6.005 elements of software construction

Event-Based Programming

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Today's lecture

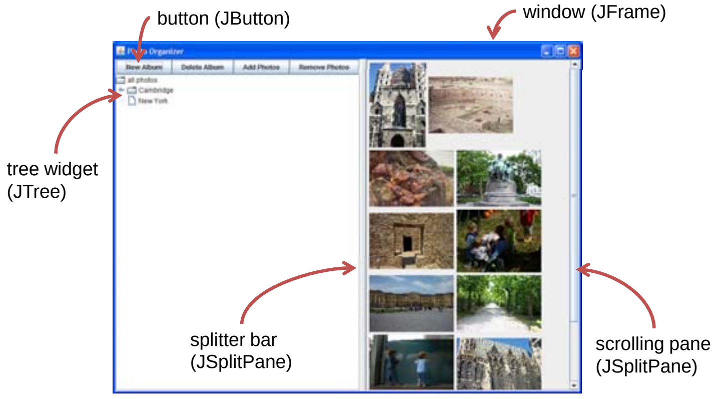
Composite pattern
- Example: view hierarchy in GUIs

Event-based programming
- Example;¡nput handling¡n graphical user¡nterfaces

Model-view-controller pattern
- Found throughout user interfaces

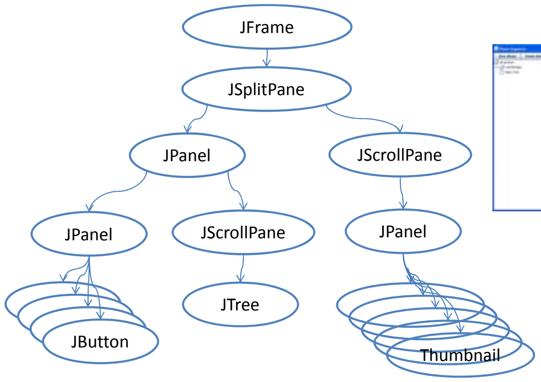
Graphical User Interfaces

GUIs are composed from small reusable pieces



View Hierarchy

A GUI is structured as a hierarchy of views
- A view is an object that displays itself on a rectangular region of the screen



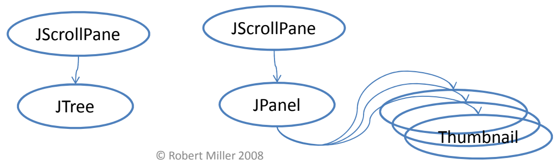
Composite Pattern

View hierarchy is an example of the Composite pattern

- Primitive views don't contain other views
  - button, tree widget, textbox, thumbnail, etc.
- Composite views are used for grouping or modifying other views
  - JSplitPane displays two views side-by-side with an adjustable splitter
  - JScrollPane displays only part of a view, with adjustable scrollbars

Key idea

- primitives and composites implement a common interface (JComponent)
- containers can hold any JComponent, so both primitives and other containers



How the View Hierarchy Is Used

Output

- GUIs change their output by **mutating** the view hierarchy
  - e.g., to show a new set of photos, the current Thumbnails are removed from the tree and a new set of Thumbnails is added in their place
- A redraw algorithm automatically redraws the affected views using the interpreter pattern (paint() method)

Input

- GUIs receive keyboard and mouse input by attaching listeners to views (more on this in a bit)

Layout

- An automatic layout algorithm automatically calculates positions and sizes of views using the interpreter pattern (doLayout() method)
  - Specialized composites (JSplitPane, JScrollPane) do layout themselves
  - Generic composites (JPanel, JFrame) delegate layout decisions to a **layout manager** (e.g. FlowLayout, GridLayout, BorderLayout, ...)

Handling Mouse Input

Centralized approach?

```
while (true) {
    read mouse click
    if (clicked on New Album) doNewAlbum();
    else if (clicked on Delete Album) doDeleteAlbum();
    else if (clicked on Add Photos) doAddPhotos();
    …
    else if (clicked on an album in the tree) doSelectAlbum();
    else if (clicked on +/- button in the tree) doToggleTreeExpansion();
    ....
    else if (clicked on a thumbnail) doToggleThumbnailSelection();
    …
```

Not modular!

