Principles of Software Construction: Objects, Design, and Concurrency (Part 5: Large-Scale Reuse)

Design for Large-Scale Reuse: Libraries, Frameworks, APIs

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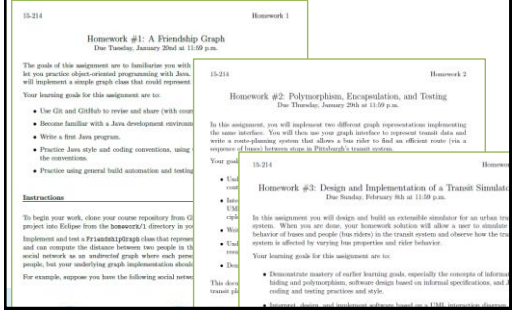
Learning goals

- 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

This and next lecture

- Design for reuse: Libraries and frameworks
  - Motivation: reuse with variation
  - Examples, terminology
  - Whitebox and blackbox frameworks
  - Design considerations
  - Implementation details
    - Responsibility for running the framework
    - Loading plugins

Reuse and variation


15-214 Homework 1

Homework #1: A Friendship Graph

Due Tuesday, January 20nd at 11:59 p.m.

The goals of this assignment are to familiarize you with

let you practice object-oriented programming with Java,

will implement a simple graph class that could represent

Your learning goals for this assignment are to:

- Use Git and GitHub to revise and share (with cour
- Become familiar with a Java development environ
- Write a first Java program.
- Practice Java style and coding conventions, using the conventions.
- Practice using general build automation and testing

Instructions

To begin your work, clone your course repository from G

project into Eclipse from the `homework/1` directory in yo

Implement and test a `FriendshipGraph` class that represen

and can compute the distance between two people in th

social network as an *undirected* graph where each perso

people, but your underlying graph implementation should

For example, suppose you have the following social netwo

15-214 Homework 2

Homework #2: Polymorphism, Encapsulation, and Testing

Due Thursday, January 29th at 11:59 p.m.

In this assignment, you will implement two different graph representations implementing the same interface. You will then use your graph interface to represent transit data and write a route-planning system that allows a bus rider to find an efficient route (via a sequence of legs) between stops in Pittsburgh's transit system.

15-214 Homework

Homework #3: Design and Implementation of a Transit Simulat

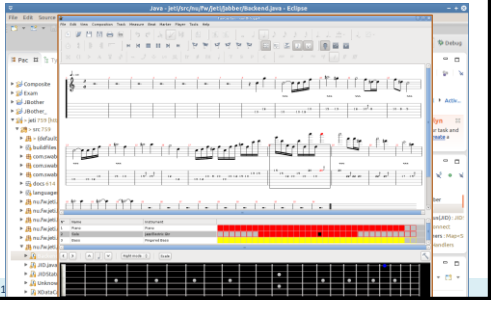
Due Sunday, February 8th at 11:59 p.m.

In this assignment you will design and build an extensible simulator for an urban tra system. When you are done, your homework solution will allow a user to simulate behavior of buses and people (bus riders) in the transit system and observe how the tra system is affected by varying bus properties and rider behavior.

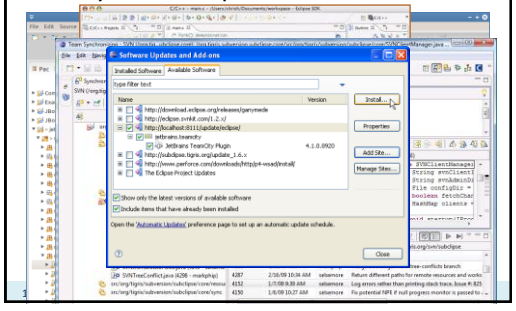
Your learning goals for this assignment are to:

- Demonstrate mastery of earlier learning goals, especially the concepts of informat hiding and polymorphism, software design based on informal specifications, and coding and testing practices and style.
- Interpret, design, and implement software based on a UML interaction diagram

