Chapter 14
Graph class design

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Abstract

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

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 in that it is a generalization.
  - You can't make an object that's "just a Shape"

Logically identical operations have the same name

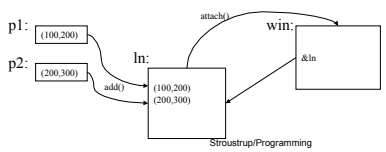
- For every class,
  - **draw_lines()** does the drawing
  - **move(dx,dy)** does the moving
  - **s.add(x)** adds some **x** (*e.g.*, a point) to a shape **s**.
- For every property **x** of a Shape,
  - **x()** gives its current value and
  - **set_x()** gives it a new value
  - e.g.,

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


Logically different operations have different names

```
Lines ln;
Point p1(100,200);
Point p2(200,300);
ln.add(p1,p2);          // add points to ln (make copies)
win.attach(ln);         // attach ln to window
```

- Why not **win.add(ln)**?
  - **add()** copies information; **attach()** just creates a reference
  - we can change a displayed object after attaching it, but not after adding it



Expose uniformly

- Data should be private
  - Data hiding – so it will not be changed inadvertently
  - Use **private** data, and pairs of public access functions to get and set the data

```
c.set_radius(12);        // set radius to 12
c.set_radius(c.radius()*2); // double the radius (fine)
c.set_radius(-9);        // set_radius() could check for negative,
                         // but doesn't yet
double r = c.radius();   // returns value of radius
c.radius = -9;           // error: radius is a function (good!)
c.r = -9;                // error: radius is private (good!)
```

- Our functions can be private or public
  - Public for interface
  - Private for functions used only internally to a class

What does private/protected buy us?

- We can change our implementation after release
- We don't expose FLTK types used in representation to our users
  - We could replace FLTK with another library without affecting user code
- We could provide checking in access functions
  - 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
  - **const** member functions
- The value of this "encapsulation" varies with application domains
  - Is often most valuable
  - Is the ideal
    - i.e., hide representation unless you have a good reason not to

"Regular" interfaces

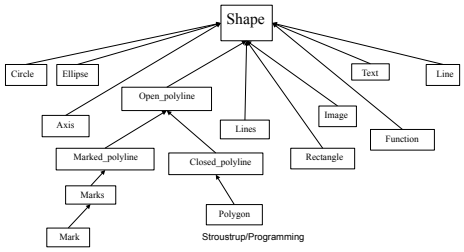
```
Line ln(Point(100,200),Point(300,400));
Mark m(Point(100,200), 'x');   // display a single point as an 'x'
Circle c(Point(200,200),250);

// Alternative (not supported):
Line ln2(x1, y1, x2, y2);          // from (x1,y1) to (x2,y2)

// How about? (not supported):
Square s1(Point(100,200),200,300);      // width==200 height==300
Square s2(Point(100,200),Point(200,300));  // width==100 height==100

Square s3(100,200,200,300); // is 200,300 a point  or a width plus a height?
```


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")

Class Shape

- All our shapes are "based on" the Shape class
  - E.g., a **Polygon** is a kind of **Shape**



Class Shape – is abstract

- You can't make a "plain" Shape

```
protected:
  Shape();   // protected to make class Shape abstract
```

  For example

```
Shape ss;  // error: cannot construct Shape
```

  - Protected means "can only be used from a derived class"
- Instead, we use Shape as a base class

```
struct Circle : Shape {     // "a Circle is a Shape"
  // ...
};
```


Class Shape

- **Shape** ties our graphics objects to "the screen"
  - **Window** "knows about" **Shape**s
  - All our graphics objects are kinds of **Shape**s
- **Shape** is the class that deals with color and style
  - It has **Color** and **Line_style** members
- **Shape** can hold **Point**s
- **Shape** has a basic notion of how to draw lines
  - It just connects its **Point**s

Class Shape

- Shape deals with color and style
  - It keeps its data private and provides access functions

```
void set_color(Color col);
int color() const;
void set_style(Line_style sty);
Line_style style() const;
// ...
private:
// ...
Color line_color;
Line_style ls;
```


Class Shape

- **Shape** stores **Point**s
  - It keeps its data private and provides access functions

```
Point point(int i) const;   // read-only access to points
int number_of_points() const;
// ...
protected:
void add(Point p);          // add p to points
// ...
private:
vector<Point> points;       // not used by all shapes
```


Class Shape

- **Shape** itself can access points directly:

```
void Shape::draw_lines() const      // draw connecting lines
{
    if (color().visible() && 1<points.size())
        for (int i=1; i<points.size(); ++i)
            fl_line(points[i-1].x,points[i-1].y,points[i].x,points[i].y);
}
```

