1 Object-Oriented Programming: Inheritance

1.1 Introduction

- Inheritance
  - Software reusability
  - Create new class from existing class
    - Absorb existing class's data and behaviors
    - Enhance with new capabilities
  - Derived class inherits from base class
    - Derived class
      - More specialized group of objects
      - Behaviors inherited from base class; can customize
      - Additional behaviors
- Class hierarchy
  - Direct base class; inherited explicitly (one level up hierarchy)
  - Indirect base class; inherited two or more levels up hierarchy
  - Single inheritance; inherits from one base class
  - Multiple inheritance; Inherits from multiple base classes (Base classes possibly unrelated); Chapter 22
- Three types of inheritance
  - **public**
    - Every object of derived class also object of base class
      - Base-class objects not objects of derived classes
      - Example: All cars vehicles, but not all vehicles cars
    - Can access non-**private** members of base class
      - Derived class can effect change to **private** base-class members
      - Through inherited non-**private** member functions
  - **private**
    - Alternative to composition
    - Chapter 17

  - **protected**
    * Rarely used

- Abstraction
  - Focus on commonalities among objects in system; "is-a" vs. "has-a"
  - "is-a"
    * Inheritance
    * Derived class object treated as base class object
    * Example: Car *is a* vehicle; Vehicle properties/behaviors also car properties/behaviors
  - "has-a"
    * Composition
    * Object contains one or more objects of other classes as members
    * Example: Car *has a* steering wheel

1.2 Base Classes and Derived Classes

- Base classes and derived classes
  - Object of one class "is an" object of another class
    * Example: Rectangle is quadrilateral.
      · Class **Rectangle** inherits from class **Quadrilateral**
      · **Quadrilateral**: base class
      · **Rectangle**: derived class
  - Base class typically represents larger set of objects than derived classes
    * Example:
      · Base class: **Vehicle**
      Cars, trucks, boats, bicycles, ...
      · Derived class: **Car**
      Smaller, more-specific subset of vehicles

- Inheritance examples (see Fig. 1)
- Inheritance hierarchy (see Fig. 2 Top)

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9.2 Base Classes and Derived Classes

- Inheritance examples

Base class	Derived classes
`Student`	`GraduateStudent` `UndergraduateStudent`

`Shape`	`Circle`
	`Triangle`
	`Rectangle`

`Loan`	`CarLoan`
	`HomeImprovementLoan`
	`MortgageLoan`

`Employee`	`FacultyMember` `StaffMember`
`Account`	`CheckingAccount` `SavingsAccount`

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Figure 1: Inheritance examples

  - Inheritance relationships: tree-like hierarchy structure
  - Each class becomes
    - Base class; supply data/behaviors to other classes
    - OR
    - Derived class; inherit data/behaviors from other classes

- public inheritance
  - Specify with:
  - **Class TwoDimensionalShape : public Shape**
    Class **TwoDimensionalShape** inherits from class **Shape** (see Fig. 2 Bottom)
  - Base class **private** members
    - Not accessible directly
    - Still inherited; manipulate through inherited member functions

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Fig. 9.2 Inheritance hierarchy for university `CommunityMember`s.

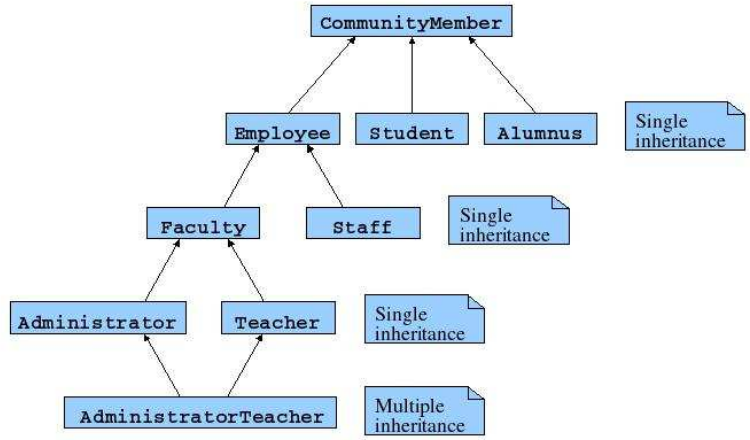

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Fig. 9.3 Inheritance hierarchy for Shapes.

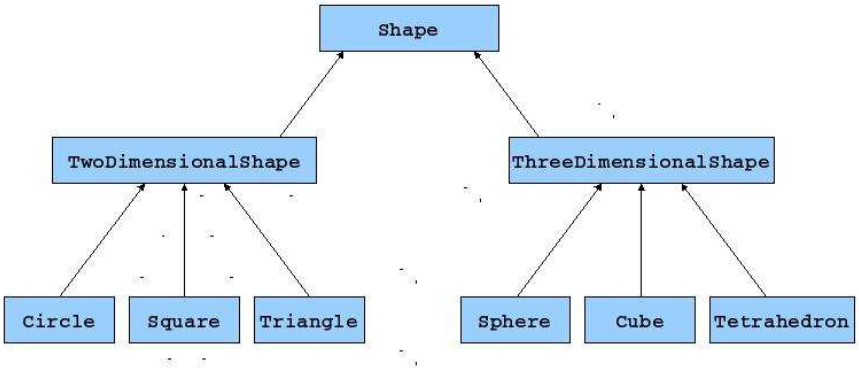

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Figure 2: Inheritance hierarchy for university **CommunityMembers** and Inheritance hierarchy for **Shape**s

  - Base class **public** and **protected** members; inherited with original member access
  - **friend** functions; not inherited