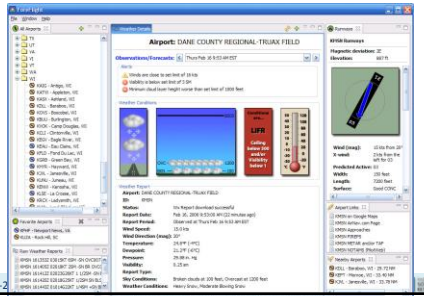
Reuse and variation: The Standard Widget Toolkit



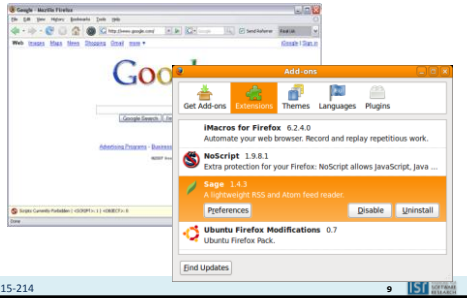
Reuse and variation:
Family of development tools



Reuse and variation:
Eclipse Rich Client Platform



Reuse and variation:
Web browser extensions



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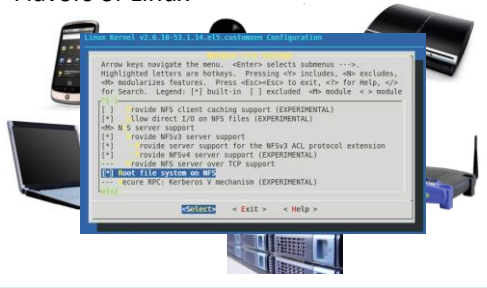
Reuse and variation:
Flavors of Linux

15-214 10

Reuse and variation:
Flavors of Linux



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Reuse and variation:
Printer product lines

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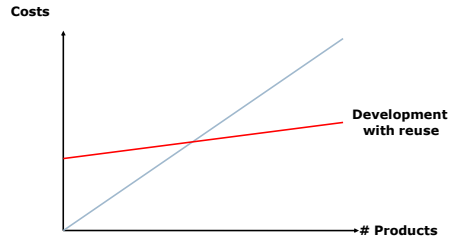
The promise:



Earlier in this course: Class-level reuse

- Design for Reuse
- Language mechanisms supporting reuse
  - Inheritance
  - Subtype polymorphism (dynamic dispatch) for delegation
  - 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, …

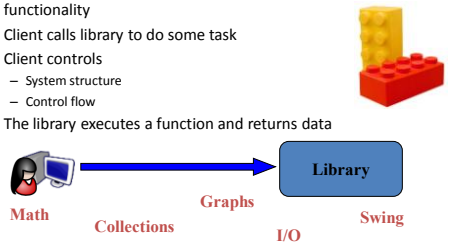
Approaches to reuse and variation

- "Clone and own"
- Subroutines
- Libraries
- Frameworks
- APIs
- Platforms
- Configuration
- Software product lines

LIBRARIES AND FRAMEWORKS

Terminology: Libraries

- Library: A set of classes and methods that provide reusable functionality
- Client calls library to do some task
- Client controls
  - System structure
  - Control flow
- The library executes a function and returns data



Terminology: Frameworks

- Framework: Reusable skeleton code that can be customized into an application
- Framework controls
  - Program structure
  - Control flow
- 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 static void main(String[] args) { new Calc().setVisible(true); }
        public Calc() { init(); }
        protected void init() {
                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(/* calculate some stuff */);
                this.setContentPane(contentPane);
                this.pack();
                this.setLocation(100, 100);
                this.setTitle("My Great Calculator");
                // impl. for closing the window
        }
}
```


A simple example framework

- Consider a family of programs consisting of buttons and text fields only:

- What source code might be shared?

A simple example framework

- Consider a family of programs consisting of buttons and text fields only:

- What source code might be shared?
  - Main method
  - Initialization of GUI
  - Layout
  - Closing the window
  - …

A calculator example

