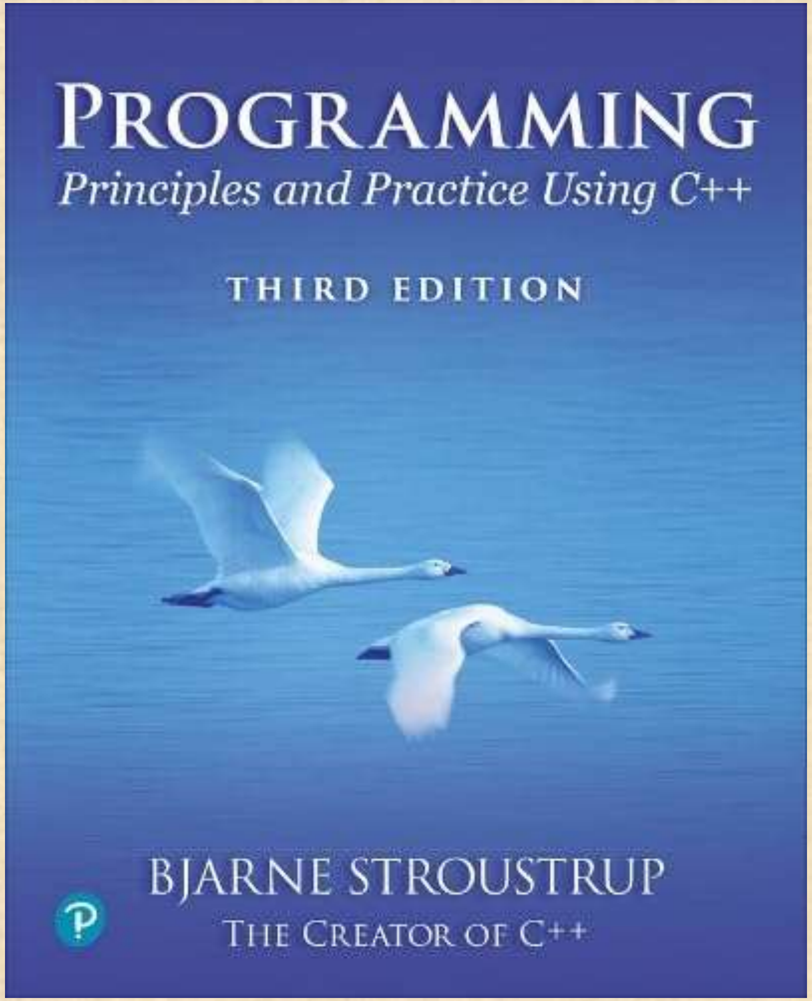
Chapter 12 – Class design



Functional, durable, beautiful.
– Vitruvius

Abstract

- We have discussed classes in previous lectures
- Here, we discuss design of classes
  - Library design considerations
  - Abstract classes and data hiding
  - Class hierarchies (object-oriented programming)
  - Some technicalities

A library

- A collection of classes and functions meant to be used together
  - As building blocks for applications
  - To build more such “building blocks”
- A good library models some aspect of a domain
  - It doesn’t try to do everything
  - Our library aims at simplicity and small size for graphing data and for very simple GUI
- We can’t define each library class and function in isolation
  - A good library exhibits a uniform style (“regularity”)
- Our Graphics/GUI library is an example

Logically identical operations have the same name

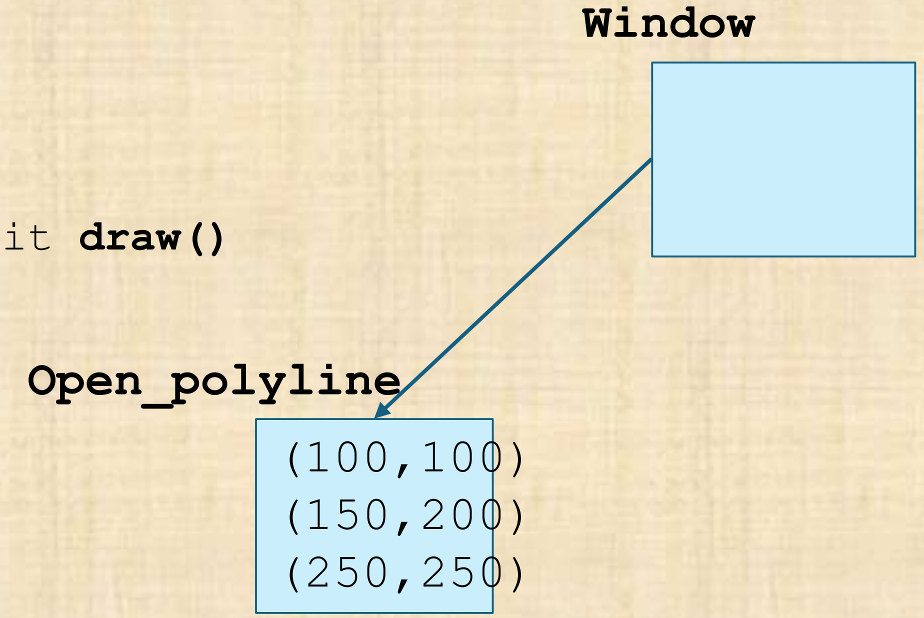
- For every class,
  - **draw()** does the drawing
  - **move(dx,dy)** does the moving
  - **s.add(x)** adds some **x** (*e.g.*, a point) to a shape **s**.
- For every property **x** of a Shape,
  - **x()** gives its current value and
  - **set_x()** gives it a new value
  - e.g.,

```
Color c = s.color();
s.set_color(Color::blue);
```

