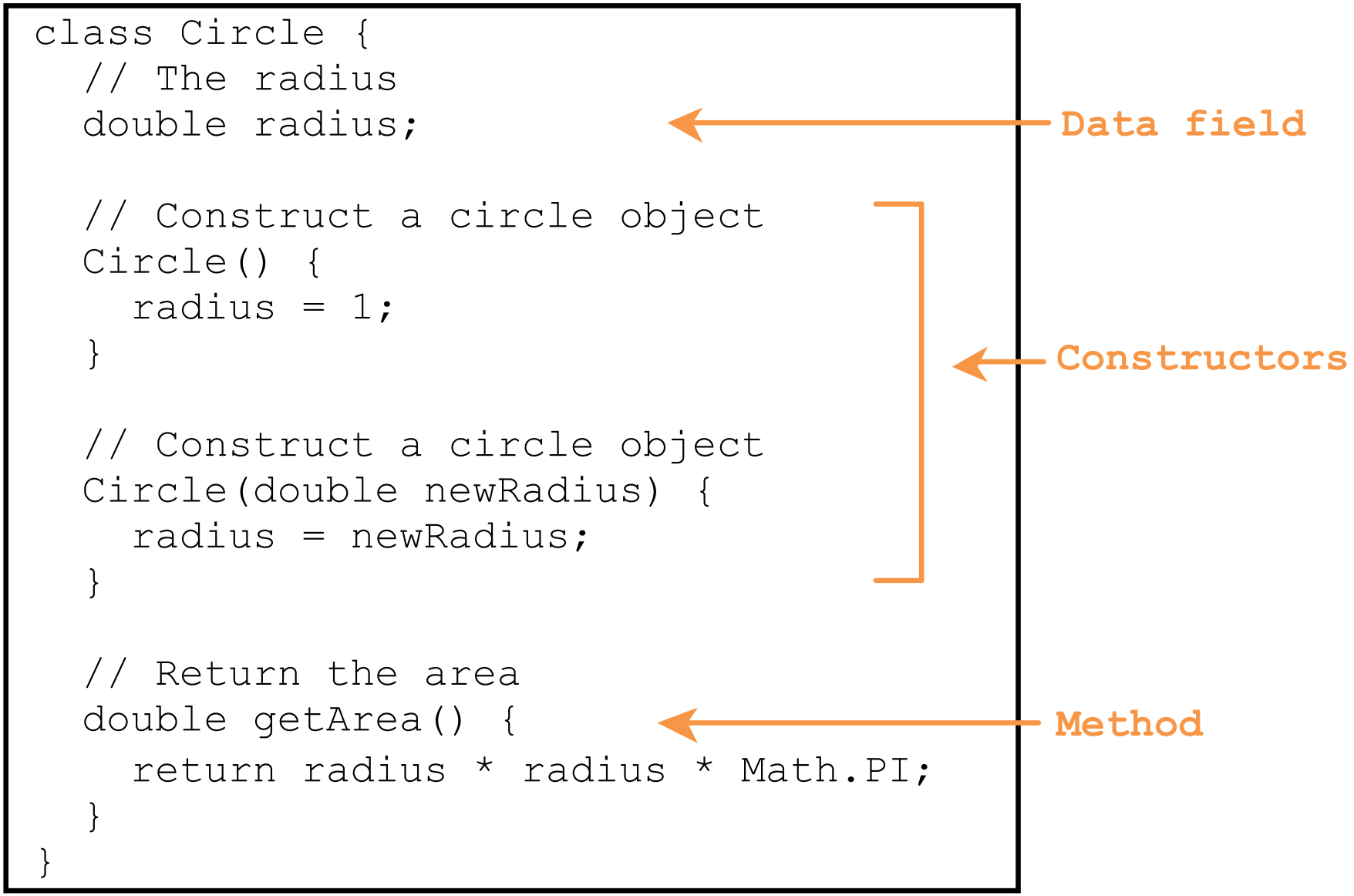
Example Class: `Circle`

```
class Circle {
  // The radius
  double radius;

  // Construct a circle object
  Circle() {
    radius = 1;
  }

  // Construct a circle object
  Circle(double newRadius) {
    radius = newRadius;
  }

  // Return the area
  double getArea() {
    return radius * radius * Math.PI;
  }
}
```



Instance Variables and Methods

The data field `radius` in the circle class is known as an *instance variable*.