```
public class Calc extends JFrame {
        private JTextField textfield;
        public static void main(String[] args) { new Calc().setVisible(true); }
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                this.pack();
                this.setLocation(100, 100);
                this.setTitle("My Great Calculator");
                // impl. for closing the window
        }
}
```


A simple example framework

```
public abstract class Application extends JFrame {
        protected abstract String getApplicationTitle();
        protected abstract String getButtonText();
        protected String getInititalText() {return "";}
        protected void buttonClicked() { }
        private JTextField textfield;
        public Application() { init(); }
        protected void init() {
                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(getInititalText());
                textfield.setPreferredSize(new Dimension(200, 20));
                contentPane.add(textfield, BorderLayout.WEST);
                button.addActionListener(/* … buttonClicked(); … */);
                this.setContentPane(contentPane);
                this.pack();
                this.setLocation(100, 100);
                this.setTitle(getApplicationTitle());
                // impl. for closing the window
        }
    protected String getInput() { return textfield.getText();}
}
```

Using the simple example framework

```
public abstract class Application extends JFrame {
        protected abstract String getApplicationTitle();
        protected abstract String getButtonText();
        protected String getInititalText() {return "";}
        protected void buttonClicked() { }
        private JTextField textfield;
        pub
        pro
                public class Calculator extends Application {
                        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())); }
                        protected String getApplicationTitle() { return "My Great Calculator"; }
                        public static void main(String[] args) {
                                new Calculator().setVisible(true);
                        }
                }
                this.setContentPane(contentPane);
                this.pack();
                this.setLocation(100, 100);
                this.setTitle(getApplicationTitle());
                // impl. for closing the window
        }
    protected String getInput() { return textfield.getText();}
}
```

Using the simple example framework (again)

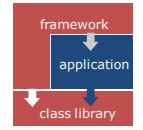
```
public abstract class Application extends JFrame {
        protected abstract String getApplicationTitle();
        protected abstract String getButtonText();
        protected String getInitialText() {return "";}
        protected void buttonClicked() { }
        private JTextField textfield;
        pub
        prot
    }
    protected Si
}
```

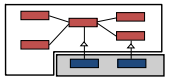
```
public class Calculator extends Application {
        protected String getButtonText() { return "calculate"; }
        protected String getInitialText() { return "(10 – 3) * 6"; }
        protected void buttonClicked() {
                JOptionPane.showMessageDialog(this, "The result of "+getInput()+
                        " is "+calculate(getInput())); }
        protected String getApplicationTitle() { return "My Great Calculator"; }
        public static void main(String[] args) {
                new Calculator().setVisible(true);
        }
}
```

```
public class Ping extends Application {
        protected String getButtonText() { return "ping"; }
        protected String getInitialText() { return "127.0.0.1"; }
        protected void buttonClicked() { /* ... */ }
        protected String getApplicationTitle() { return "Ping Anything"; }
        public static void main(String[] args) {
                new Ping().setVisible(true);
        }
}
```

OO frameworks

- A customizable set of cooperating classes that defines a reusable solution for a given problem
  - Defines key abstractions and their interfaces
  - Defines object interactions & invariants
  - Provides flow of control
  - Provides defaults
- Reuse
  - Reuse of design and code
  - Reuse of a macro architecture
- Framework provides architectural guidance

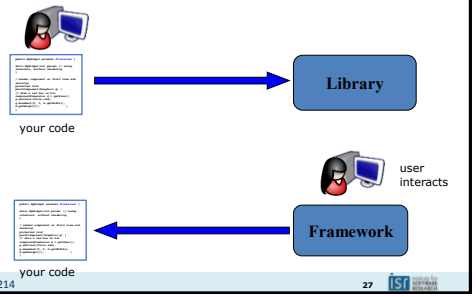




reusing a framework

credit: Erich Gamma

General distinction: Library vs. framework



Framework or Library?

- Java Collections
- Eclipse
- The Java Logging Framework
- Java Encryption Services
- Wordpress
- Ruby on Rails
- Homework 1 Graph Implementation

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, hot spot: 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 of an object that gets called in a sequence according to the protocol and the state of the plugin

Platform/software ecosystem

- Hardware/software environment (frameworks, libraries) for building applications
- Ecosystem: Interaction of multiple parties on a platform, third-party contributions, co-dependencies, …
  - Typically describes more business-related and social aspects

WHITE-BOX VS BLACK-BOX FRAMEWORKS

Whitebox frameworks

- Extension via subclassing and overriding methods
- Common design pattern(s):
  - Template Method
- Design steps:
  - Identify the common code and the variable code
  - Abstract variable code as method calls
- Subclass has main method but gives control to framework

Blackbox frameworks

- Extension via implementing a plugin interface
- Common design pattern(s):
  - Strategy
  - Observer
- Design steps:
  - Identify the common code and the variable code
  - Abstract variable code as methods of an interface
  - Decide whether there might be one or multiple plugins
- 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 abstract String getApplicationTitle();
        protected abstract String getButtonText();
        protected String getInititalText() {return "";}
        protected void buttonClicked() { }
        private JTextField textfield;
        pub
        pro
}
protected St
}
```

```
public class Calculator extends Application {
        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()));}
        protected String getApplicationTitle() { return "My Great Calculator"; }
        public static void main(String[] args) {
                new Calculator().setVisible(true);
        }
}
```