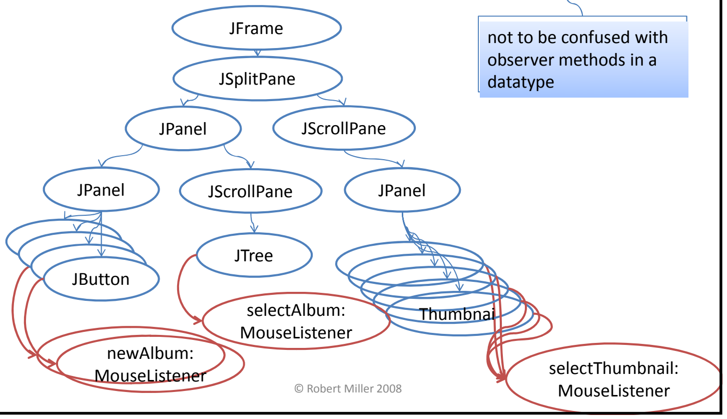
- Mixes up responsibilities for button panel, album tree, and thumbnails all in one place

Input Handling on the View Hierarchy

Input handlers are associated with views

- Also called **listeners**, event handlers, subscribers, and observers

not to be confused with observer methods in a datatype



Event-Based Programming

Control flow through a graphical user interface

- A top-level **event loop** reads input from mouse and keyboard
- For each input event, it finds the right view in the hierarchy (by looking at the x,y position of the mouse) and sends the event to that view's listeners
- Listener does its thing (e.g. modifying the view hierarchy) and returns immediately to the event loop

A Closer Look at Listeners

JComponent
Listener

```
class JComponent {
  ...

  public void addMouseListener(MouseListener l) ...
  public void removeMouseListener(MouseListener l) ...

  private void fireMousePress(int x, int y) {
    MouseEvent event = new MouseEvent(..., x, y, ...);
    for (MouseListener l : listeners) {
      l.mousePressed(e);
    }
  }
```

```
interface MouseListener {
    void mousePressed(MouseEvent e);
    void mouseReleased(MouseEvent e);
    void mouseMoved(MouseEvent e);
    ...
}
```

Component is very weakly coupled to its listeners

- Component doesn't depend on the identity of the listening class, only that it implements the MouseListener interface
- Component doesn't depend on the number of listeners, and listeners can come and go

Publish-Subscribe Pattern

GUI input handling is an example of the Publish-Subscribe pattern

- aka Listener, Event, Observer

An event source generates a stream of discrete events

- In this example, the mouse is the event source
- Events are state transitions in the source
- Events often include additional info about the transition (e.g. x,y position of mouse), bundled into an **event object** or passed as parameters

Listeners register interest in events from the source

- Can often register only for specific events – e.g., only want mouse events occurring inside a view's bounds
- Listeners can unsubscribe when they no longer want events

When an event occurs, event source distributes it to all interested listeners

Other Examples of Publish-Subscribe

Higher-level GUI input events

- JButton sends an action event when it is pressed (whether by the mouse or by the keyboard)
- JTree sends a selection event when the selected element changes (whether by mouse or by keyboard)
- JTextbox sends change events when the text inside it changes for any reason

Internet messaging

- Email mailing lists
- IM chatrooms

Separating Frontend from Backend

We've seen how to separate input and output in GUIs

- Output is represented by the view hierarchy
- Input is handled by listeners attached to views

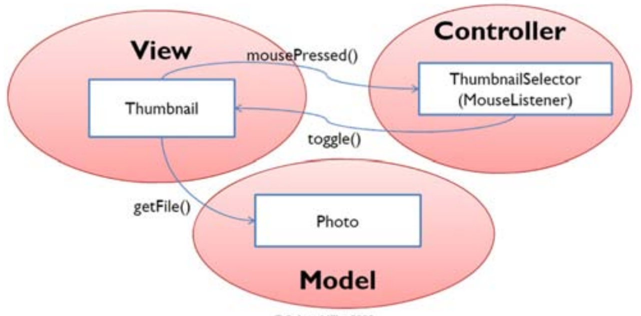
Missing piece is the backend of the system

- Backend (aka **model**) represents the actual data that the user interface is showing and editing
- Why do we want to separate this from the user interface?

Model-View-Controller Pattern

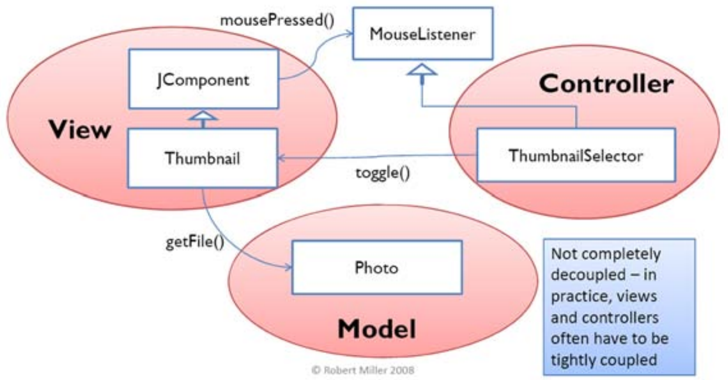
Model-View-Controller (MVC) separates responsibilities