An instance variable is tied to a specific instance of the class – it is not shared among objects of the same class.

For example, suppose that you create the following objects:

```
Circle c1 = new Circle(2);
Circle c2 = new Circle(5);
```

The radius in `c1` is independent of the radius in `c2`.

Changes to `c1`'s radius do not affect `c2`'s radius, and vice versa.

Instance variables and instance methods are accessed via a reference variable – for example `c1.radius`, `c1.getArea()`.

Static Variables, Constants, Methods

If you want all the instances of a class to share data, use *static variables* (aka *class variables*).

Static variables are shared by all objects of the class. If one object changes the value of a static variable, all objects of the same class are affected.

Static methods are not tied to a specific object. Static methods cannot access instance members of the class.

Constants in a class are shared by all objects of the class. Constants should be declared as `final static`. For example, the constant `PI` in the Math class is defined as:

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

Static variables, constants and methods should be accessed from their class name – for example `Math.PI`, `Math.pow(2,3)`

To declare static variables, methods, and constants, use the `static` modifier.

Scope of Instance and Static Variables

The scope of instance and static variables is the entire class. They can be declared anywhere inside a class.

Typically, instance and static variables are declared at the beginning of a class.

Example Using Instance and Static Variables and Methods

Objective:

- Demonstrate the roles of instance and static variables and their uses.
- This example uses a static variable `numberOfObjects` and a static method `getNumberOfObjects()` to track the number of objects created.

CircleWithStaticMembers

TestCircleWithStaticMembers

UML Class Diagrams

Consider television sets...

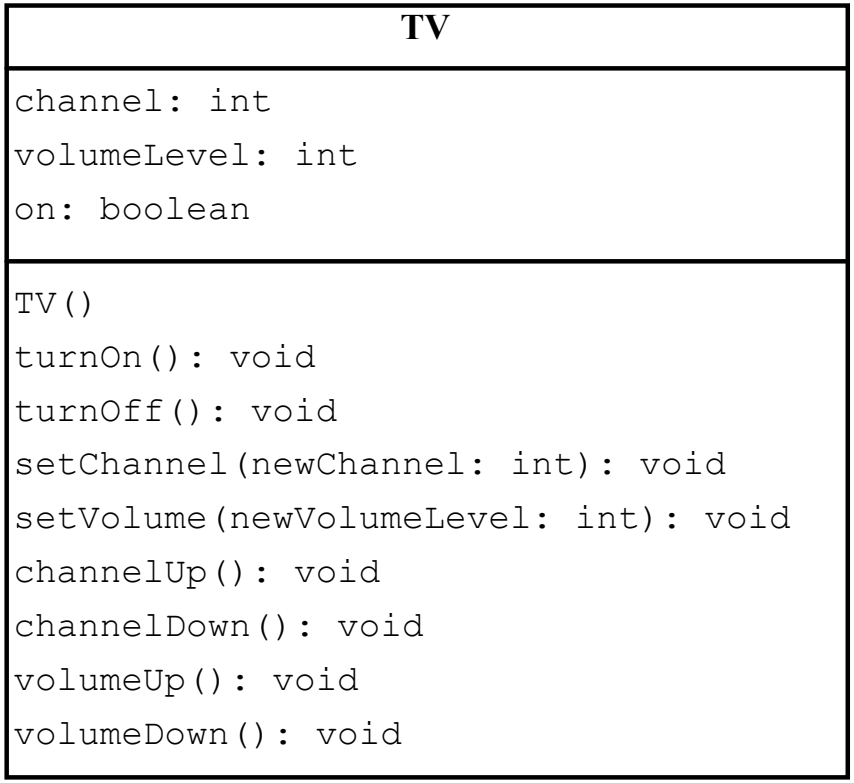
Each TV is an object with:

- State (current channel, current volume level, power on or off)
- Behaviour (change channel, adjust volume, turn on/off)

You can use a class to model TV sets. The UML diagram for the class is shown on the next slide

UML Class Diagrams

UML Class Diagram



The current channel (1 to 120) of this TV.

The current volume level (1 to 7) of this TV.

Indicates whether this TV is on/off.

Constructs a default TV object.

Turns on this TV.

Turns off this TV.

Sets a new channel for this TV.

Sets a new volume level for this TV.

Increases the channel number by 1.