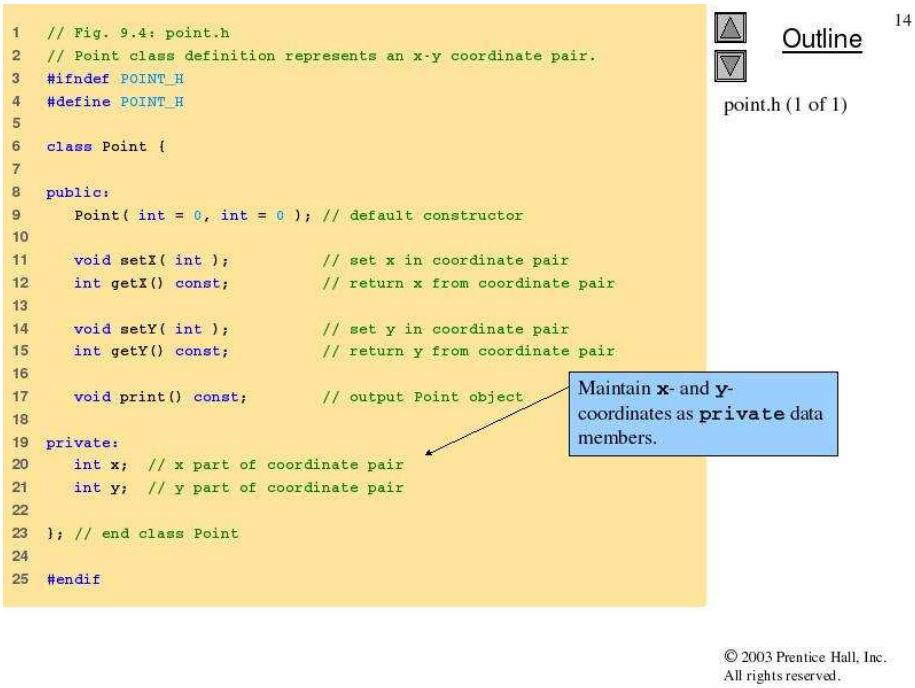
1.3 protected Members

Protected access

- Intermediate level of protection between **public** and **private**
- **protected** members accessible to
  - Base class members
  - Base class **friend**s
  - Derived class members
  - Derived class **friend**s
- Derived-class members
  - Refer to **public** and **protected** members of base class; simply use member names

1.4 Relationship between *Base Classes* and *Derived Classes*

- Base class and derived class relationship
- Example: Point/circle inheritance hierarchy
  - Point
    x-y coordinate pair
  - Circle
    x-y coordinate pair
    Radius



```
1  // Fig. 9.4: point.h
2  // Point class definition represents an x-y coordinate pair.
3  #ifndef POINT_H
4  #define POINT_H
5
6  class Point {
7
8  public:
9     Point( int = 0, int = 0 ); // default constructor
10
11    void setX( int );          // set x in coordinate pair
12    int getX() const;          // return x from coordinate pair
13
14    void setY( int );          // set y in coordinate pair
15    int getY() const;          // return y from coordinate pair
16
17    void print() const;        // output Point object
18
19 private:
20    int x;  // x part of coordinate pair
21    int y;  // y part of coordinate pair
22
23 }; // end class Point
24
25 #endif
```


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Figure 3: **Point** class header file

```
1  // Fig. 9.5: point.cpp
2  // Point class member-function definitions.
3  #include <iostream>
4
5  using std::cout;
6
7  #include "point.h"   // Point class definition
8
9  // default constructor
10 Point::Point( int xValue, int yValue )
11 {
12    x = xValue;
13    y = yValue;
14
15 } // end Point constructor
16
17 // set x in coordinate pair
18 void Point::setX( int xValue )
19 {
20    x = xValue; // no need for validation
21
22 } // end function setX
23
```

Outline

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point.cpp (1 of 3)

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```
24 // return x from coordinate pair
25 int Point::getX() const
26 {
27    return x;
28
29 } // end function getX
30
31 // set y in coordinate pair
32 void Point::setY( int yValue )
33 {
34    y = yValue; // no need for validation
35
36 } // end function setY
37
38 // return y from coordinate pair
39 int Point::getY() const
40 {
41    return y;
42
43 } // end function getY
44
```

Outline

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point.cpp (2 of 3)

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Figure 4: **Point** class represents an xy-coordinate pair. (part 1 of 2)

