

Principles of Software Construction: Objects, Design, and Concurrency

Part 2: Designing (sub-) systems

Design for large-scale reuse: Libraries and frameworks

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Administrivia

- Required reading due today: Effective Java Items 6, 7, and 63
- Homework 4b due Thursday
- Homework 4a feedback available
 - Can regain up to 75% of lost Homework 4a credit
 - Directly address TA comments when you turn in Homework 4c
 - Turn in revised design documents + description of what you changed (process details TBD)
- Next required reading due next Tuesday
 - Effective Java, Items 51, 60, 62, and 64

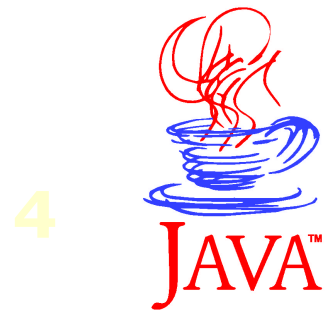


Key concepts from last Thursday

- Java Collections
 - Design patterns to achieve various design goals
 - Iterator to abstract internal structure
 - Decorator to alter behavior at runtime
 - Template method and factory method to support customization
 - Adapter to convert between implementations
 - Strategy pattern for sorting
 - Marker interface to refine a specification
 - For widespread use:
 - Design for extensibility, reuse
 - Design for change
 - Prelude to API design

Convenience Implementations

- `Arrays.asList(Object[] a)`
 - Allows array to be "viewed" as List
 - Adapter to Collection-based APIs
- ...



The adapter pattern

- Problem: You have a client that expects one API for a service provider, and a service provider with a different API
- Solution: Write a class that implements the expected API, converting calls to the service provider's actual API
- Consequences:
 - Easy interoperability of unrelated clients and libraries
 - Client can use unforeseen future libraries
 - Adapter class is coupled to concrete service provider, can make it harder to override service provider behavior

The adapter pattern, illustrated

Have this



and this?



Use this!



Key concepts from last Thursday

- **It takes a lot of work to make something that appears obvious**
 - Coherent, unified vision
 - Willingness to listen to others
 - Flexibility to accept change
 - Tenacity to resist change
 - Good documentation!
- **It's worth the effort!**
 - A solid foundation can last two+ decades

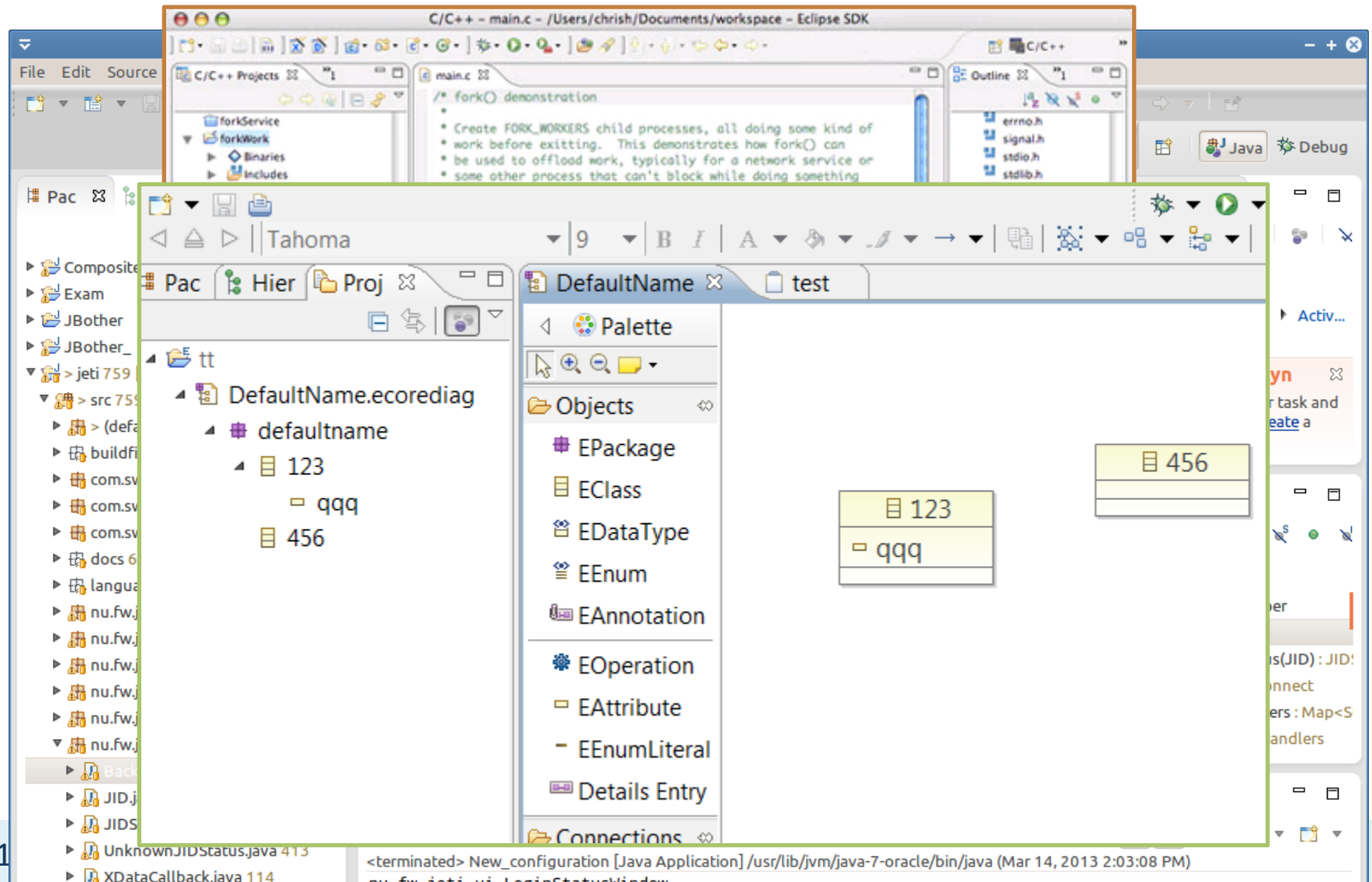
Learning goals for today

- Describe example well-known example frameworks
- Know key terminology related to frameworks
- Know common design patterns in different types of frameworks
- Discuss differences in design trade-offs for libraries vs. frameworks
- Analyze a problem domain to define commonalities and extension points (cold spots and hot spots)
- Analyze trade-offs in the use vs. reuse dilemma
- Know common framework implementation choices