Decreases the channel number by 1.

Increases the volume level by 1.

Decreases the volume level by 1.

UML Class Diagrams

UML Class Diagram

TV
channel: int volumeLevel: int on: boolean
TV() turnOn(): void turnOff(): void setChannel(newChannel: int): void setVolume(newVolumeLevel: int): void channelUp(): void channelDown(): void volumeUp(): void volumeDown(): void

The current channel (1 to 120) of this TV.
The current volume level (1 to 7) of this TV.
Indicates whether this TV is on/off.

Constructs a default TV object.
Turns on this TV.
Turns off this TV.
Sets a new channel for this TV.
Sets a new volume level for this TV.
Increases the channel number by 1.
Decreases the channel number by 1.
Increases the volume level by 1.
Decreases the volume level by 1.

UML notation for objects

```
TV tv1 = new TV()
```

tv1: TV
channel = 30 volumeLevel = 3 on = true

```
TV tv2 = new TV()
```

tv2: TV
channel = 3 volumeLevel = 2 on = true

Visibility Modifiers

Visibility modifiers can be used to specify the visibility of a class and its members.

If no visibility modifier is used, then classes, data fields and methods can be accessed by any class in the same *package* (referred to as *package-private* or *package access*).

`public` visibility modifier – classes, data fields and methods can be accessed by any class in any package.

`private` visibility modifier – data fields and methods can be accessed only by the declaring class.

Visibility Modifiers

```
package p1;

class C1 {
  ...
}
```

```
package p1;

public class C2 {
  can access C1
}
```

```
package p2;

public class C3 {
  cannot access C1;
  can access C2;
}
```

If a class is not defined as public, it can be accessed only within the same package.

Class `C1` can be accessed from `C2` but not from `C3`.

Visibility Modifiers

```
package p1;

public class C1 {
  public int x;
  int y;
  private int z;

  public void m1() {
  }
  void m2() {
  }
  private void m3() {
  }
}
```

```
package p1;

public class C2 {
  void aMethod() {
    C1 o = new C1();
    can access o.x;
    can access o.y;
    cannot access o.z;

    can invoke o.m1();
    can invoke o.m2();
    cannot invoke o.m3();
  }
}
```

```
package p2;

public class C3 {
  void aMethod() {
    C1 o = new C1();
    can access o.x;
    cannot access o.y;
    cannot access o.z;

    can invoke o.m1();
    cannot invoke o.m2();
    cannot invoke o.m3();
  }
}
```

The `private` modifier restricts access to within a class, the default modifier restricts access to within a package, and the `public` modifier enables unrestricted access.

Data Field Encapsulation

Making data fields `private` makes code robust and classes easy to maintain.

To prevent direct modifications of data fields, data fields should be declared private, using the `private` modifier.

This is known as *data field encapsulation*.

Getter and Setter Methods

A private data field cannot be accessed by an object from outside the class that defines it.

However, a client program often needs to retrieve and/or modify data fields:

- To make a private data field accessible, use a *getter* (aka *accessor*) method.
- To enable a private data field to be updated, use a *setter* (aka *mutator*) method.
- Each data field has its own getter/setter methods.

```
public class Circle {
  private double radius;

  public Circle() {
    radius = 1;
  }

  public double getRadius() { // getter method
    return radius;
  }

  public void setRadius(double newRadius) { // setter method
    radius = newRadius;
  }
}
```

Getter and Setter Methods

A getter method has the following signature:

- `public returnType getPropertyName()`
- Example: `public double getRadius()`

A setter method has the following signature:

- `public void setPropertyName(dataType propertyValue)`
- Example: `public void setRadius(double radius)`

Data Field Encapsulation

Why is it good practice?

- Recall, we defined a static variable `numberOfObjects` in class `CircleWithStaticMembers` to track the number of objects created:
  - If this variable is not private, client programs can set it to an arbitrary value, e.g. `CircleWithStaticMembers.numberOfObjects = 100;`
- As an another example, consider a database application where we wish to allow client programs to view data fields but not to modify them:
  - Make data fields private and provide getter methods, but not setter methods (more later: *immutable objects and classes*)

Make all data fields (instance and static) private.

Provide getter/setter methods when you wish to allow a client program to retrieve/modify data fields.

Preventing Instantiation

In most cases, constructors are public or package-private.