```
45 // output Point object
46 void Point::print() const
47 {
48    cout << '[' << x << ", " << y << ']';
49
50 } // end function print
```

Outline

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point.cpp (3 of 3)

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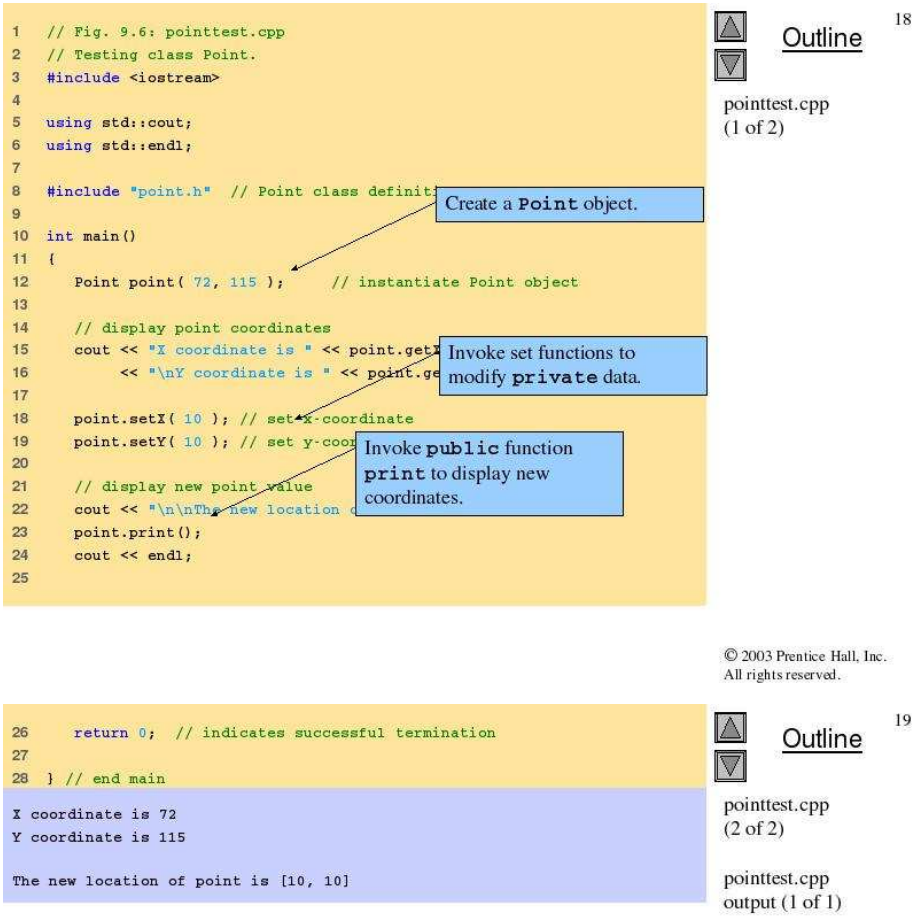
Figure 5: **Point** class represents an xy-coordinate pair. (part 2 of 2)



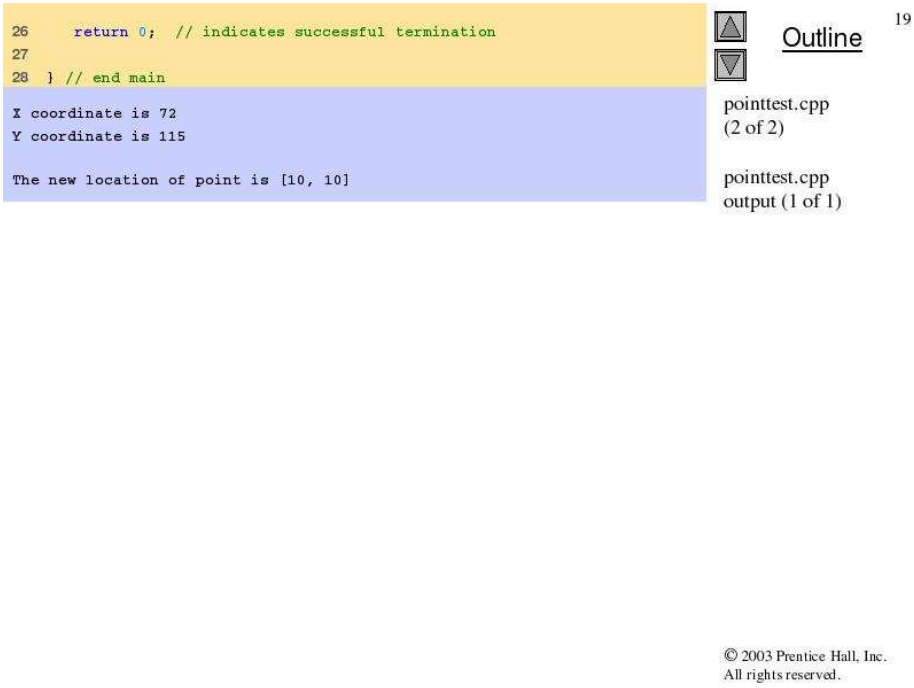


Figure 6: **Point** class test program.

1.4.1 Creating a Circle class without using inheritance

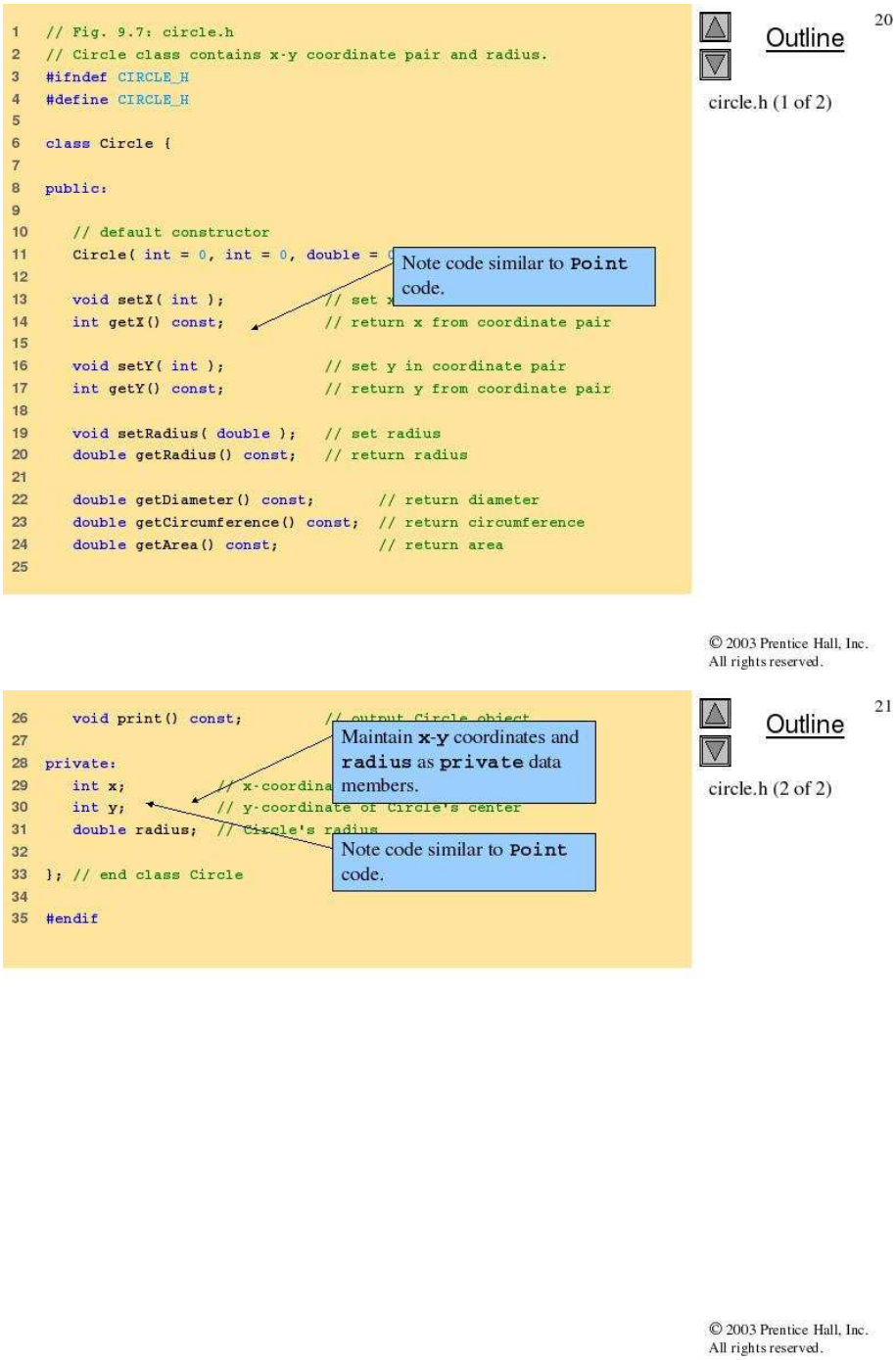


Figure 7: **Circle** class header file.