- View displays output
- Controller handles input
- Model stores application data



A More Detailed Look

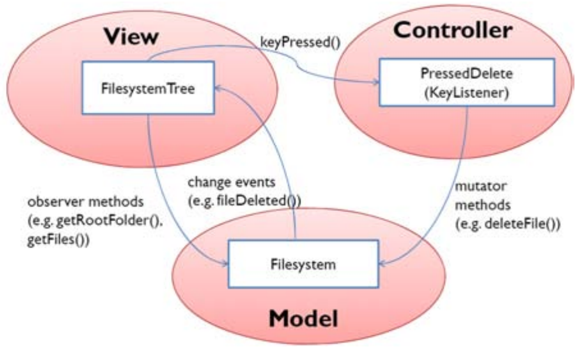
Listener interface decouples the view from the controller (somewhat)



Not completely decoupled – in practice, views and controllers often have to be tightly coupled

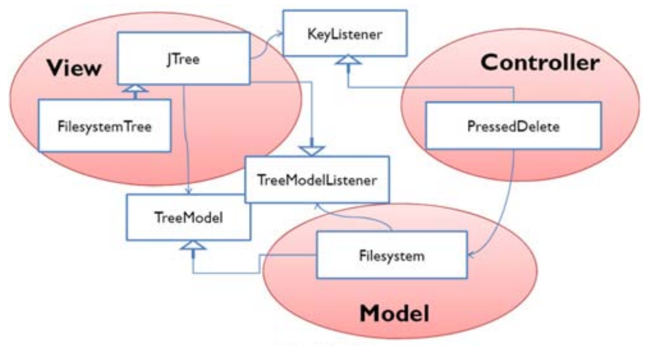
MVC with a Mutable Model

Controller mutates the model; model updates the view

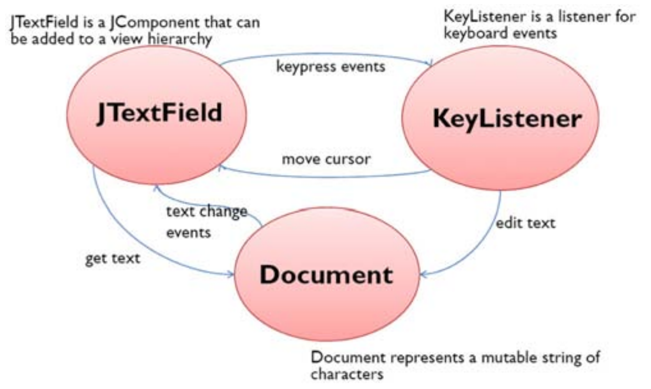

View
keyPressed()
Controller
FilesystemTree
PressedDelete (KeyListener)
change events (e.g. fileDeleted())
observer methods (e.g. getRootFolder(), getFiles())
mutator methods (e.g. deleteFile())
Filesystem
Model

Decoupling the Model from the View

More interfaces decouple the view and the model



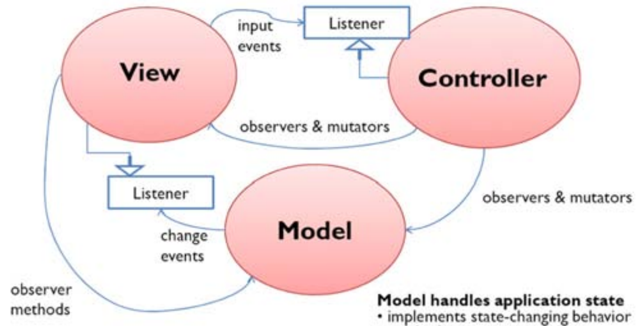
Another MVC Example: Textbox


JTextField is a JComponent that can be added to a view hierarchy
KeyListener is a listener for keyboard events
keypress events
JTextField
KeyListener
move cursor
text change events
edit text
get text
Document
Document represents a mutable string of characters

Summary of MVC

View handles output
• calls observers on the model to display it
• listens for model changes and updates display

Controller handles input
• listens for input events on the view hierarchy
• calls mutators on model or view



Model handles application state
• implements state-changing behavior
• sends change events to views

Advantages of Model-View-Controller

Separation of responsibilities

➢ Each module is responsible for just one feature
- Model: data
- View: output
- Controller: input

Decoupling

➢ View and model are decoupled from each other, so they can be changed independently

➢ Model can be reused with other views
- e.g. JTree view that displays the full filesystem tree, and a JLabel view that just displays the number of files

➢ Multiple views can simultaneously share the same model

➢ Views can be reused with other models, as long as the model implements an interface
- e.g. JTree class (the view) and TreeModel interface