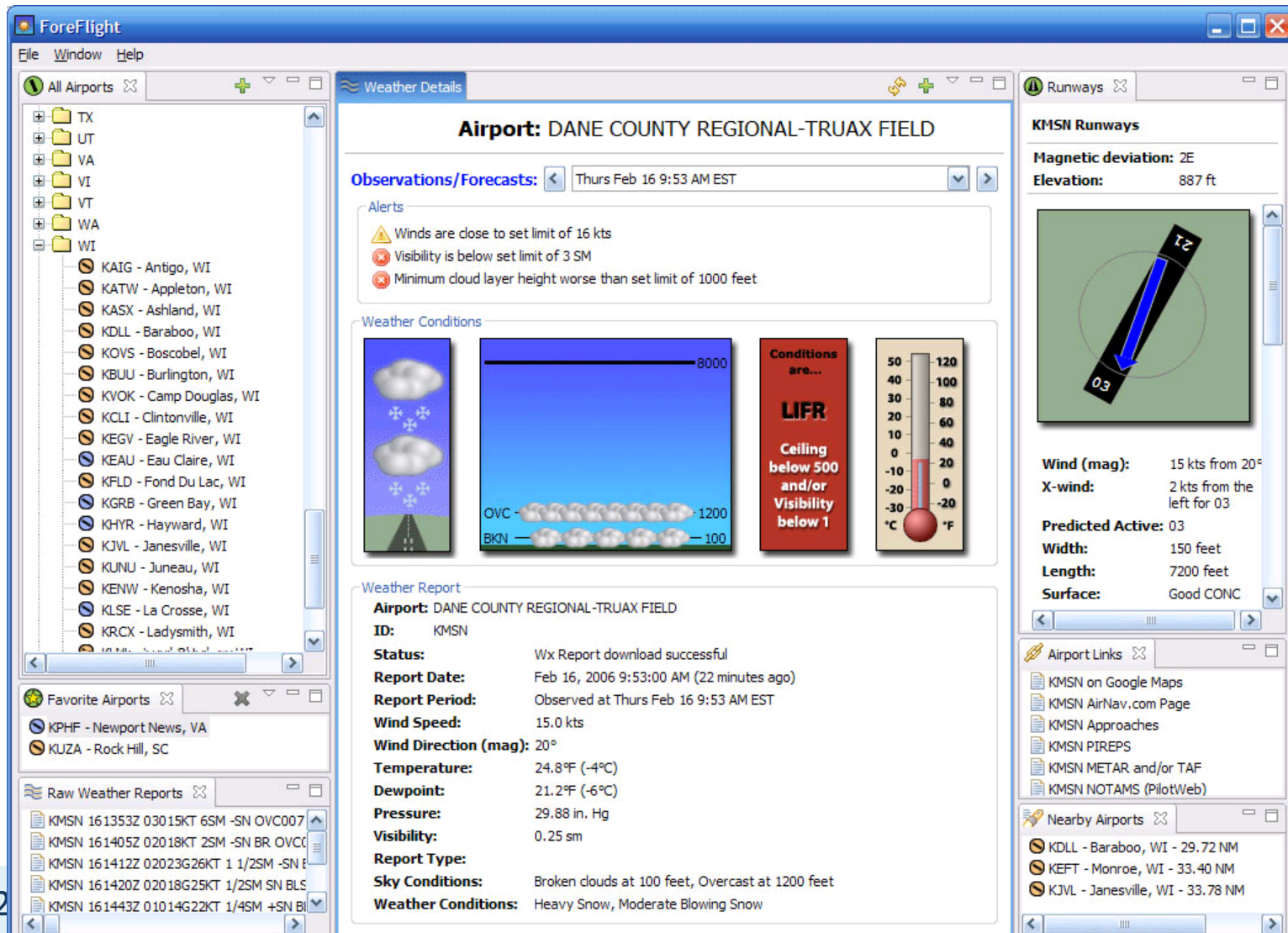
Today: Libraries and frameworks for reuse

Reuse and variation:

Family of development tools



Reuse and variation: Eclipse Rich Client Platform



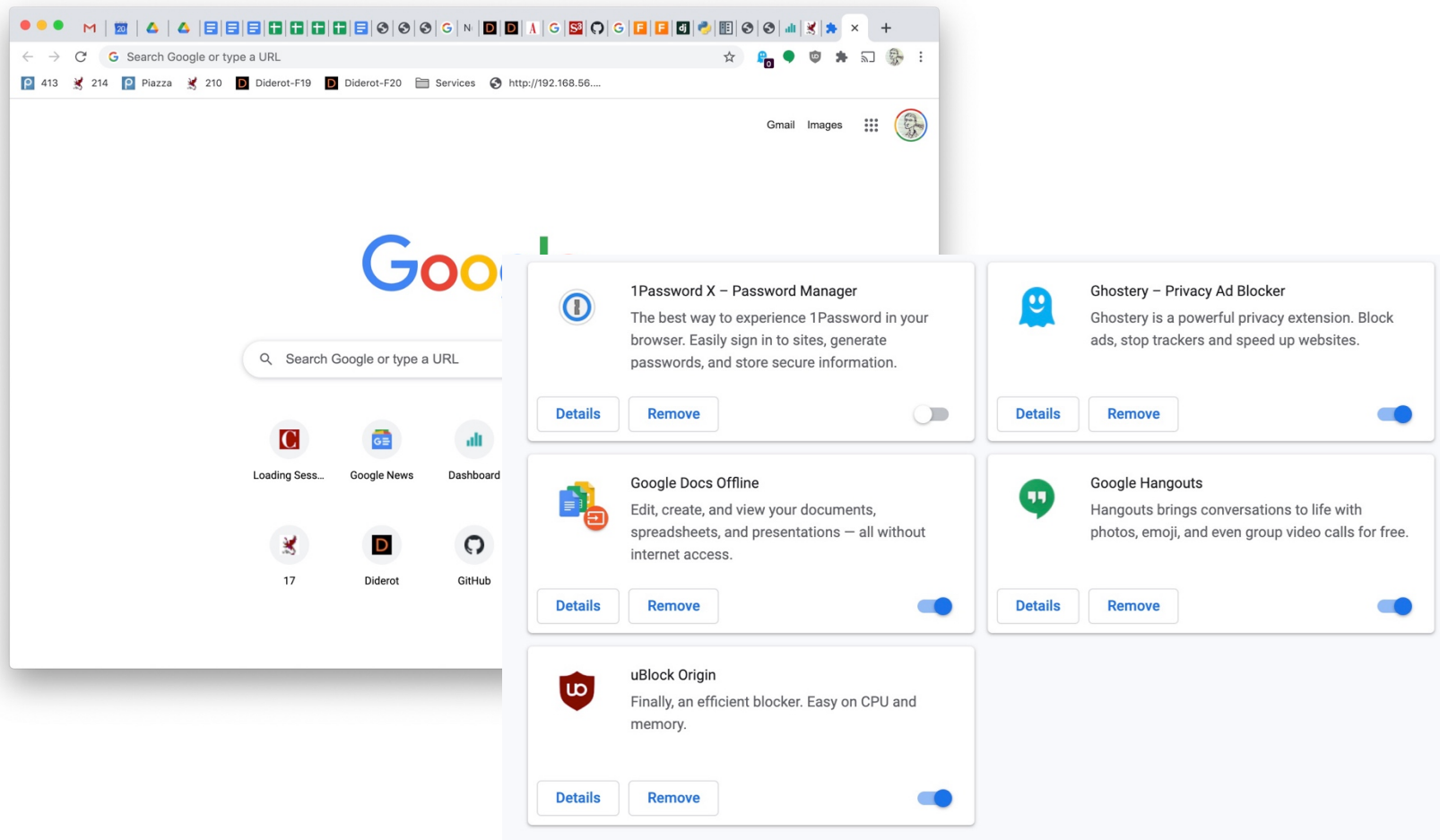
The screenshot displays the ForeFlight application window, which is divided into several panes. The main pane shows the 'Weather Details' for 'Airport: DANE COUNTY REGIONAL-TRUAX FIELD'. The 'Observations/Forecasts' section shows the current time as 'Thurs Feb 16 9:53 AM EST'. The 'Alerts' section lists three warnings: 'Winds are close to set limit of 16 kts', 'Visibility is below set limit of 3 SM', and 'Minimum cloud layer height worse than set limit of 1000 feet'. The 'Weather Conditions' section includes a visual representation of the sky with clouds and snow, a temperature gauge showing 24.8°F (-4°C), and a red box indicating 'LIFR' (Low Visibility) conditions with a ceiling below 500 feet and/or visibility below 1 mile. The 'Weather Report' section provides a summary of the report, including the status 'Wx Report download successful', the report date 'Feb 16, 2006 9:53:00 AM (22 minutes ago)', and various weather parameters: Wind Speed (15.0 kts), Wind Direction (mag): 20°, Temperature (24.8°F (-4°C)), Dewpoint (21.2°F (-6°C)), Pressure (29.88 in. Hg), Visibility (0.25 sm), Report Type, Sky Conditions (Broken clouds at 100 feet, Overcast at 1200 feet), and Weather Conditions (Heavy Snow, Moderate Blowing Snow).

The left pane shows a list of 'All Airports' with a tree view of airport categories (TX, UT, VA, VI, VT, WA, WI) and a list of airports including KAIG - Antigo, WI, KATW - Appleton, WI, KASX - Ashland, WI, KDLL - Baraboo, WI, KOVS - Boscobel, WI, KBUU - Burlington, WI, KVOK - Camp Douglas, WI, KCLI - Clintonville, WI, KEGV - Eagle River, WI, KEAU - Eau Claire, WI, KFLL - Fond Du Lac, WI, KGRB - Green Bay, WI, KHyr - Hayward, WI, KJVL - Janesville, WI, KUNU - Juneau, WI, KENW - Kenosha, WI, KLSE - La Crosse, WI, and KRCC - Ladysmith, WI. Below this is a 'Favorite Airports' section with KPHF - Newport News, VA and KUZA - Rock Hill, SC. The bottom left pane shows 'Raw Weather Reports' for KMSN, including reports for 161353Z, 161405Z, 161412Z, 161420Z, and 161443Z.