Logically different operations have different names

```
Open_polyline opl;
opl.add(Point{100,100});
opl.add(Point{150,200});
opl.add(Point{250,250});
win.attach(opl);
```

- Why not **win.add(opl)**?
  - **add()** copies information into **opl**
  - **attach()** just creates a reference to use when it **draw()**



Keep interfaces "regular"

- **Point**s are {x,y}
  - "plain" pairs of integers are not points
- For almost all shapes the first point is the top-left corner
  - Circles and ellipses use the center point

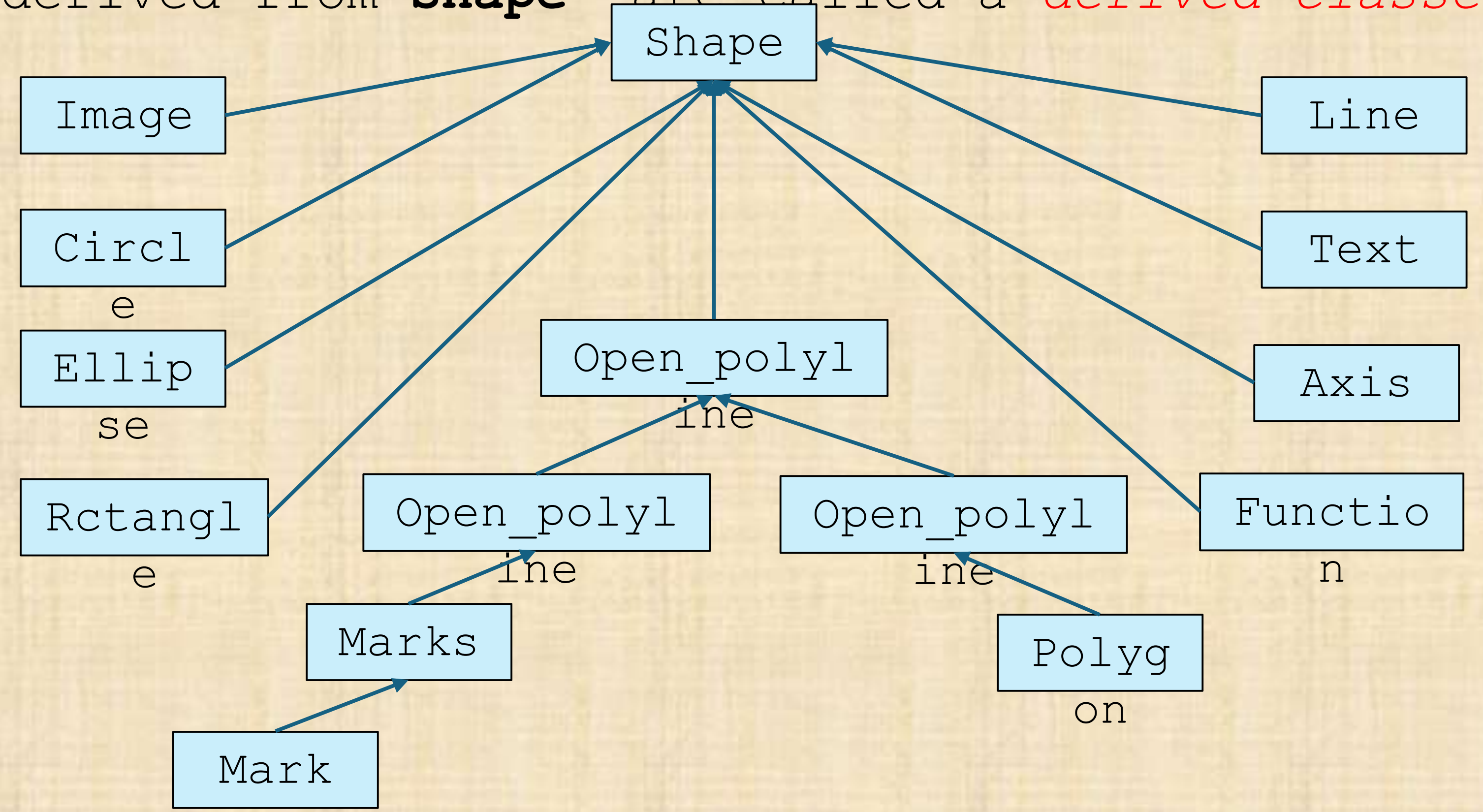
```
Line ln {Point{100,200},Point{300,400}};  // from {100,200} to {300,400}
Mark m {Point{100,200}, 'x'};         // an 'x' at {100,200}
Circle c {Point{200,200},250};              // center and radius

Line ln2 {x1, y1, x2, y2};          // error: integer arguments: from
  (x1,y1) to (x2,y2) or (width,height)?

Rectangle s1 {Point{100,200},200,300};          // top left at {100,200}
  width==200 height==300
Rectangle s2 {Point{100,200},Point{200,300}};   // width==100 height==100
```