```
1  // Fig. 9.8: circle.cpp
2  // Circle class member-function definitions.
3  #include <iostream>
4
5  using std::cout;
6
7  #include "circle.h"   // Circle class definition
8
9  // default constructor
10 Circle::Circle( int xValue, int yValue, double radiusValue )
11 {
12    x = xValue;
13    y = yValue;
14    setRadius( radiusValue );
15
16 } // end Circle constructor
17
18 // set x in coordinate pair
19 void Circle::setX( int xValue )
20 {
21    x = xValue; // no need for validation
22
23 } // end function setX
24
```

Outline

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circle.cpp (1 of 4)

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```
25 // return x from coordinate pair
26 int Circle::getX() const
27 {
28    return x;
29
30 } // end function getX
31
32 // set y in coordinate pair
33 void Circle::setY( int yValue )
34 {
35    y = yValue; // no need for validation
36
37 } // end function setY
38
39 // return y from coordinate pair
40 int Circle::getY() const
41 {
42    return y;
43
44 } // end function getY
45
```

Outline

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circle.cpp (2 of 4)

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Figure 8: **Circle** class contains an xy-coordinate pair and a radius. (part 1 of 2)


```
46 // set radius
47 void Circle::setRadius( double radiusValue )
48 {
49    radius = ( radiusValue < 0.0 ? 0.0 : radiusValue );
50
51 } // end function setRadius
52
53 // return radius
54 double Circle::getRadius() const
55 {
56    return radius;
57
58 } // end function getRadius
59
60 // calculate and return diameter
61 double Circle::getDiameter() const
62 {
63    return 2 * radius;
64
65 } // end function getDiameter
66
```

```
67 // calculate and return circumference
68 double Circle::getCircumference() const
69 {
70    return 3.14159 * getDiameter();
71
72 } // end function getCircumference
73
74 // calculate and return area
75 double Circle::getArea() const
76 {
77    return 3.14159 * radius * radius;
78
79 } // end function getArea
80
81 // output Circle object
82 void Circle::print() const
83 {
84    cout << "Center = [" << x << ", " << y << ']'
85         << "; Radius = " << radius;
86
87 } // end function print
```

Figure 9: **Circle** class contains an xy-coordinate pair and a radius. (part 2 of 2)