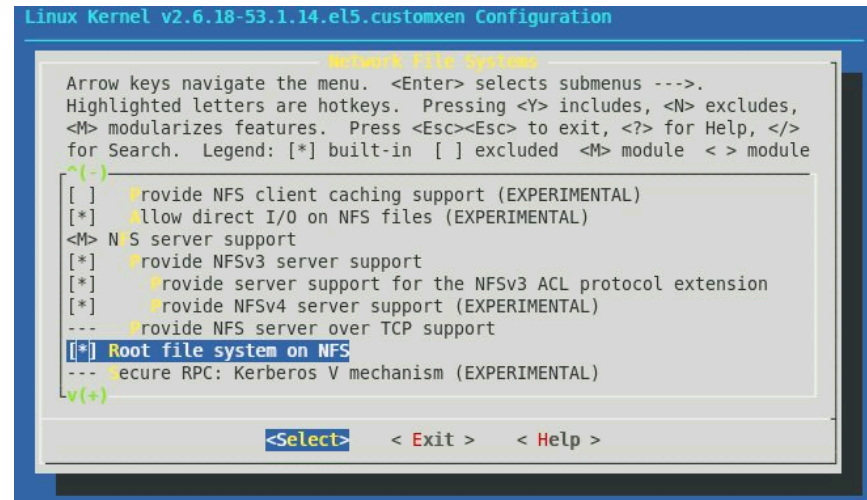
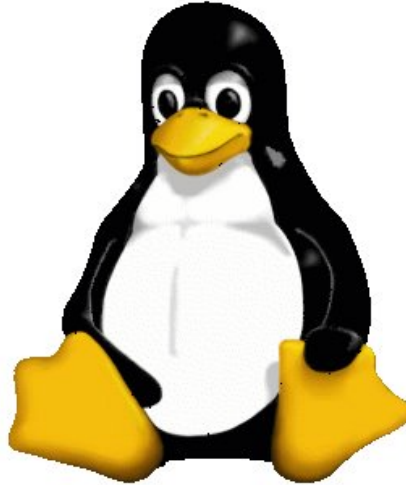
The right pane shows 'Runways' for KMSN, including 'Magnetic deviation: 2E', 'Elevation: 887 ft', and a diagram of the runway layout. Below this is a 'Wind (mag): 15 kts from 20°', 'X-wind: 2 kts from the left for 03', 'Predicted Active: 03', 'Width: 150 feet', 'Length: 7200 feet', and 'Surface: Good CONC'. The bottom right pane shows 'Airport Links' for KMSN, including links to Google Maps, AirNav.com, Approaches, PIREPS, METAR and/or TAF, and NOTAMS. The bottom right corner of the application window shows 'Nearby Airports' including KDLL - Baraboo, WI (29.72 NM), KEFT - Monroe, WI (33.40 NM), and KJVL - Janesville, WI (33.78 NM).

Reuse and variation:

Web browser extensions



Reuse and variation: Flavors of Linux



Reuse and variation: Product lines



Earlier in this course: Class-level reuse

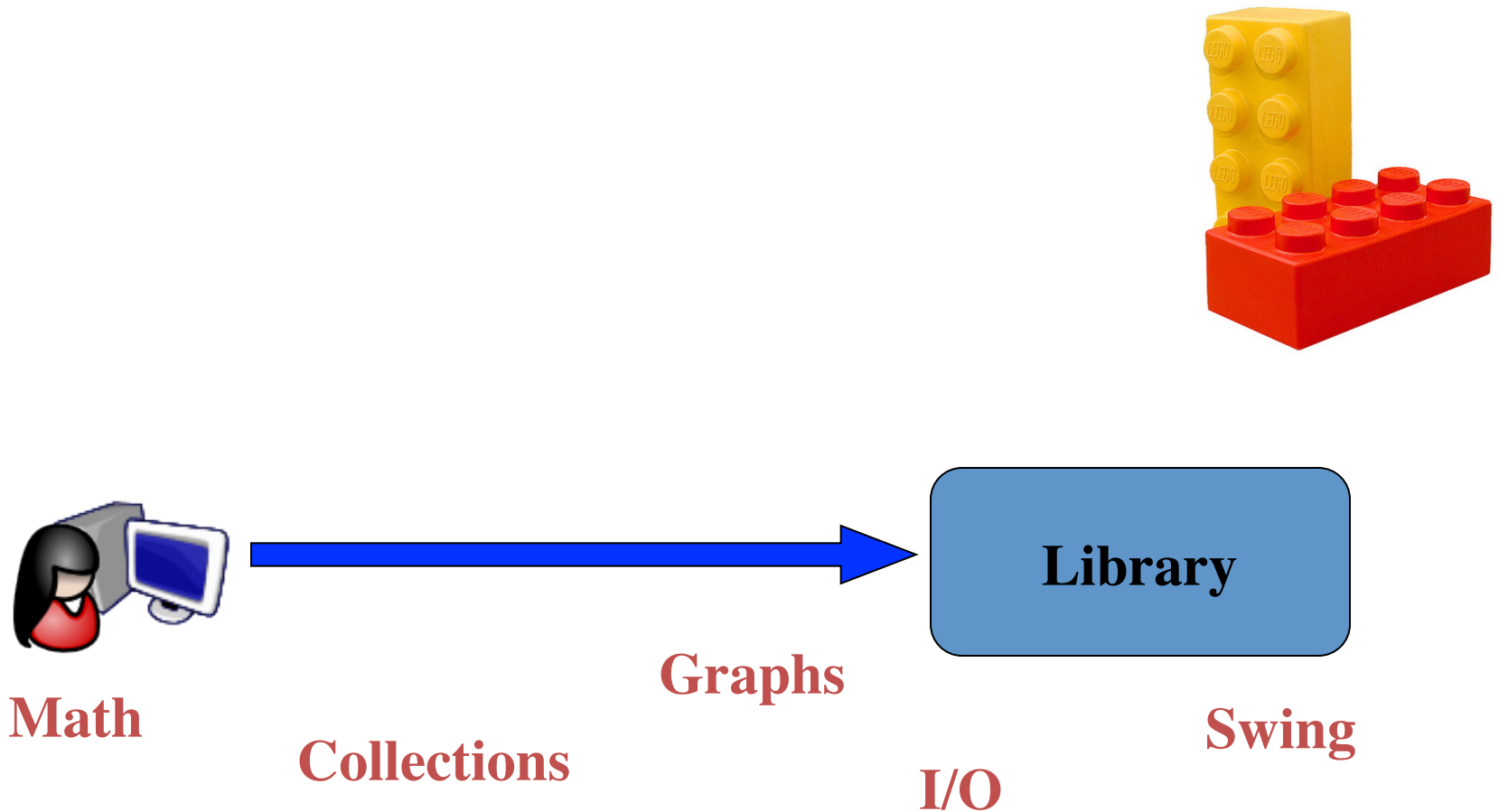
- Language mechanisms supporting reuse
 - Inheritance
 - Subtype polymorphism (dynamic dispatch)
 - Parametric polymorphism (generics)
- Design principles supporting reuse
 - Small interfaces
 - Information hiding
 - Low coupling
 - High cohesion
- Design patterns supporting reuse
 - Template method, decorator, strategy, composite, adapter, ...