Ideals

- Our ideal of program design is to represent the concepts of the application domain directly in code.
  - If you understand the application domain, you understand the code, and *vice versa*. For example:
    - **Window** – a window as presented by the operating system
    - **Line** – a line as you see it on the screen
    - **Point** – a coordinate point
    - **Color** – as you see it on the screen
    - **Shape** – what's common for all shapes in our Graph/GUI view of the world
- The last example, **Shape**, is different from the rest
  - You can't make an object that's "just a Shape"
  - Shape is an "abstract class" representing a generalization

Class Shape

- All our shapes are “based on” the Shape class
  - E.g., a **Polygon** is a kind of **Shape**
  - **Shape** is called a *base class*
  - Classes derived from **Shape** are called a *derived classes*



Class Shape

Shape represents the general notion of something that can appear in a **Window** on a screen:

- ties our graphical objects to our **Window** abstraction
  - **Window** provides the connection to the operating system and the physical screen
- deals with color and the style used to draw lines
  - To do that it holds a **Line_style**, a **Color** for lines, and a **Color** for filling closed shades
- can hold a sequence of **Point**s and has a basic notion of how to draw them
  - Many, but not all, **Shape**s, have some points

Class Shape: an interface to all Shapes

- **draw_all()** can draw all kinds of shapes
  - Even ones that the person who wrote **draw_all()** had never heard of

```
void draw_all(Window& win, Vector_ref<Shape>& v)      // give the Shapes to
the Window to draw
{
    for (auto x : v)
       win.attach(*x);
}

Vector_ref<Shape> vs = { make_unique<Circle>(Point{100,100},10),
             make_unique<Image>(Point{300,200},« mars_copter.jpg"),
             make_unique<Triangle>(Point{100,100},Point{ 300,200},
Point{200,300})
};
```

Class Shape is an abstract class

```
class Shape {
    // …
protected:
    Shape(initializer_list<Point> lst = {});          // add() the Points to this Shape
    // …
};
```

- The constructor is *protected*; that is, it can only be called by **Shape**'s derived classes

```
    Shape ss;   // error: cannot construct a Shape (you can only have particular shapes)
```

- The argument is a list of **Point**s (the default is an empty list: **{}**)

Access control

- Class **Shape** declares all data members **private:**
  - Directly accessible only by the Shape

```
class Shape {
    // …
private:
    Window* parent_window = nullptr;     // The window in which the Shape appears
    vector<Point> points;                // not used by all shapes
    Color lcolor = Color::black;         // color for lines and characters (with a default)
    Line_style ls;                       // by default use the default line style
    Color fcolor = Color::invisible;          // fill color (default: no color)
};
```

What does **private** buy us?

- Provides a less error-prone interface
  - Protects against undesired changes that violates a class invariant
- Makes it possible to change the representation without requiring user code to change
  - We don't expose Qt types used in representation to our users
  - Earlier implementation used another library (FLTK)
- We could provide checking in access functions
  - E.g., preventing negative radius for a Circle
  - But we haven't done so systematically (later?)
- Functional interfaces can be nicer to read and use
  - E.g., **s.add(x)** rather than **s.points.push_back(x)**
- We enforce immutability of shape
  - Only color and style change; not the relative position of points
- The value of this "encapsulation" varies with application domains
  - Is the ideal: hide representation unless you have a good reason not to
  - Is often most valuable