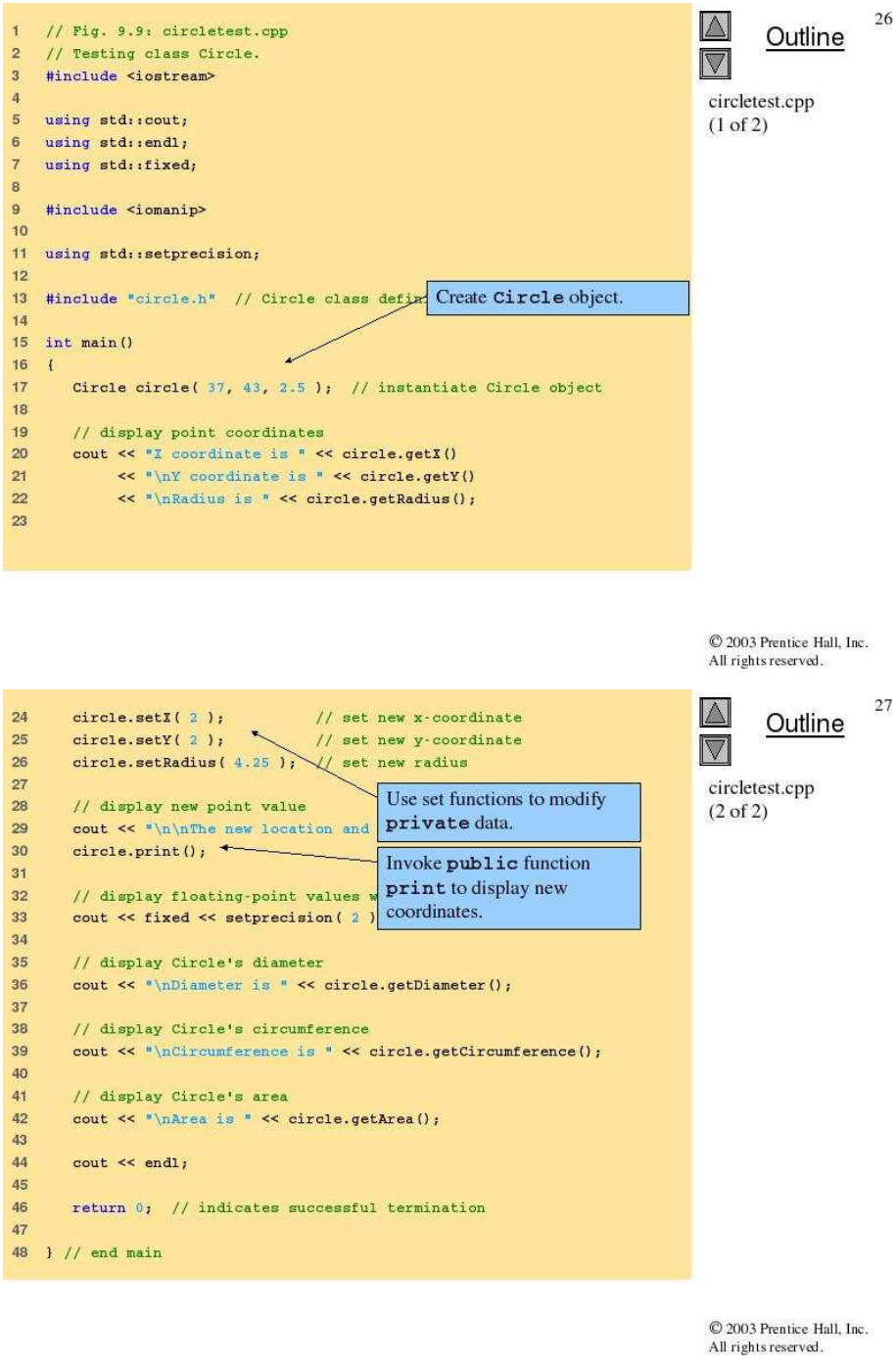

Figure 10: **Circle** class test program. (part 1 of 2)

1.4.2 Point/Circle Hierarchy using Inheritance

```
X coordinate is 37
Y coordinate is 43
Radius is 2.5

The new location and radius of circle are
Center = [2, 2]; Radius = 4.25
Diameter is 8.50
Circumference is 26.70
Area is 56.74
```

Outline

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circletest.cpp
output (1 of 1)

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```
1  // Fig. 9.10: circle2.h
2  // Circle2 class contains x-y coordinate pair and radius.
3  #ifndef CIRCLE2_H
4  #define CIRCLE2_H
5
6  #include "point.h"  // Point class
7
8  class Circle2 : public Point {
9
10 public:
11
12    // default constructor
13    Circle2( int = 0, int = 0,
14
15    void setRadius( double );   // set radius
16    double getRadius() const;   // return radius
17
18    double getDiameter() const;       // return diameter
19    double getCircumference() const;  // return circumference
20    double getArea() const;           // return area
21
22    void print() const;
23
24 private:
25    double radius;  // Circle2's radius
```

Class **Circle2** inherits from class **Point**.

Keyword **public** indicates type of inheritance.

Maintain **private** data member **radius**.

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circle2.h (1 of 2)

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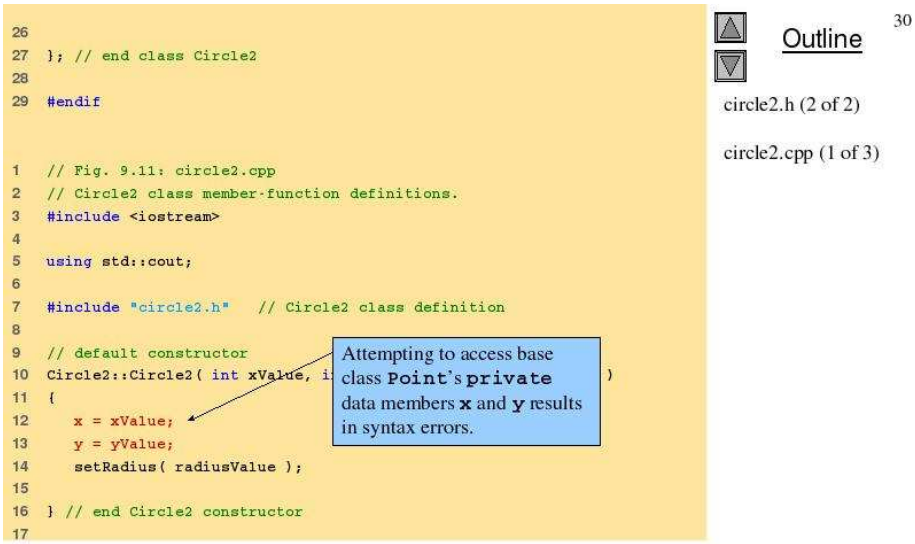
Figure 11: **Circle** class test program. (part 2 of 2) and **Circle2** class header file. (part 1 of 2)



```
26
27 }; // end class Circle2
28
29 #endif
```

Outline

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circle2.h (2 of 2)

circle2.cpp (1 of 3)