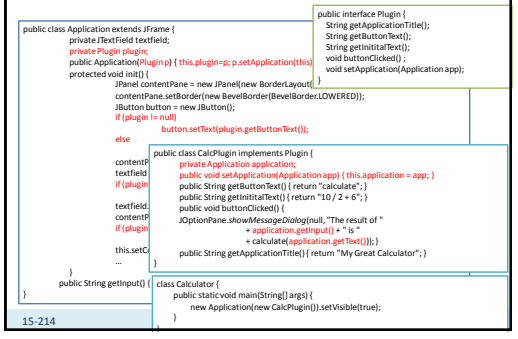
```
public class Ping extends Application {
        protected String getButtonText() { return "ping"; }
        protected String getInititalText() { return "127.0.0.1"; }
        protected void buttonClicked() { /* ... */ }
        protected String getApplicationTitle() { return "Ping"; }
        public static void main(String[] args) {
                new Ping().setVisible(true);
        }
}
```

An example blackbox framework

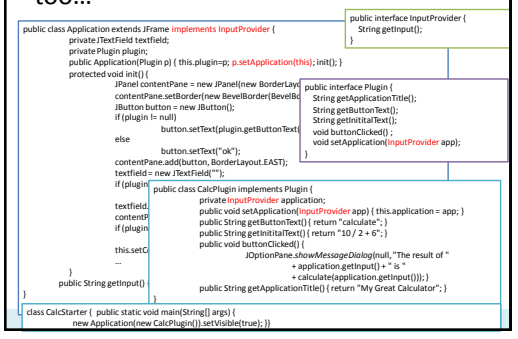
```
public class Application extends JFrame {
        private JTextField textfield;
        private Plugin plugin;
        public Application(Plugin p) { this.plugin=p; p.setApplication(this); init(); }
        protected void init() {
                JPanel contentPane = new JPanel(new BorderLayout());
                contentPane.setBorder(new BevelBorder(BevelBorder.LOWERED));
                JButton button = new JButton();
                if (plugin != null)
                        button.setText(plugin.getButtonText());
                else
                        button.setText("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(/* ... 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



An aside: Plugins could be reusable, too…



Whitebox vs. blackbox framework summary

- Whitebox frameworks use subclassing
  - Allows to extend 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 to extend only 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

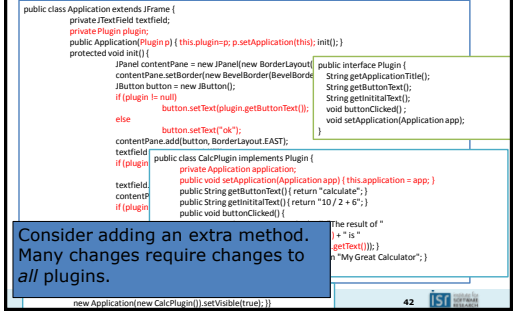
Scrabble Framework

- In what way is Homework 4 (Scrabble with Stuff) a framework?

Framework design considerations

- Once designed there is little opportunity for change
- Key decision: Separating common parts from variable parts
  - Identify hot spots vs. cold spots
- 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
- The golden rule of framework design:
  - Writing a plugin/extension should NOT require modifying the framework source code

The cost of changing a framework



Consider adding an extra method. Many changes require changes to *all* plugins.

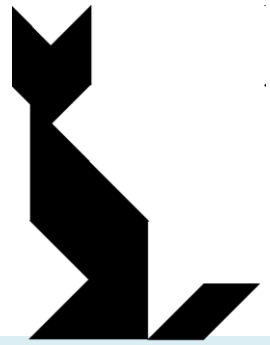
USE VS REUSE:
DOMAIN ENGINEERING

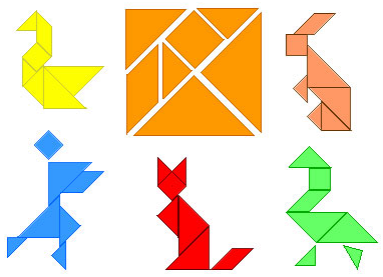
The use vs. reuse dilemma

- 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





(one modularization: tangrams)

Domain engineering

- Understand users/customers in your domain