To prevent a client program from creating an instance of a class, use a private constructor.

For example, there is no reason to create an instance of the `Math` class – its constructor is defined as:

```
private Math() {
}
```

Consider the `MyMath` class from Chapter 6...

MyMath

TestMyMath

`this` Reference

`this` is a reference that refers to an object itself.

There are two common uses for the reference `this` …

`this` Reference

Using `this` to reference a class's *hidden instance data fields*:

- A data field name is often used as the parameter name in a setter method – in such cases, the data field is said to be *hidden* in the setter method
- A hidden instance variable is accessed using the keyword `this`

A *hidden static variable* is accessed using `ClassName.variable`

`this` Reference

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- A hidden instance variable is accessed using the keyword `this`

A *hidden static variable* is accessed using `ClassName.variable`

```
public class F {
  private int j = 1;
  private static int k = 2;

  public void setJ(int newJ) {
    j = newJ;
  }

  public static void setK(int newK) {
    k = newK;
  }
  …
}
```

`this` Reference

Using `this` to reference a class's *hidden instance data fields*:

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  }

  public static void setK(int newK) {
    k = newK;
  }
  …
}
```

≡

```
public class F {
  private int j = 1;
  private static int k = 2;

  public void setJ(int j) {
    this.j = j;
  }

  public static void setK(int k) {
    F.k = k;
  }
  …
}
```

`this` Reference

Using `this` to enable a constructor to invoke another constructor of the same class.

`this` Reference

Using `this` to enable a constructor to invoke another constructor of the same class.

```
public class Circle {
  private double radius;

  public Circle() {
    radius = 1.0;
  }

  public Circle(double radius) {
    this.radius = radius;
  }
  …
}
```

`this` Reference

Using `this` to enable a constructor to invoke another constructor of the same class.

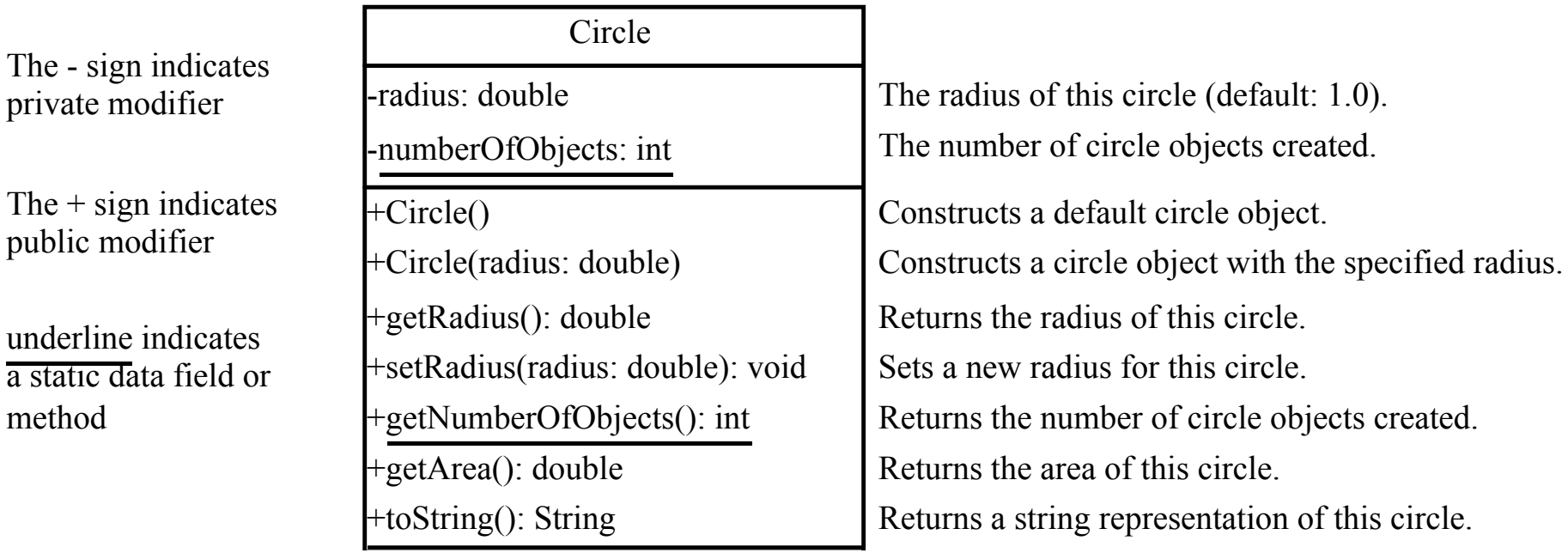
```
public class Circle {
  private double radius;