Shape: color and line style

- **Shape**
  - Keeps its data private and provides access functions
  - After changing color or style, the Shape needs to be redrawn on the screen
    - That's one reason to use functions, rather than direct access to the representations

```
void Shape::set_color(Color col) { lcolor = col; redraw(); }
    // write
Color Shape:: color() const { return lcolor; }            // read

void set_style(Line_style sty) { ls = sty; redraw(); }
Line_style Shape:: style() const { return ls; }

void Shape:: set_fill_color(Color col) { fcolor = col; redraw();
}
Color Shape:: fill_color() const { return fcolor; }
```

Class Shape

- **Shape** can store **Points**
  - Not all shapes uses Points, but many do (e.g., Line, Polyline, and Rectangle)
  - Only a derived class can add a Point

```
class Shape {
    // …
public:
    Point point(int i) const { return points[i]; }
    int number_of_points() const { return narow<int>(points.size()); }
    // …
protected:
    void add(Point p){ points.push_back(p); redraw(); }
    void set_point(int i, Point p) { points[i] = p; redraw(); }
    // …
};
```

Shape: The basic idea of drawing

```
struct Shape {
public:
  void draw(Painter&) const;                    // deal with color and call draw_specifics()
  // …
protected:
  virtual void draw_specifics(Painter& painter) const =0;   // draw this specific shape
  // …
};
```

- **Painter** is an implementation detail
  - Never used directly by the user
  - Essential part of the interface to the underlying library (Qt)
- Every class derived from Shape must define its **draw_specifics()**

Shape: Implementing draw()

```
void Shape::draw(Painter& painter) const
{
	painter.save();				// save the old state
	painter.set_line_style(style());		// set the desired color and style
	painter.set_color(color());
	painter.set_fill_color(fill_color());
	draw_specifics(painter);			// ask for the drawing to be done
	painter.restore();				// restore the old state
}
```

- **Painter** is an implementation detail
- This is very different from the initial implementation that used FLTK rather than Qt
  - Without hiding the representation of Shape, we could never have made that change

Class Shape

- In class **Shape**

```
virtual void draw_specifics(Painter&) const;      // draw the as appropriate for a given kind of shape
```

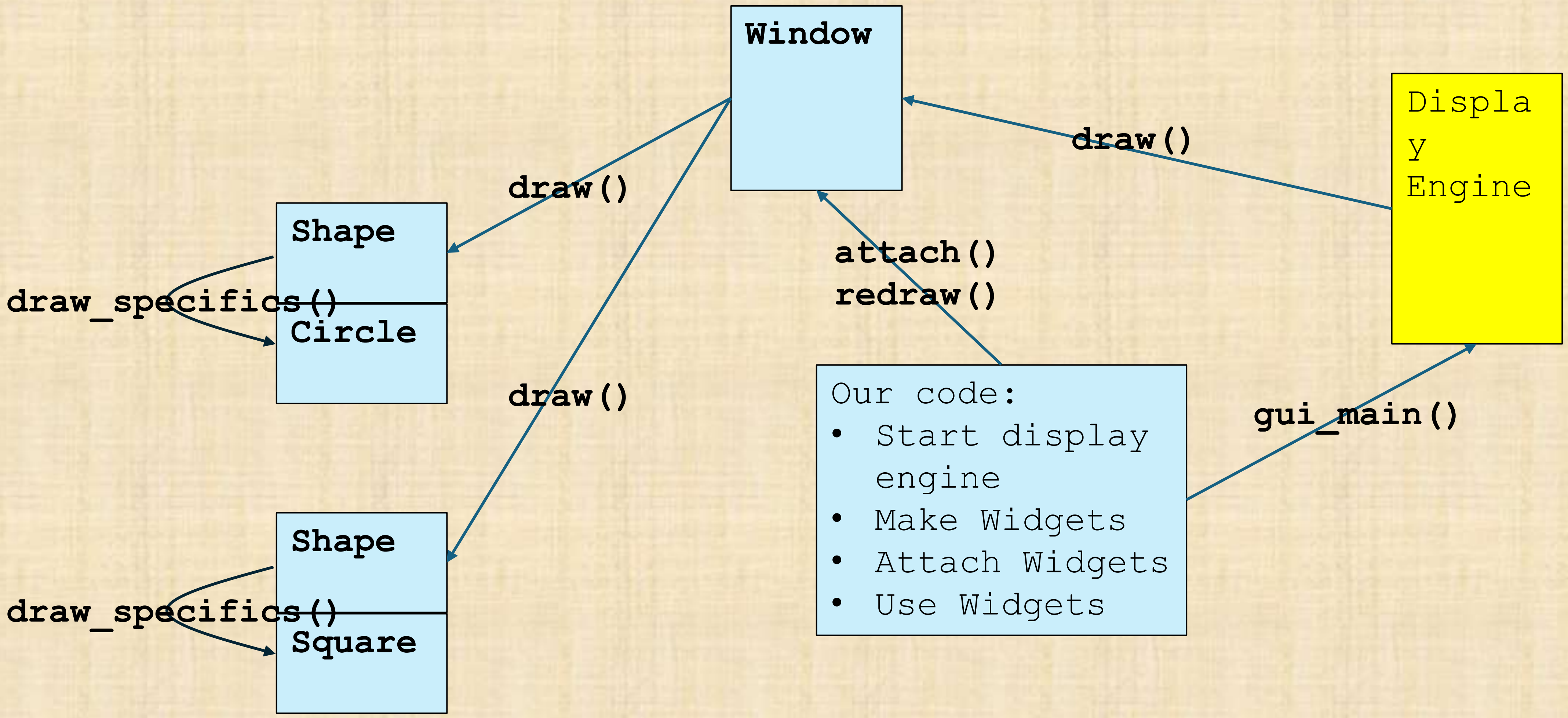
- In class **Circle**

```
void draw_specifics(Painter&) const { /* draw the Circle */ }
```