Today: Libraries and frameworks for reuse

- Examples, terminology
- Whitebox and blackbox frameworks
- Design considerations
- Implementation details
 - Responsibility for running the framework
 - Loading plugins

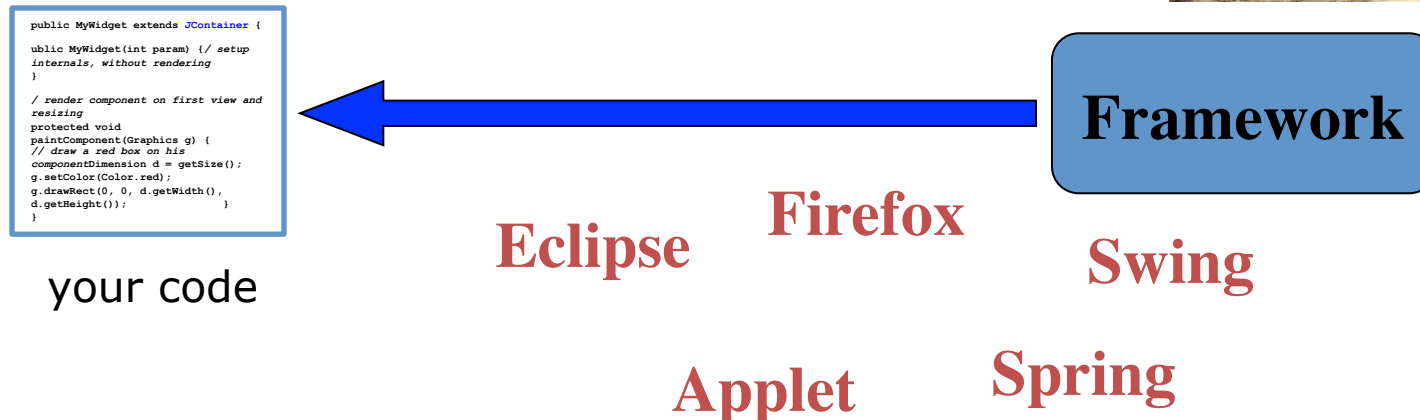
Terminology: Libraries

- **Library**: A set of classes and methods that provide reusable functionality



Terminology: Frameworks

- Framework: Reusable skeleton code that can be customized into an application
- Framework calls back into client code
 - The Hollywood principle: “Don’t call us. We’ll call you.”



A calculator example (without a framework)



```
public class Calc extends JFrame {
    private JTextField textField;
    public Calc() {
        JPanel contentPane = new JPanel(new BorderLayout());
        contentPane.setBorder(new BevelBorder(BevelBorder.LOWERED));
        JButton button = new JButton();
        button.setText("calculate");
        contentPane.add(button, BorderLayout.EAST);
        textField = new JTextField("");
        textField.setText("10 / 2 + 6");
        textField.setPreferredSize(new Dimension(200, 20));
        contentPane.add(textfield, BorderLayout.WEST);
        button.addActionListener(/* calculation code */);
        this.setContentPane(contentPane);
        this.pack();
        this.setLocation(100, 100);
        this.setTitle("My Great Calculator");
        ...
    }
}
```

A simple example framework

- Consider a family of programs consisting of a button and text field only:



- What source code might be shared?

A calculator example (without a framework)



```
public class Calc extends JFrame {
    private JTextField textField;
    public Calc() {
        JPanel contentPane = new JPanel(new BorderLayout());
        contentPane.setBorder(new BevelBorder(BevelBorder.LOWERED));
        JButton button = new JButton();
        button.setText("calculate");
        contentPane.add(button, BorderLayout.EAST);
        textField = new JTextField("");
        textField.setText("10 / 2 + 6");
        textField.setPreferredSize(new Dimension(200, 20));
        contentPane.add(textfield, BorderLayout.WEST);
        button.addActionListener(/* calculation code */);
        this.setContentPane(contentPane);
        this.pack();
        this.setLocation(100, 100);
        this.setTitle("My Great Calculator");
        ...
    }
}
```

A simple example framework

```
public abstract class Application extends JFrame {
    protected String getApplicationTitle() { return ""; }
    protected String getButtonText() { return ""; }
    protected String getInitialText() { return ""; }
    protected void buttonClicked() { }
    private JTextField textField;
    public Application() {
        JPanel contentPane = new JPanel(new BorderLayout());
        contentPane.setBorder(new BevelBorder(BevelBorder.LOWERED));
        JButton button = new JButton();
        button.setText(getButtonText());
        contentPane.add(button, BorderLayout.EAST);
        textField = new JTextField("");
        textField.setText(getInitialText());
        textField.setPreferredSize(new Dimension(200, 20));
        contentPane.add(textField, BorderLayout.WEST);
        button.addActionListener((e) -> { buttonClicked(); });
        this.setContentPane(contentPane);
        this.pack();
        this.setLocation(100, 100);
        this.setTitle(getApplicationTitle());
        ...
    }
}
```

Using the example framework

```
public abstract class Application extends JFrame {  
    protected String getApplicationTitle() { return ""; }  
    protected String getButtonText() { return ""; }  
    protected String getInitialText() { return ""; }  
    protected void buttonClicked() { }
```

```
public class Calculator extends Application {  
    protected String getApplicationTitle() { return "My Great Calculator"; }  
    protected String getButtonText() { return "calculate"; }  
    protected String getInitialText() { return "(10 - 3) * 6"; }  
    protected void buttonClicked() {  
        JOptionPane.showMessageDialog(this, "The result of " + getInput() +  
            " is " + calculate(getInput()));  
    }  
    private String calculate(String text) { ... }  
}
```

```
    button.addActionListener((e) -> { buttonClicked(); });  
    this.setContentPane(contentPane);  
    this.pack();  
    this.setLocation(100, 100);  
    this.setTitle(getApplicationTitle());  
    ...  
}
```