- Others (incl. derived classes) use **point()** and **number_of_points()**
  - why?

```
void Lines::draw_lines() const // draw a line for each pair of points
{
    for (int i=1; i<number_of_points(); i+=2)
        fl_line(point(i-1).x, point(i-1).y, point(i).x, point(i).y);
}
```


Class Shape (basic idea of drawing)

```
void Shape::draw() const
    // The real heart of class Shape (and of our graphics interface system)
    // called by Window (only)
{
    // ... save old color and style ...
    // ... set color and style for this shape...

    // ... draw what is specific for this particular shape ...
    // ... Note: this varies dramatically depending on the type of shape ...
    // ... e.g. Text, Circle, Closed_polyline

    // ... reset the color and style to their old values ...
}
```


Class Shape (implementation of drawing)

```
void Shape::draw() const
    // The real heart of class Shape (and of our graphics interface system)
    // called by Window (only)
{
    Fl_Color oldc = fl_color();// save old color
    // there is no good portable way of retrieving the current style (sigh!)
    fl_color(line_color.as_int());    // set color and style
    fl_line_style(ls.style(),ls.width());

    draw_lines(); // call the appropriate draw_lines()
                  // a "virtual call"
                  // here is what is specific for a "derived class" is done

    fl_color(oldc);     // reset color to previous
    fl_line_style(0);   // (re)set style to default
}
```

Note!

Class shape

- In class **Shape**

```
virtual void draw_lines() const;    // draw the appropriate lines
```

- In class **Circle**

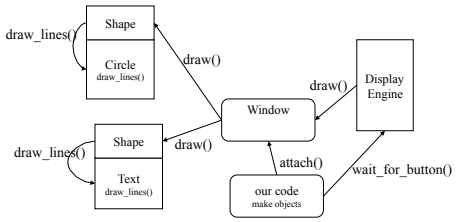
```
void draw_lines() const { /* draw the Circle */ }
```

- In class **Text**
  - `void draw_lines() const { /* draw the Text */ }`

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

```
class Shape { // deals with color and style, and holds a sequence of lines
public:
    void draw() const;          // deal with color and call draw_lines()
    virtual void move(int dx, int dy);  // move the shape +=dx and +=dy

    void set_color(Color col);      // color access
    int color() const;
    // … style and fill_color access functions …

    Point point(int i) const;  // (read-only) access to points
    int number_of_points() const;
protected:
    Shape();                // protected to make class Shape abstract
    void add(Point p);      // add p to points
    virtual void draw_lines() const;    // simply draw the appropriate lines
private:
    vector<Point> points;       // not used by all shapes
    Color  lcolor;              // line color
    Line_style  ls;             // line style
    Color  fcolor;              // fill color

    // … prevent copying …
};
```


Display model completed



Language mechanisms

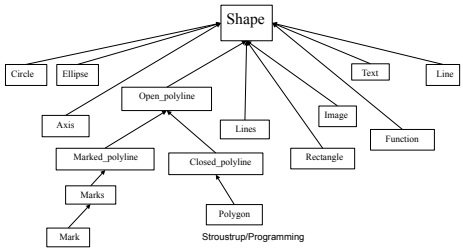
- Most popular definition of object-oriented programming:

  OOP == inheritance + polymorphism + encapsulation

- Base and derived classes // *inheritance*
  - **struct Circle : Shape { … };**
  - Also called "inheritance"
- Virtual functions // *polymorphism*
  - **virtual void draw_lines() const;**
  - Also called "run-time polymorphism" or "dynamic dispatch"
- Private and protected // *encapsulation*
  - **protected: Shape();**
  - **private: vector<Point> points;**

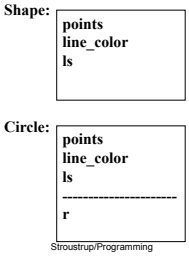
A simple class hierarchy

- We chose to use a simple (and mostly shallow) class hierarchy
  - Based on Shape



Object layout

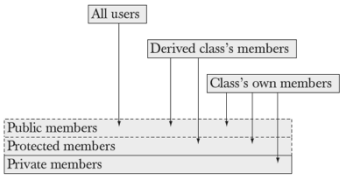
- The data members of a derived class are simply added at the end of its base class (a Circle is a Shape with a radius)



Benefits of inheritance

- Interface inheritance
  - A function expecting a shape (a **Shape&**) can accept any object of a class derived from Shape.
  - 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

Next lecture

- Graphing functions and data