  - What might they need? What extensions are likely?
- Collect example applications before starting a framework/component
- Make a conscious decision what to support
  - Called *scoping*
- e.g., the Eclipse policy:
  - Interfaces are internal at first
    - Unsupported, may change
  - Public stable extension points created when there are at least two distinct customers

Typical framework design and implementation

- Identify common parts and variable parts
- Implement common parts
  - Also design and write sample plugins/applications
- Provide plugin interface/extension/callback mechanisms for variable parts
  - Use well-known design principles and patterns: Strategy, Decorator, Observer, Command, Template Method, Factories …

Evolutionary design: Extract interfaces from classes

- Extracting interfaces is a new step in evolutionary design:
  - Abstract classes are discovered from concrete classes
  - Interfaces are distilled from abstract classes
- Start once the architecture is stable
  - Remove non-public methods from class
  - Move default implementations into an abstract class which implements the interface

(credit: Erich Gamma)

FRAMEWORK MECHANICS

Running a framework

- Some frameworks are runnable by themselves
  - e.g. Eclipse
- Other frameworks must be extended to be run
  - MapReduce, Swing, Servlets, JUnit

Methods to load plugins

- Client writes main(), creates a plugin, and passes it to framework
  - (see blackbox example above)
- Framework writes main(), client passes name of plugin as a command line argument or environment variable
  - (see next slide)
- Framework looks in a magic location
  - Config files or .jar files are automatically loaded and processed
- GUI for plugin management

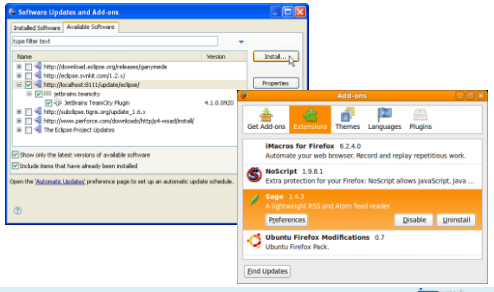
An example plugin loader using Java Reflection

```
public static void main(String[] args) {
    if (args.length != 1)
        System.out.println("Plugin name not specified");
    else {
        String pluginName = args[0];
        try {
            Class<?> pluginClass = Class.forName(pluginName);
            new Application((Plugin) pluginClass.newInstance())
                .setVisible(true);
        } catch (Exception e) {
            System.out.println("Cannot load plugin " + pluginName
                + ", reason: " + e);
        }
    }
}
```


Another plugin loader using Java Reflection