Using the example framework again

```
public abstract class Application extends JFrame {  
    protected String getApplicationTitle() { return ""; }  
    protected String getButtonText() { return ""; }  
    protected String getInititalText() { return ""; }  
    protected void buttonClicked() { }
```

```
public class Calculator extends Application {  
    protected String getApplicationTitle() { return "My Great Calculator"; }  
    protected String getButtonText() { return "calculate"; }  
    protected String getInititalText() { return "(10 - 3) * 6"; }  
    protected void buttonClicked() {  
        JOptionPane.showMessageDialog(this, "The result of " + getInput() +  
            " is " + calculate(getInput()));  
    }  
    private String calculate(String text) { ... }  
}
```

```
public class Ping extends Application {  
    protected String getApplicationTitle() { return "Ping"; }  
    protected String getButtonText() { return "ping"; }  
    protected String getInititalText() { return "127.0.0.1"; }  
    protected void buttonClicked() { ... }  
}
```

General distinction: Library vs. framework



```
public MyWidget extends JContainer {  
    public MyWidget(int param) { // setup  
        internals, without rendering  
    }  
  
    // render component on first view and  
    // resizing  
    protected void  
    paintComponent(Graphics g) {  
        // draw a red box on this  
        componentDimension d = getSize();  
        g.setColor(Color.red);  
        g.drawRect(0, 0, d.getWidth(),  
            d.getHeight());  
    }  
}
```

your code



Library



user
interacts

```
public MyWidget extends JContainer {  
    public MyWidget(int param) { // setup  
        internals, without rendering  
    }  
  
    // render component on first view and  
    // resizing  
    protected void  
    paintComponent(Graphics g) {  
        // draw a red box on this  
        componentDimension d = getSize();  
        g.setColor(Color.red);  
        g.drawRect(0, 0, d.getWidth(),  
            d.getHeight());  
    }  
}
```

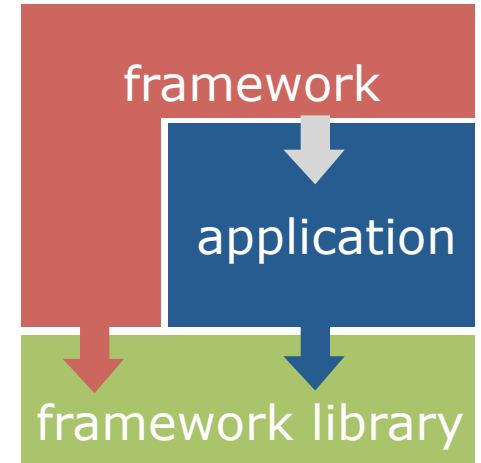
your code



Framework

Libraries and frameworks in practice

- Defines key abstractions and their interfaces
- Defines object interactions & invariants
- Defines flow of control
- Provides architectural guidance
- Provides defaults



credit: Erich Gamma

Framework or library?

- Eclipse
- Java Collections

Framework or library?

- Eclipse
- Java Collections
- The Java Logging Framework
- Java Cryptographic Extensions
- Wordpress
- Django

- On a piece of paper:
 1. Describe the software ($\leq$ one sentence)
 2. Describe one way the software is like a library.
 3. Describe one way the software is like a framework.

Framework or library?

- Eclipse
- Java Collections
- The Java Logging Framework
- Java Cryptographic Extensions
- Wordpress
- Django

- On Gradescope:
 1. Describe one way the software is like a library.
 2. Describe one way the software is like a framework.
 3. Discuss whether the software seems more like a library or framework.

A Carcassonne framework?



More terms

- *API*: Application Programming Interface, the interface of a library or framework
- *Client*: The code that uses an API
- *Plugin*: Client code that customizes a framework
- *Extension point*: A place where a framework supports extension with a plugin

More terms

- *Protocol*: The expected sequence of interactions between the API and the client
- *Callback*: A plugin method that the framework will call to access customized functionality
- *Lifecycle method*: A callback method that gets called in a sequence according to the protocol and the state of the plugin

WHITE-BOX VS BLACK-BOX FRAMEWORKS

Whitebox frameworks

- Extension via subclassing and overriding methods
- Common design pattern(s):
 - Template method
- Subclass has main method but gives control to framework

Blackbox frameworks

- Extension via implementing a plugin interface
- Common design pattern(s):
 - Command
 - Observer
- Plugin-loading mechanism loads plugins and gives control to the framework

Whitebox vs. blackbox frameworks

- Whitebox frameworks
 - Extension via subclassing and overriding methods
 - Common design pattern(s): Template method
 - Subclass has main method but gives control to framework
- Blackbox frameworks
 - Extension via implementing a plugin interface
 - Common design pattern(s): Command, Observer
 - Plugin-loading mechanism loads plugins and gives control to the framework

Is this a whitebox or blackbox framework?

```
public abstract class Application extends JFrame {  
    protected String getApplicationTitle() { return ""; }  
    protected String getButtonText() { return ""; }  
    protected String getInititalText() { return ""; }  
    protected void buttonClicked() { }
```

```
public class Calculator extends Application {  
    protected String getApplicationTitle() { return "My Great Calculator"; }  
    protected String getButtonText() { return "calculate"; }  
    protected String getInititalText() { return "(10 - 3) * 6"; }  
    protected void buttonClicked() {  
        JOptionPane.showMessageDialog(this, "The result of " + getInput() +  
            " is " + calculate(getInput()));  
    }  
    private String calculate(String text) { ... }  
}
```

```
public class Ping extends Application {  
    protected String getApplicationTitle() { return "Ping"; }  
    protected String getButtonText() { return "ping"; }  
    protected String getInititalText() { return "127.0.0.1"; }  
    protected void buttonClicked() { ... }  
}
```