```
1  // Fig. 9.11: circle2.cpp
2  // Circle2 class member-function definitions.
3  #include <iostream>
4
5  using std::cout;
6
7  #include "circle2.h"    // Circle2 class definition
8
9  // default constructor
10 Circle2::Circle2( int xValue, i                    )
11 {
12    x = xValue;
13    y = yValue;
14    setRadius( radiusValue );
15
16 } // end Circle2 constructor
17
```

Attempting to access base class **Point**'s **private** data members **x** and **y** results in syntax errors.

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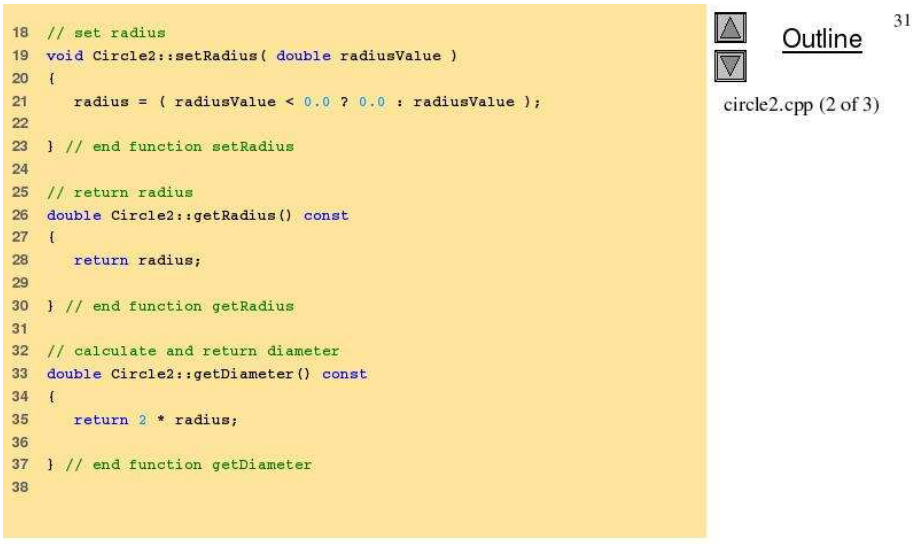

```
18 // set radius
19 void Circle2::setRadius( double radiusValue )
20 {
21    radius = ( radiusValue < 0.0 ? 0.0 : radiusValue );
22
23 } // end function setRadius
24
25 // return radius
26 double Circle2::getRadius() const
27 {
28    return radius;
29
30 } // end function getRadius
31
32 // calculate and return diameter
33 double Circle2::getDiameter() const
34 {
35    return 2 * radius;
36
37 } // end function getDiameter
38
```

Outline

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circle2.cpp (2 of 3)

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Figure 12: **Circle2** class header file (part 2 of 2) and Private base-class data can not be accessed from derived class. (part 1 of 2)

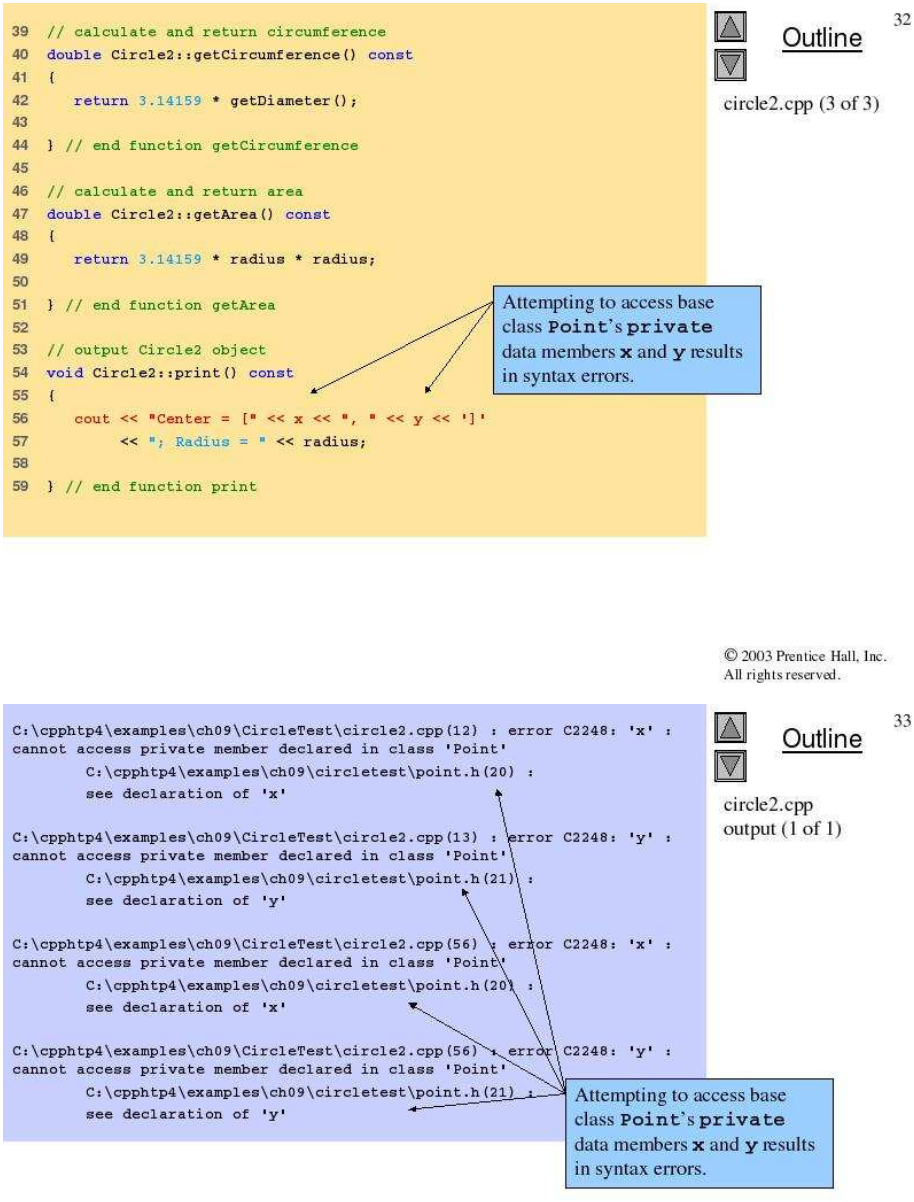

Figure 13: Private base-class data can not be accessed from derived class. (part 2 of 2)

1.4.3 Point/Circle Hierarchy using protected data