- In class **Text**
  - `void draw_specifics(Painter&) const { /* draw the Text */ }`

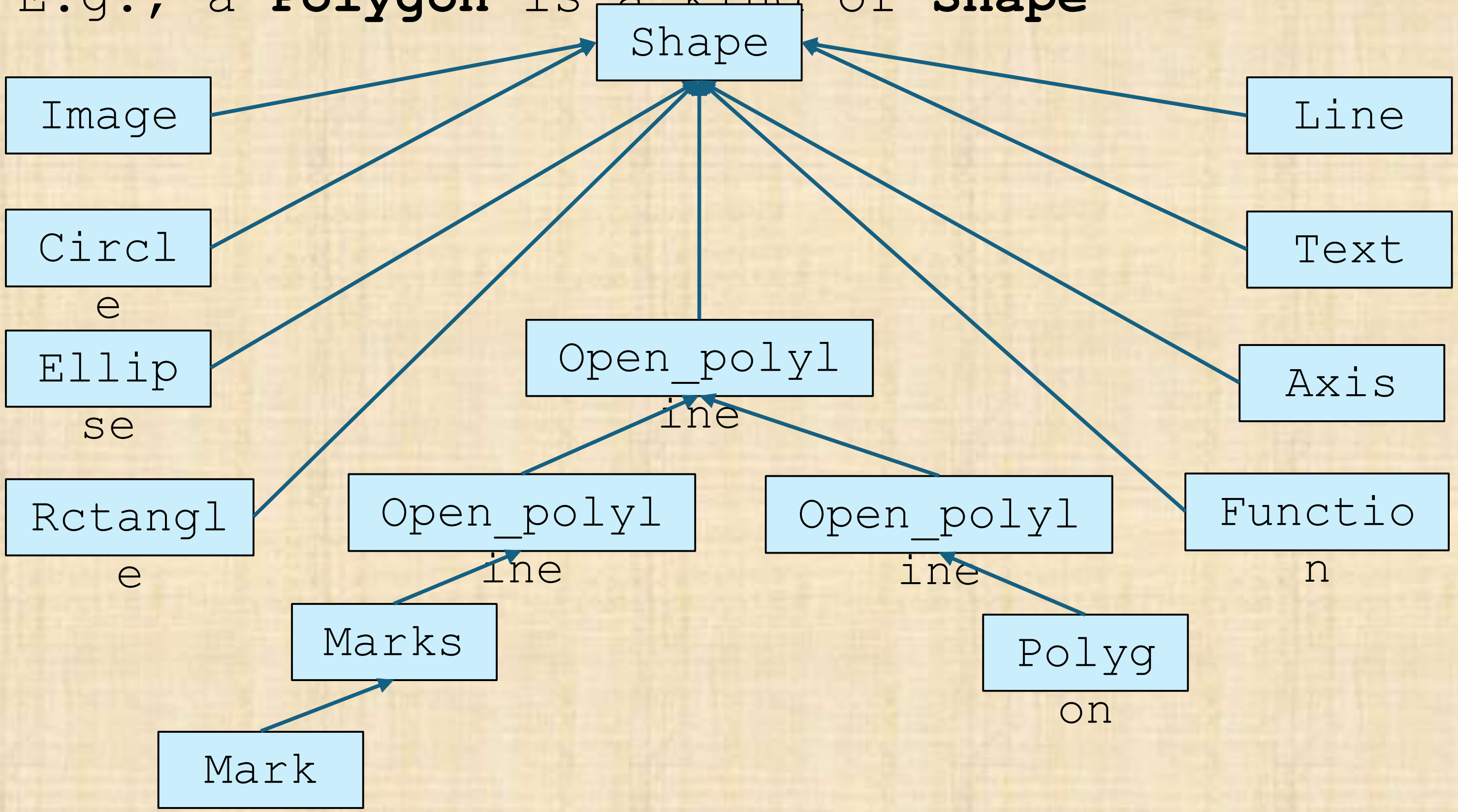
- **Circle**, **Text**, and other classes
  - "Derive from" **Shape**
  - May "override" **draw_specifics()**