  public Circle() {
    radius = 1.0;
  }

  public Circle(double radius) {
    this.radius = radius;
  }
  …
}
```

```
public class Circle {
  private double radius;

  public Circle() {
    this(1.0);
  }

  public Circle(double radius) {
    this.radius = radius;
  }
  …
}
```

Example

Bringing it all together – example using visibility modifiers, getter (accessor) and setter (mutator) methods and using the `this` reference.

UML diagram for class `Circle`:



Circle

TestCircle

Differences between Variables of Primitive Data Types and Object Types

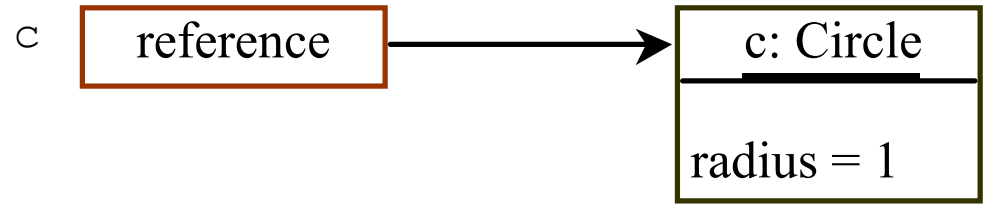
Differences between Variables of Primitive Data Types and Object Types

Primitive type

```
int i = 1;
```

Object type

```
Circle c = new Circle();
```

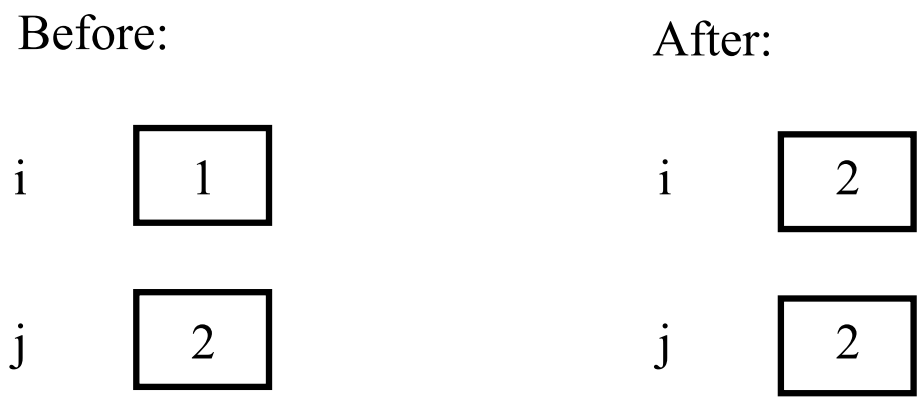


Copying Variables of Primitive Data Types

```
int i = 1;
int j = 2;

i = j; // primitive type assignment
```

Copying Variables of Primitive Data Types

```
int i = 1;
int j = 2;

i = j; // primitive type assignment
```



Copying Variables of Object Types

```
Circle c1 = new Circle(5);
Circle c2 = new Circle(9);