An example blackbox framework

```
public class Application extends JFrame {
    private JTextField textField;
    private Plugin plugin;
    public Application() { }
    protected void init(Plugin p) {
        p.setApplication(this);
        this.plugin = p;
        JPanel contentPane = new JPanel();
        contentPane.setBorder(new BorderLayout());
        JButton button = new JButton();
        button.setText(plugin != null ? plugin.getButtonText() : "ok");
        contentPane.add(button, BorderLayout.EAST);
        textField = new JTextField("");
        if (plugin != null) textField.setText(plugin.getInititalText());
        textField.setPreferredSize(new Dimension(200, 20));
        contentPane.add(textField, BorderLayout.WEST);
        if (plugin != null)
            button.addActionListener((e) -> { plugin.buttonClicked(); } );
        this.setContentPane(contentPane);
        ...
    }
    public String getInput() { return textField.getText(); }
}
```

```
public interface Plugin {
    String getApplicationTitle();
    String getButtonText();
    String getInititalText();
    void buttonClicked();
    void setApplication(Application app);
}
```

An example blackbox framework

```
public class Application extends JFrame {
    private JTextField textField;
    private Plugin plugin;
    public Application() { }
    protected void init(Plugin p) {
        p.setApplication(this);
        this.plugin = p;
        JPanel contentPane = new JPanel()
        contentPane.setBorder(new BevelBorder(1));
        JButton button = new JButton("Calculate");
```

```
public interface Plugin {
    String getApplicationTitle();
    String getButtonText();
    String getInititalText();
    void buttonClicked();
    void setApplication(Application app);
}
```

```
public class CalcPlugin implements Plugin {
    private Application app;
    public void setApplication(Application app) { this.app = app; }
    public String getButtonText() { return "calculate"; }
    public String getInititalText() { return "10 / 2 + 6"; }
    public void buttonClicked() {
        JOptionPane.showMessageDialog(null, "The result of "
            + app.getInput() + " is "
            + calculate(app.getInput()));
    }
    public String getApplicationTitle() { return "My Great Calculator"; }
}
```

```
}
```

An aside: Plugins could be reusable too...

```
public class Application extends JFrame implements InputProvider {
    private JTextField textField;
    private Plugin plugin;
    public Application() { }
    protected void init(Plugin p)
        p.setApplication(this);
        this.plugin = p;
        JPanel contentPane = new
        contentPane.setBorder(new
        JButton button = new JButton();

    public interface Plugin {
        String getApplicationTitle();
        String getButtonText();
        String getInititalText();
        void buttonClicked() ;
        void setApplication(InputProvider app);
    }

    public class CalcPlugin implements Plugin {
        private InputProvider app;
        public void setApplication(InputProvider app) { this.app = app; }
        public String getButtonText() { return "Calculate"; }
        public String getInititalText() { return "0"; }
        public void buttonClicked() {
            JOptionPane.showMessageDialog(null,
                + application.getInput() + " is "
                + calculate(application.getInput()));
        }
        public String getApplicationTitle() { return "My Great Calculator"; }
    }
}
```