The display model completed



Class Shape

- All our shapes are derived from **Shape**
  - E.g., a **Polygon** is a kind of **Shape**



An example: **Circle**

- **Circle** is derived from **Shape**
  - A Circle is a kind of Shape

```
struct Circle : Shape {
   Circle(Point p, int rr)  :r{ rr } { add(Point{ p.x - r, p.y - r });
}        // center and radius

   void draw_specifics(Painter& painter) const override;

   Point center() const { return { point(0).x + r, point(0).y + r }; }
   void set_radius(int rr) { r=rr; redraw(); }
   int radius() const { return r; }
private:
   int r;
};
```

We can define our own Shapes

- Not in the library

```
struct Triangle : Closed_polyline {
    Triangle(Point a, Point b, Point c) :Closed_polyline { a,b,c }
{}
};
```

- **Triangle** *inherits* all of its interesting properties from **Closed_polyline**
  - You can use all public members of a base class from a derived class. That's called *inheritance*
  - **Closed_polyline** inherits from **Open_polyline**
  - **Open_polyline** inherits from **Shape**

Language mechanisms

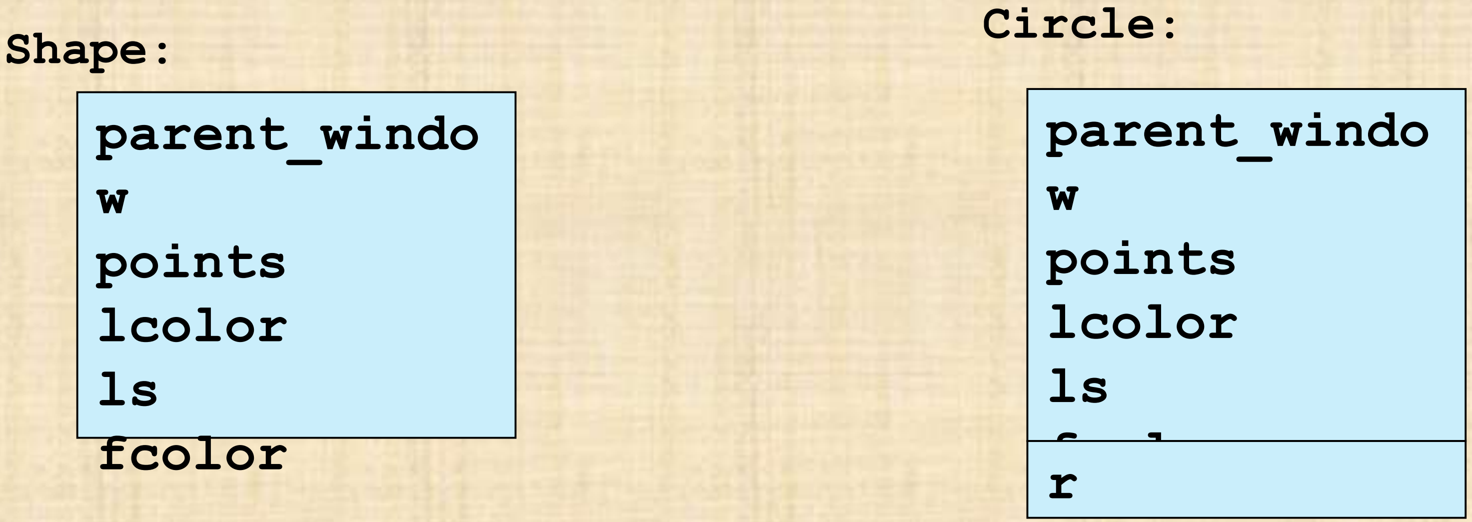
- Most popular definition of object-oriented programming:

  OOP == inheritance + polymorphism + encapsulation

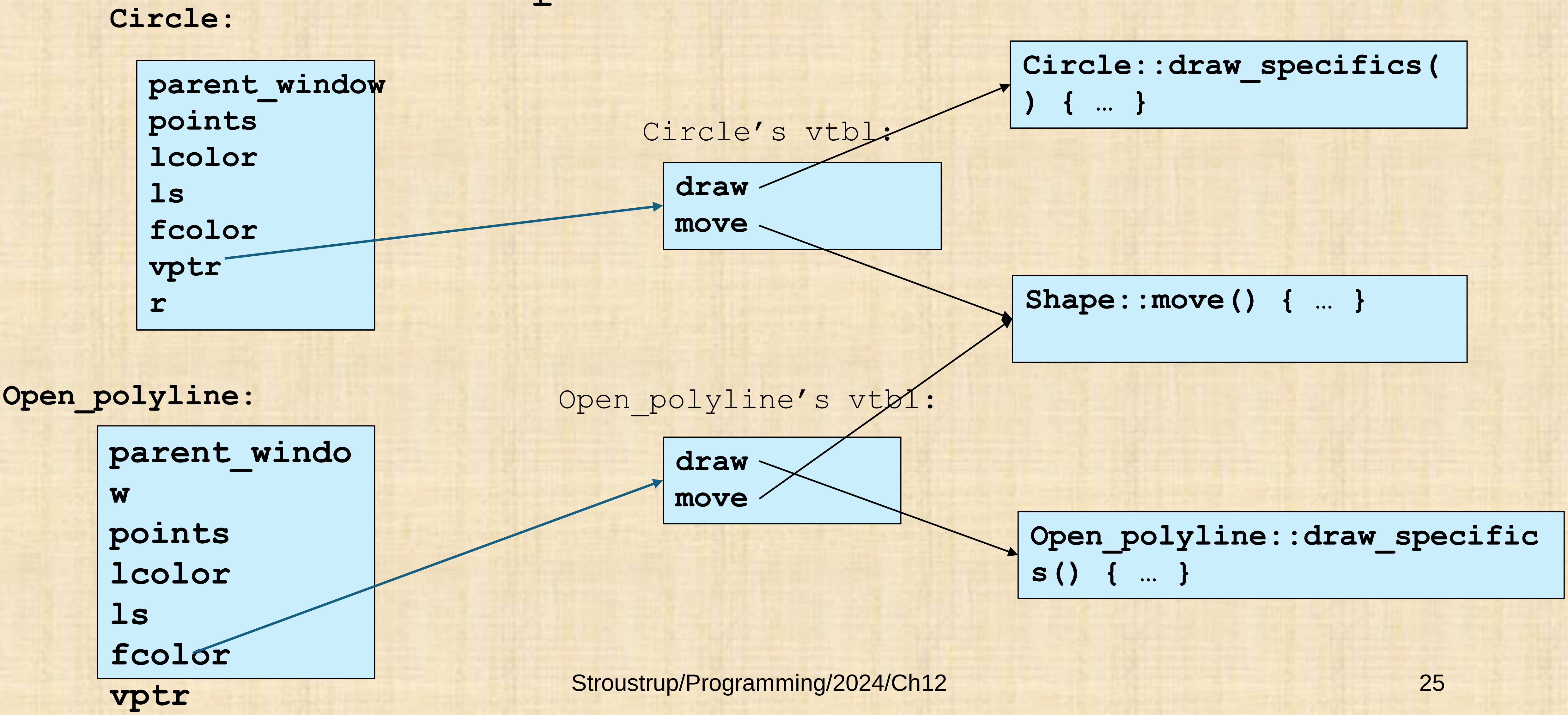
- Inheritance: Base and derived classes
  - We can use all public members of a base class from a derived class.
  - **struct Circle : Shape { … };**
- Polymorphism: Virtual functions
  - We can call function from a derived class through the interface of a base class
  - **virtual void draw_lines() const;**
  - Also called “run-time polymorphism” or “dynamic dispatch”
- Encapsulation: Private and protected
  - We can protect members from direct access from user code
  - **protected: Shape();**

Object layout

- The data members of a derived class are simply added at the end of its base class
  - E.g., a Circle is a Shape with a radius