c1 = c2; // object type assignment
```

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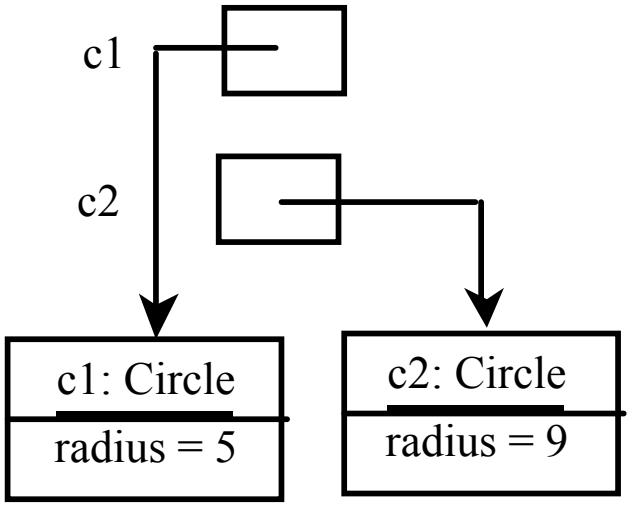
Before:



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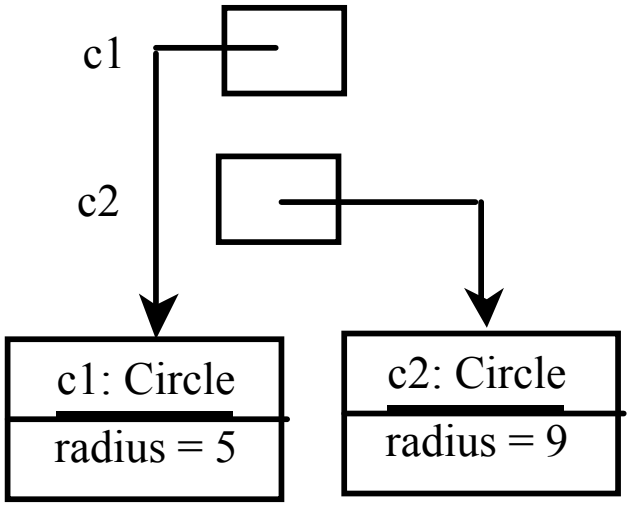
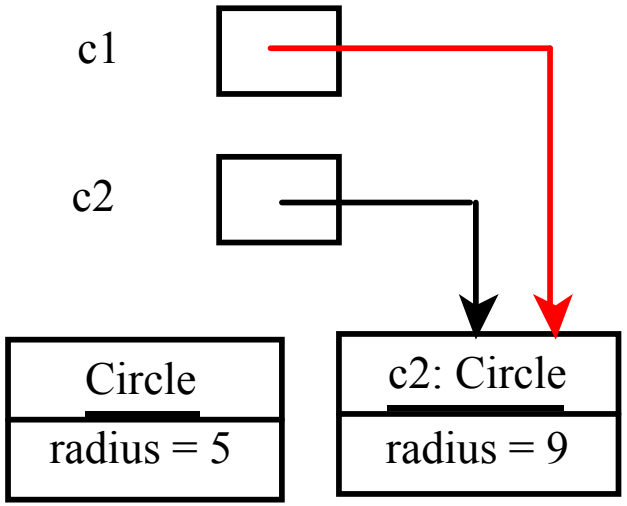


After:



Garbage Collection

As shown in the previous example, after the assignment statement `c1 = c2`, `c1` references the same object referenced by `c2`.

The object previously referenced by `c1` is no longer referenced.

This object is known as *garbage* – i.e. when it is no longer referenced by any reference variable.

Garbage is automatically collected by the JVM.

Immutable Objects and Classes

Normally, you create an object and allow its contents to be changed at a later time as needed (e.g. updating the radius of a `Circle` object).

Occasionally it is desirable to create an object whose contents cannot be changed once the object has been created.

To this end, *immutable classes* can be defined to create *immutable objects*. The contents of immutable objects cannot be changed.

For example, the `String` class is designed to be immutable.

Immutable Objects and Classes

If the setter method in the `Circle` class was deleted, then the class would be immutable (because `radius` is private and cannot be changed without a setter method).

```
public class Circle {
  private double radius;

  public Circle() {
    radius = 1;
  }

  public double getRadius() { // getter method
    return radius;
  }

  public void setRadius(double radius) { // setter method
    this.radius = radius;
  }
  …
}
```

Immutable Objects and Classes

However – a class with all private data fields and without setter methods is not necessarily immutable.

For example, the following class `Student` has all private data fields and no setter methods, but it is mutable.

```
public class BirthDate {
  private int year;
  private int month;
  private int day;

  public BirthDate(int year,
    int month, int day) {

    this.year = year;
    this.month = month;
    this.day = day;
  }

  public void setYear(int year) {
    this.year = year;
  }
}
```

```
public class BirthDate {
  private int year;
  private int month;
  private int day;

  public BirthDate(int year,
    int month, int day) {

    this.year = year;
    this.month = month;
    this.day = day;
  }

  public void setYear(int year) {
    this.year = year;
  }
}
```

```
public class Student {
  private int id;
  private BirthDate birthDate;