```
public static void main(String[] args) {
    File config = new File(".config");
    BufferedReader reader = new BufferedReader(new FileReader(config));
    Application = new Application();
    Line line = null;
    while ((line = reader.readLine()) != null) {
        try {
            Class<?> pluginClass = Class.forName(pluginName);
            application.addPlugin((Plugin) pluginClass.newInstance());
        } catch (Exception e) {
            System.out.println("Cannot load plugin " + pluginName
                + ", reason: " + e);
        }
    }
    reader.close();
    application.setVisible(true);
}
```

GUI-based plugin management



Supporting multiple plugins

- Observer design pattern is commonly used
- Load and initialize multiple plugins
- Plugins can register for events
- Multiple plugins can react to same events
- Different interfaces for different events possible

```
public class Application {
    private List<Plugin> plugins;
    public Application(List<Plugin> plugins) {
        this.plugins=plugins;
        for (Plugin plugin: plugins)
            plugin.setApplication(this);
    }
    public Message processMsg (Message msg) {
        for (Plugin plugin: plugins)
            msg = plugin.process(msg);
        ...
        return msg;
    }
}
```


Example: An Eclipse plugin

- A popular Java IDE
- More generally, a framework for tools that facilitate "building, deploying and managing software across the lifecycle."
- Plugin framework based on OSGI standard
- Starting point: Manifest file
  - Plugin name
  - Activator class
  - Meta-data

```
Manifest-Version: 1.0
Bundle-ManifestVersion: 2
Bundle-Name: MyEditor Plug-in
Bundle-SymbolicName: MyEditor;
singleton:=true
Bundle-Version: 1.0.0
Bundle-Activator:
 myeditor.Activator
Require-Bundle:
 org.eclipse.ui,
 org.eclipse.core.runtime,
 org.eclipse.jface.text,
 org.eclipse.ui.editors
Bundle-ActivationPolicy: lazy
Bundle-
RequiredExecutionEnvironment:
JavaSE-1.6
```


Example: An Eclipse plugin

- plugin.xml
  - Main configuration file
  - XML format
  - Lists extension points
- Editor extension
  - extension point: org.eclipse.ui.editors
  - file extension
  - icon used in corner of editor
  - class name
  - unique id
    - refer to this editor
    - other plugins can extend with new menu items, etc.!

```
<?xml version="1.0" encoding="UTF-8"?>
<?eclipse version="3.2"?>
<plugin>

  <extension
        point="org.eclipse.ui.editors">
    <editor
          name="Sample XML Editor"
          extensions="xml"
          icon="icons/sample.gif"
contributorClass="org.eclipse.ui.texteditor.Basic
TextEditorActionContributor"
          class="myeditor.editors.XMLEditor"
          id="myeditor.editors.XMLEditor">
    </editor>
  </extension>

</plugin>
```


Example: An Eclipse plugin

- At last, code!
- XMLEditor.java
  - Inherits TextEditor behavior
    - open, close, save, display, select, cut/copy/paste, search/replace, ...
    - REALLY NICE not to have to implement this
    - But could have used ITextEditor interface if we wanted to
  - Extends with syntax highlighting
    - XMLDocumentProvider partitions into tags and comments
    - XMLConfiguration shows how to color partitions

```
package myeditor.editors;

import org.eclipse.ui.editors.text.TextEditor;

public class XMLEditor extends TextEditor {
        private ColorManager colorManager;

        public XMLEditor() {
                super();
                colorManager = new
                        ColorManager();
                setSourceViewerConfiguration(
                        new
XMLConfiguration(colorManager));
                setDocumentProvider(
                        new
XMLDocumentProvider());
        }

        public void dispose() {
                colorManager.dispose();
                super.dispose();
        }
}
```


Example: A JUnit Plugin

```
public class SampleTest {
    private List<String> emptyList;

    @Before
    public void setUp() {
        emptyList = new ArrayList<String>();
    }