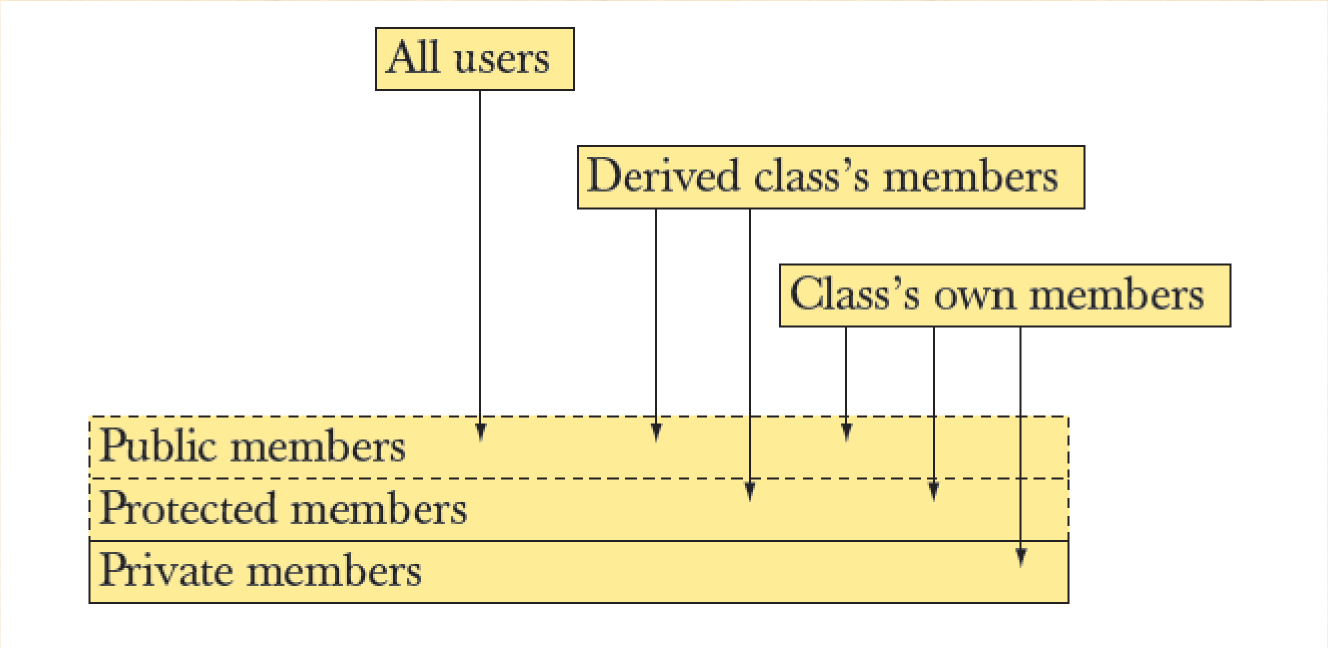
Object layout: Virtual function implementation



Benefits of inheritance

- Interface inheritance
  - A function expecting a shape (a **Shape&**) can accept any object of a class derived from **Shape**
    - E.g., the **draw_all()** example
  - Simplifies use
    - Sometimes dramatically
  - We can add classes derived from **Shape** to a program without rewriting user code
    - Adding without touching old code is one of the "holy grails" of programming
- Implementation inheritance
  - Simplifies implementation of derived classes
    - Common functionality can be provided in one place
    - Changes can be done in one place and have universal effect: Another "holy grail"

Access model



- A member (data, function, or type member) or a base can be
  - Private, protected, or public

Pure virtual functions

- Often, a function in an interface (a base class) can't be implemented
  - E.g., the data needed is "hidden" in the derived class
  - We must ensure that a derived class implements that function
  - Make it a "pure virtual function" (**=0**)
  - E.g., **Shape::draw_specifics()** is a pure virtual function; it must be overridden
- This is how we define truly abstract interfaces

```
struct Engine {        // interface to electric motors
  // no data
  // (usually) no constructor
  virtual double increase_power(int i) =0;    // must be defined in a derived class
  // …
  virtual ~Engine();                          // (usually) a virtual destructor
```

Pure virtual functions

- A pure interface is used as a base class
  - Constructors and destructors will be described in detail in chapters 15-17

```
Class M123 : public Engine {      // engine model M123
  // representation
public:
  M123();                                     // constructor:  initialization,
  acquire resources
  double increase_power(int i) override { /* … */ } // overrides Engine
  ::increase
  // …
  ~M123();                                          // destructor: cleanup,
  release resources
};

M123 left_rear_window_control;   // OK
```

Prevent copying

- If you don't know how to copy an object, prevent copying
  - Abstract classes typically should not be copied
  - **Shape** does that

```
class Shape {
  // …
  Shape(const Shape&) = delete;                    // don't "copy construct"
  Shape& operator=(const Shape&); = delete         // don't "copy assign"
};

void copy_to(Circle& c, Rectangle& r)
{
  c = r;  // error:  Shape copy assignment is deleted
          // good! A Circle doesn't have 4 sides
```

Technicality: Overriding

- To override a virtual function, you need
  - A virtual function in the base class
  - Exactly the same name in the derived class
  - Exactly the same function type in the derived class

```
struct B {
    void f1();                  // not virtual
    virtual void f2(char);
    virtual void f3(char) const;
    virtual void f4(int);
};
```

```
struct D : B {
    void f1();          // doesn't override
    void f2(int);       // doesn't override
    void f3(char);      // doesn't override
    void f4(int);// overrides
```

Next lecture

- Graphing functions and data