  public Student(int ssn,
    int year, int month, int day) {

    id = ssn;
    birthDate =
      new BirthDate(year, month, day);
  }

  public int getId() {
    return id;
  }

  public BirthDate getBirthDate() {
    return birthDate;
  }
}
```

```
public class BirthDate {
  private int year;
  private int month;
  private int day;

  public BirthDate(int year,
    int month, int day) {

    this.year = year;
    this.month = month;
    this.day = day;
  }

  public void setYear(int year) {
    this.year = year;
  }
}
```

```
public class Student {
  private int id;
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  public Student(int ssn,
    int year, int month, int day) {

    id = ssn;
    birthDate =
      new BirthDate(year, month, day);
  }

  public int getId() {
    return id;
  }

  public BirthDate getBirthDate() {
    return birthDate;
  }
}
```

```
public class Test {
  public static void main(String[] args) {
    Student student = new Student(111223333, 1970, 5, 3);
    BirthDate date = student.getBirthDate();
    date.setYear(2010); // Now the student birth year is changed!
  }
}
```

Immutable Objects and Classes

For a class to be immutable, it must meet the following requirements:

- All data fields must be private.
- No setter (mutator) methods for data fields.
- No getter (accessor) methods that can return a reference to a data field that is mutable.

Passing Objects to Methods

Recall – Java uses exactly one mode of passing arguments to methods: pass-by-value.

Passing an object to a method is to pass the *reference* of the object to the method.

(Same as passing an array to a method – the array reference variable is passed.)

Examples – illustrate pass-by-value and the difference between passing a primitive type and an object to a method.

TestPassObject1

TestPassObject2

Arrays of Objects

An array can hold objects as well as primitive type values.

Recall – to declare and create a primitive type array of 10 integers:

```
int[] array = new int[10];
```

The following statement declares and creates an array of 10 `Circle` objects:

```
Circle[] circleArray = new Circle[10];
```

To initialize `circleArray`, you can use a `for` loop like this for example:

```
for (int i = 0; i < circleArray.length; i++)
  circleArray[i] = new Circle(i + 1);
```

Array of Objects

An array of objects is actually an *array of reference variables*.

Invoking `circleArray[1].getArea()` involves two levels of referencing:

- `circleArray` references the entire array
- `circleArray[1]` references a `Circle` object

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Example:

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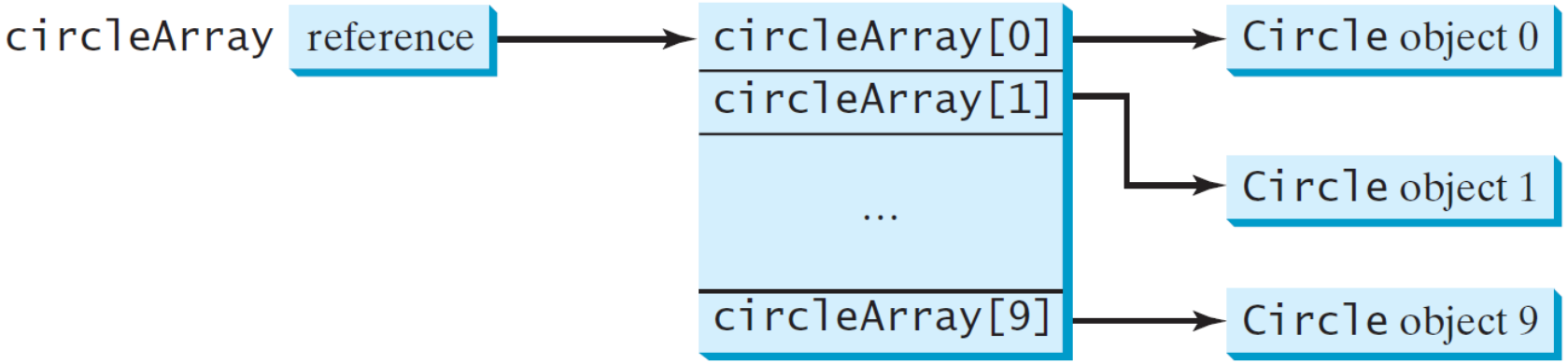

Array of Objects

Example – using arrays of objects and passing/returning arrays of objects to/from methods.

TotalArea

Next topics…

This lecture: concluded Chapter 9 – introducing classes and objects.

Next lectures: Chapter 10 – strings, object-oriented paradigm, class relationships.