    @After
    public void tearDown() {
        emptyList = null;
    }

    @Test
    public void testEmptyList() {
        assertEquals("Empty list should have 0
elements",
                0, emptyList.size());
    }
}
```

Here the important plugin mechanism is Java annotations

SWING DISCUSSION

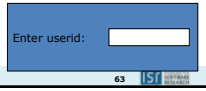
Java Swing: It's a library?

- Create a GUI using pre-defined containers
  - JFrame, JPanel, JDialog, JMenuBar
- Use a layout manager to organize components in the container
- Add pre-defined components to the layout
  - Components: JLabel, JTextField, JButton

This is no different that the File I/O library.

Swing: Containers and components

```
// create the container
JPanel panel = new JPanel();

// create the label, add to the container
JLabel label = new JLabel();
label.setText("Enter your userid:");
panel.add(label);

// create a text field, add to the container
JTextField textfield = new JTextField(16);
panel.add(textfield)
```



Swing: Layout managers

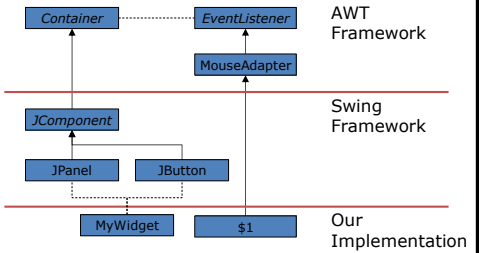
```
panel.setLayout(new GridBagLayout());

GridBagConstraints c = new GridBagConstraints();

// create and position the button
JButton button = new JButton("Click Me!");
c.fill = GridBagConstraints.HORIZONTAL;
c.gridx = 0;  // first column
c.gridy = 1;  // second row
c.gridwidth = 2;     // span two columns
c.weightx = 1.0;     // use all horizontal space
c.anchor = GridBagConstraints.WEST;
c.insets = new Insets(0,5,0,5); // add side padding
pane.add(button, c);
```


Swing: Events

```
// create an anonymous MouseAdapter, which extends
// the MouseListener class
button.add(new MouseAdapter () {
   public void mouseClicked(MouseEvent e) {
      System.err.println("You clicked me! " +
         "Do it again!")
   }
});
```

But this extending a class to add custom behaviors, right?

Where is the boundary?



Swing: Custom components

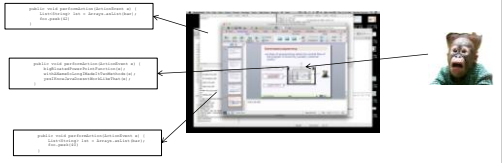
```
public MyWidget extends JPanel {

    public MyWidget(int param) {
        setLayout(new GridBagLayout());
        GridBagConstraints c = new GridBagConstraints();
        …
        add(label, c);
        add(textfield, c);
        add(button, c);
    }
    public void setParameter(int param) {
        // update the widget, as needed
    }
}
```


Swing: Custom components

```
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 component
                Dimension d = getSize();
                g.setColor(Color.red);
                g.drawRect(0, 0, d.getWidth(), d.getHeight());
        }
}
```


Recall event-based programming

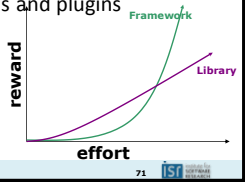
- A style of programming where the control-flow of the program is driven by (usually-) external events



FRAMEWORK COSTS

Learning a framework

- Documentation
- Tutorials, wizards, and examples
- Communities, email lists and forums
- Other client applications and plugins



DESIGN CHALLENGES

Framework design exercises

- Think about a framework for:
  - Video playing software
  - Viewing, printing, editing a portable document format
  - Compression and archiving software
  - Instant messaging software
  - Music editing software
- Questions
  - What are the dimensions of variability/extensibility?
  - What interfaces would you need?
  - What are the core methods for each interface?
  - How do you set up the framework?

Framework design exercises

Framework design exercises

Framework design exercises

Framework design exercises

Summary

- Reuse and variation essential
  - Avoid reimplementing from scratch
- Object-oriented design principles for library design
- From low-level code reuse to design/behavior reuse with frameworks
- Design for reuse with domain analysis: find common and variable parts
- Use design patterns for framework design and implementation