```
1  // Fig. 9.12: point2.h
2  // Point2 class definition represents an x-y coordinate pair.
3  #ifndef POINT2_H
4  #define POINT2_H
5
6  class Point2 {
7
8  public:
9     Point2( int = 0, int = 0 ); // default constructor
10
11    void setX( int );    // set x in coordinate pair
12    int getX() const;    // return x from coordinate pair
13
14    void setY( int );    // set y in coordinate pair
15    int getY() const;    //
16
17    void print() const;  //
18
19 protected:
20    int x;  // x part of coordinate pair
21    int y;  // y part of coordinate pair
22
23 }; // end class Point2
24
25 #endif
```

Maintain **x**- and **y**-coordinates as **protected** data, accessible to derived classes.

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point2.h (1 of 1)

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```
1  // Fig. 9.13: point2.cpp
2  // Point2 class member-function definitions.
3  #include <iostream>
4
5  using std::cout;
6
7  #include "point2.h"   // Point2 class definition
8
9  // default constructor
10 Point2::Point2( int xValue, int yValue )
11 {
12    x = xValue;
13    y = yValue;
14
15 } // end Point2 constructor
16
17 // set x in coordinate pair
18 void Point2::setX( int xValue )
19 {
20    x = xValue; // no need for validation
21
22 } // end function setX
23
```

Outline

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point2.cpp (1 of 3)

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Figure 14: **Point2** class header file.

```
24 // return x from coordinate pair
25 int Point2::getX() const
26 {
27    return x;
28
29 } // end function getX
30
31 // set y in coordinate pair
32 void Point2::setY( int yValue )
33 {
34    y = yValue; // no need for validation
35
36 } // end function setY
37
38 // return y from coordinate pair
39 int Point2::getY() const
40 {
41    return y;
42
43 } // end function getY
44
```

Outline

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point2.cpp (2 of 3)

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```
45 // output Point2 object
46 void Point2::print() const
47 {
48    cout << '[' << x << ", " << y << ']';
49
50 } // end function print
```

Outline

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point2.cpp (3 of 3)

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Figure 15: **Point2** class represents an xy-coordinate pair as **protected** data.

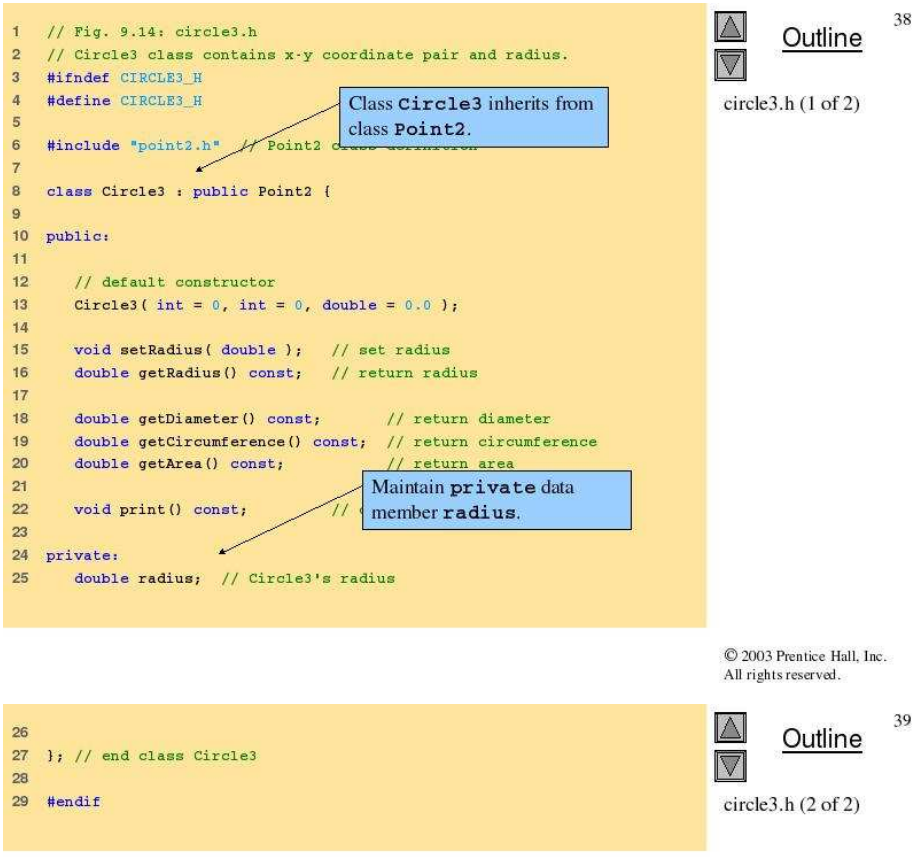

Figure 16: **Circle3** class header file.