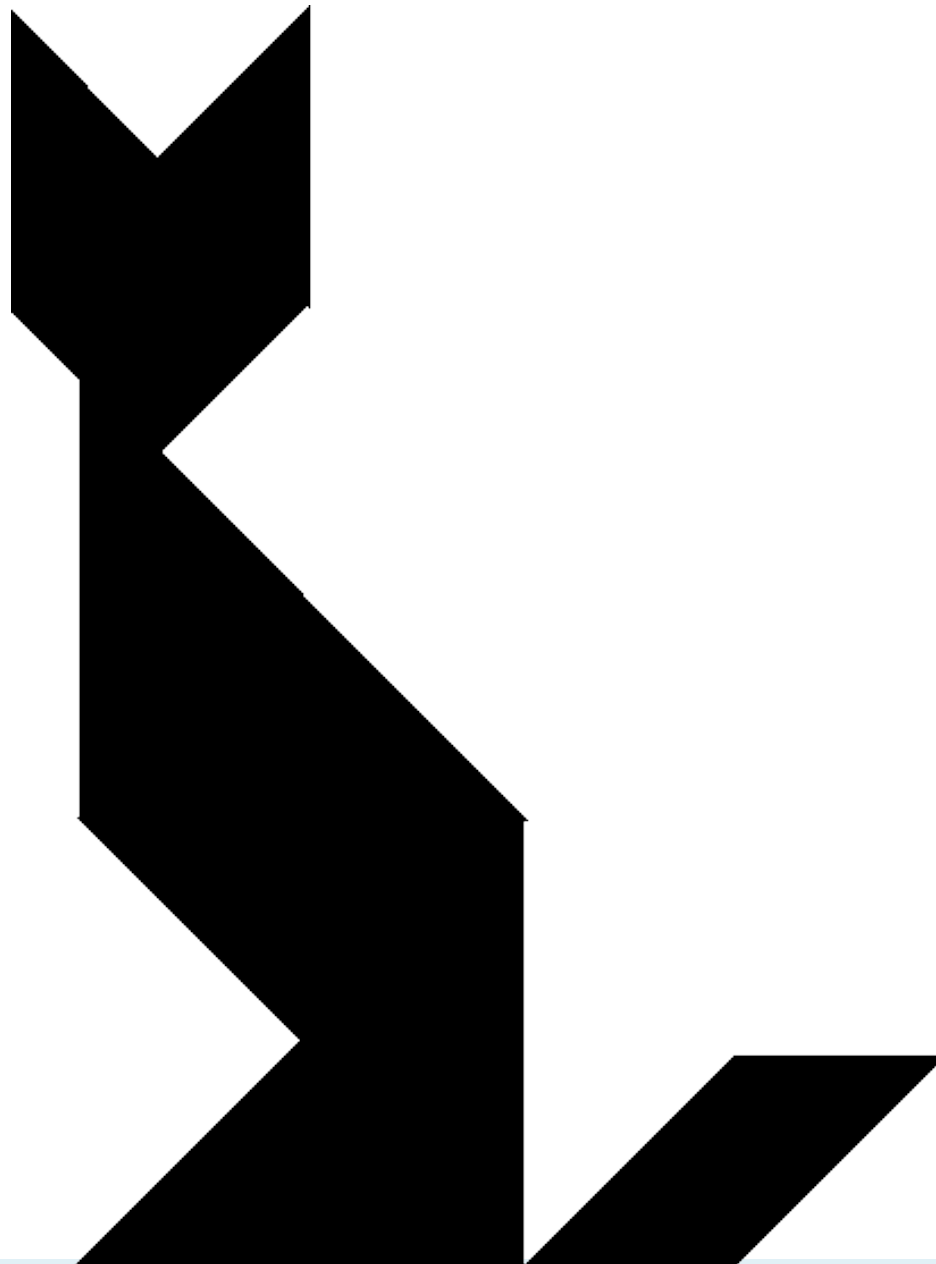
Whitebox vs. blackbox framework summary

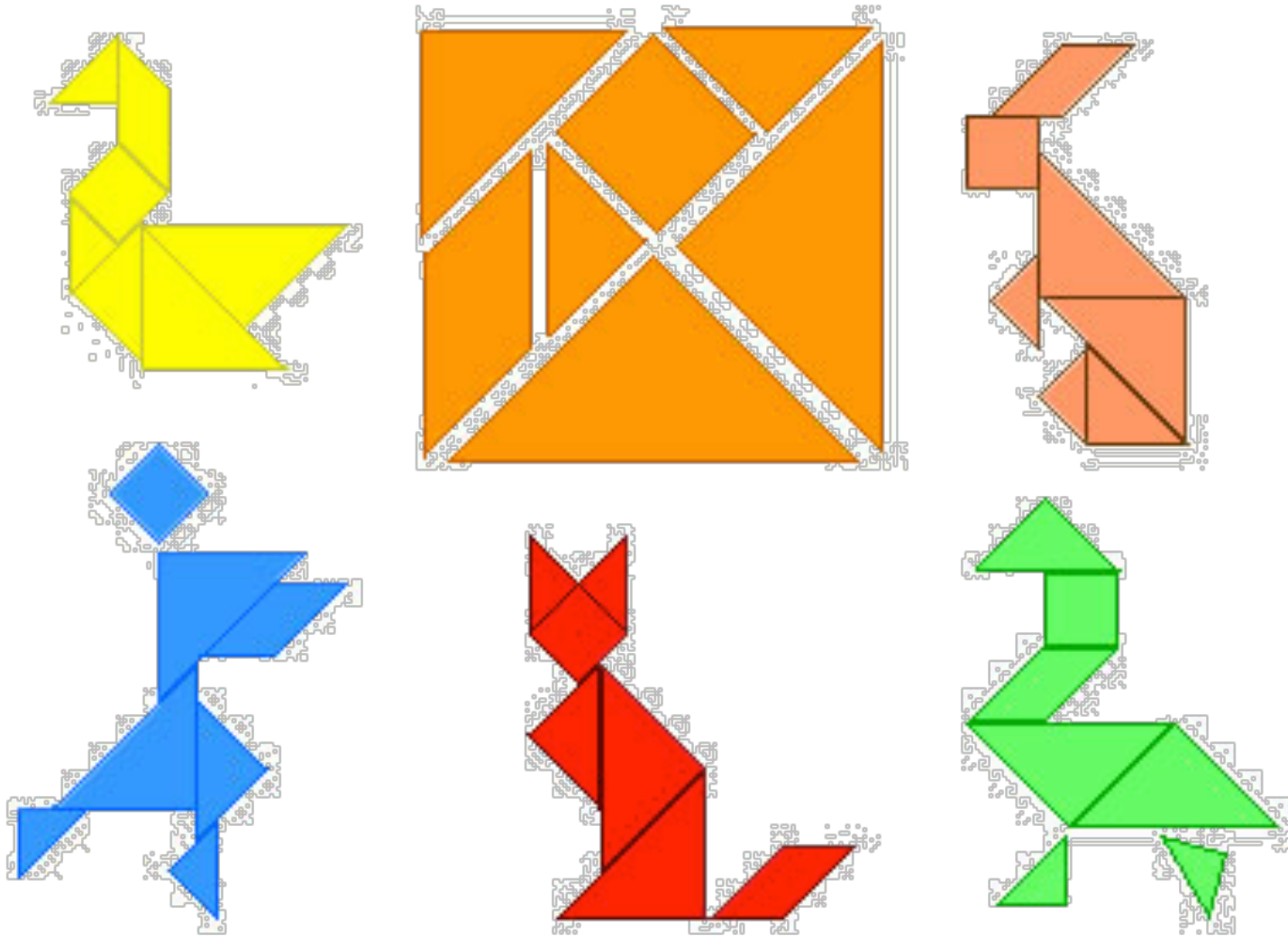
- Whitebox frameworks use subclassing
 - Allows extension of every nonprivate method
 - Need to understand implementation of superclass
 - Only one extension at a time
 - Compiled together
 - Often so-called developer frameworks
- Blackbox frameworks use composition
 - Allows extension of functionality exposed in interface
 - Only need to understand the interface
 - Multiple plugins
 - Often provides more modularity
 - Separate deployment possible (.jar, .dll, ...)
 - Often so-called end-user frameworks, platforms

Framework design considerations

- Once designed there is little opportunity for change
- Key decision: Separating common parts from variable parts
 - What problems do you want to solve?
- Possible problems:
 - Too few extension points: Limited to a narrow class of users
 - Too many extension points: Hard to learn, slow
 - Too generic: Little reuse value

USE VS REUSE: DOMAIN ENGINEERING





(one modularization: tangrams)

The use vs. reuse dilemma

- Large rich components are very useful, but rarely fit a specific need
- Small or extremely generic components often fit a specific need, but provide little benefit

“maximizing reuse minimizes use”

C. Szyperski

Not discussed here...

- Framework implementation details
 - Mechanics of running the framework
 - Mechanics of loading plugins

Summary

- Reuse and variation essential
 - Libraries and frameworks
- Whitebox frameworks vs. blackbox frameworks
- Design for reuse with domain analysis
 - Find common and variable parts
 - Write client applications to find common parts