```
1  // Fig. 9.15: circle3.cpp
2  // Circle3 class member-function definitions.
3  #include <iostream>
4
5  using std::cout;
6
7  #include "circle3.h"    // Cir
8
9  // default constructor
10 Circle3::Circle3( int xValue,                    )
11 {
12    x = xValue;
13    y = yValue;
14    setRadius( radiusValue );
15
16 } // end Circle3 constructor
17
18 // set radius
19 void Circle3::setRadius( double radiusValue )
20 {
21    radius = ( radiusValue < 0.0 ? 0.0 : radiusValue );
22
23 } // end function setRadius
24
```

Constructor first implicitly calls base class's default constructor.

`protected` in base class `Point2`.

circle3.cpp (1 of 3)

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```
25 // return radius
26 double Circle3::getRadius() const
27 {
28    return radius;
29
30 } // end function getRadius
31
32 // calculate and return diameter
33 double Circle3::getDiameter() const
34 {
35    return 2 * radius;
36
37 } // end function getDiameter
38
39 // calculate and return circumference
40 double Circle3::getCircumference() const
41 {
42    return 3.14159 * getDiameter();
43
44 } // end function getCircumference
45
```


circle3.cpp (2 of 3)

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Figure 17: **Circle3** class that inherits from class **Point2**.

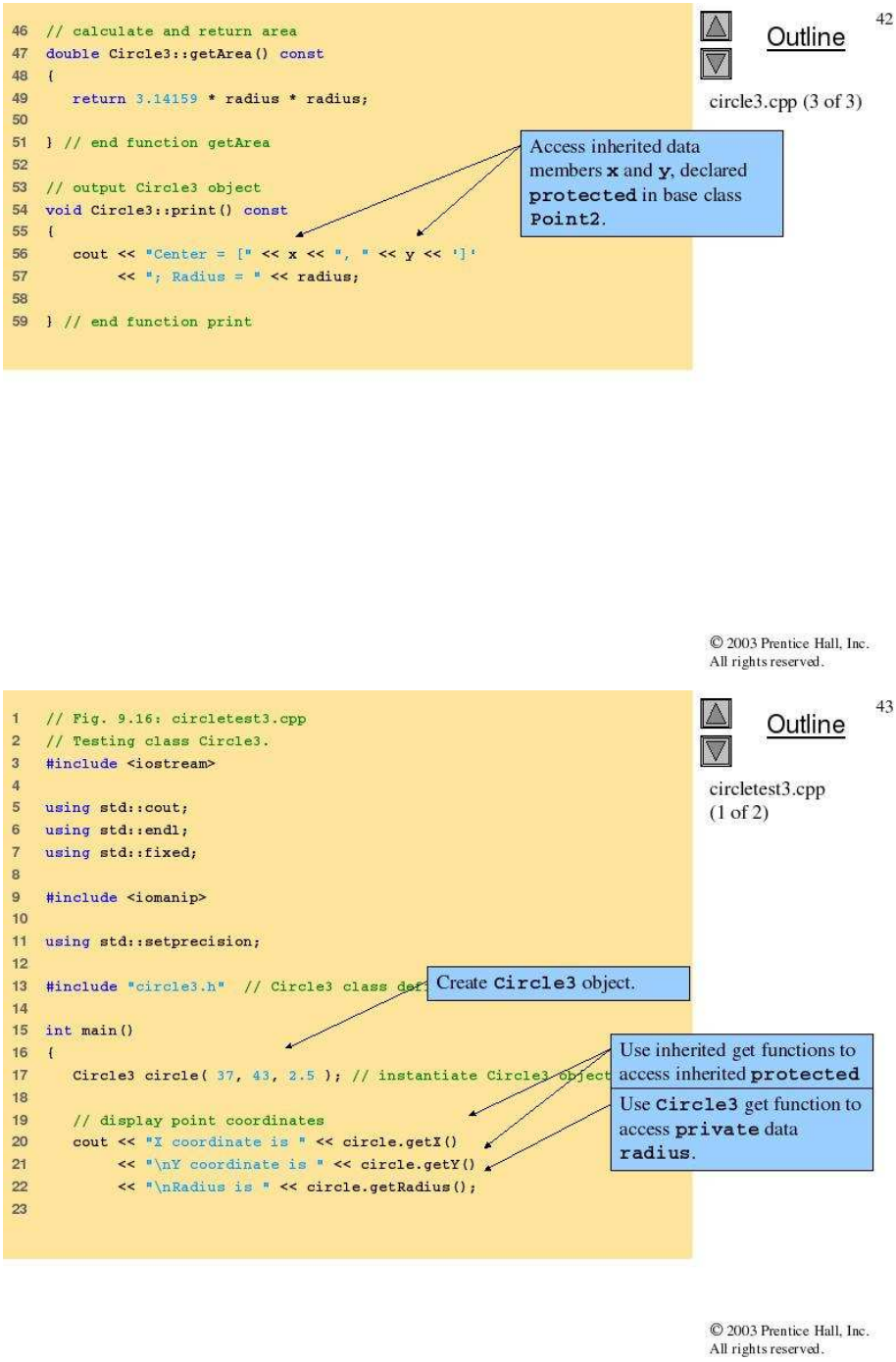

Figure 18: Protected base-class data can be accessed from derived class. (part 1 of 2)

Figure 19: Protected base-class data can be accessed from derived class. (part 2 of 2)

- Using protected data members
  - Advantages
    - Derived classes can modify values directly
    - Slight increase in performance; avoid set/get function call overhead
  - Disadvantages
    - No validity checking; derived class can assign illegal value
    - Implementation dependent
      - Derived class member functions more likely dependent on base class implementation
      - Base class implementation changes may result in derived class modifications; fragile (brittle) software