Risks of Event-Based Programming

Spaghetti of event handlers

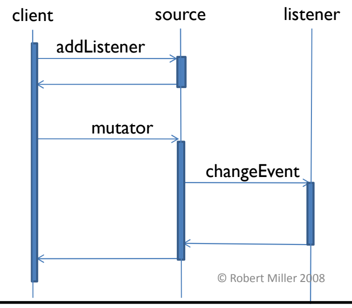
- Control flow through an event-based program is not simple
- You can't follow the control just by studying the source code, because control flow depends on listener relationships established at runtime
- Careful discipline about who listens to what (like the model-view-controller pattern) is essential for limiting the complexity of control flow

Obscured control flow leads to some unexpected pitfalls…

Basic Interaction of Event Passing

Sequence diagram is good for depicting control flow

- Time flows downward
- Each vertical time line shows one object's lifetime
- Horizontal arrows show calls and returns, trading control between objects
- Dark rectangles show when a method is active (i.e., has been called but hasn't returned yet)



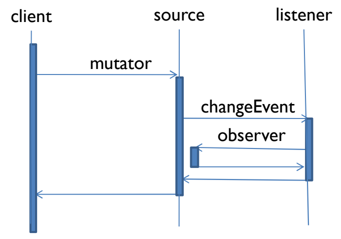
```
interface Source {
    addListener()
    removeListener()
    observer()
    mutator()
}

interface Listener {
    changeEvent()
}
```

Pitfall #1: Listener Calls Observers

The listener often calls methods on the source

- e.g., when a textbox gets a change event from its model, it needs to call getText() to get the new text and display it
- So observer method calls may occur while the mutator is still in progress



Why is this a potential problem?

Pitfall #1: Specific Example

```
class Filesystem {
   private Map<File, List<File>> cache;
   public List<File> getContents(File folder) {
      check for folder in cache, otherwise read it from disk and update cache }
   public void deleteContents(File folder) {
      for (File f: getContents(folder)) {
         f.delete();
         fireChangeEvent(f, REMOVED);  // notify listeners that f was deleted }
      cache.remove(folder);  // cache is no longer valid for this folder}
}
```

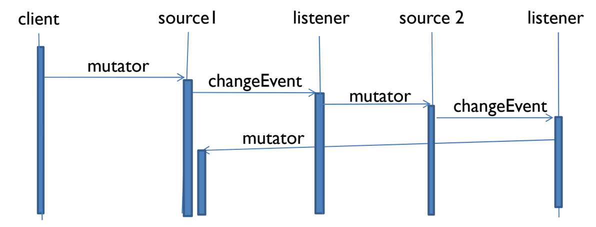
Solution

- source must establish rep invariant before giving up control to any listeners
- often done simply by waiting to send events until end of mutator

Pitfall #2: Listener Calls Mutators

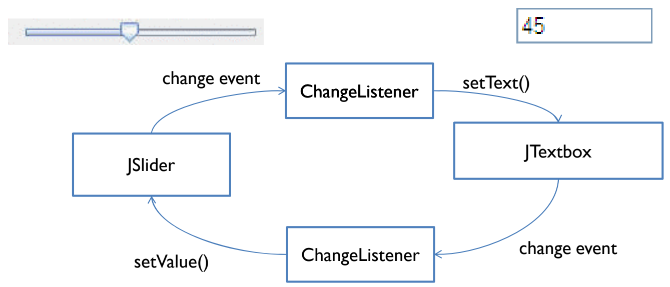
The listener might call mutator on the source

- e.g., when two sources are listening to each other in order to keep their state synchronized
- So calls to mutators may occur while mutator is still in progress



Why is this a potential problem?

Pitfall #2: Specific Example



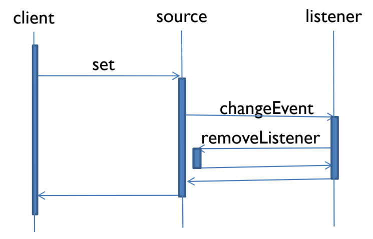
Solution

- only send events when mutator actually causes a state change

Pitfall #3: Listener Removes Itself

The listener might call removeListener() on the source

- This happens when the listener is done its work, e.g. a listener that executes a stock trade as soon as a certain price is reached
- So calls to removeListener() may occur while mutator is still in progress



Why is this a potential problem?

Pitfall #3: Specific Example

```
class Source {
   private Listener[] listeners;
   private int size;
   public void removeListener(Listener l) {
      for (int i = 0; i < size; ++i) {
         if (listeners[i] == l) { listeners[i] = listeners[size-1]; --size; } }
   private void fireChangeEvent(...) {
      for (int i = 0; i < size; ++i) listeners[i].changed(...);   }
}
```

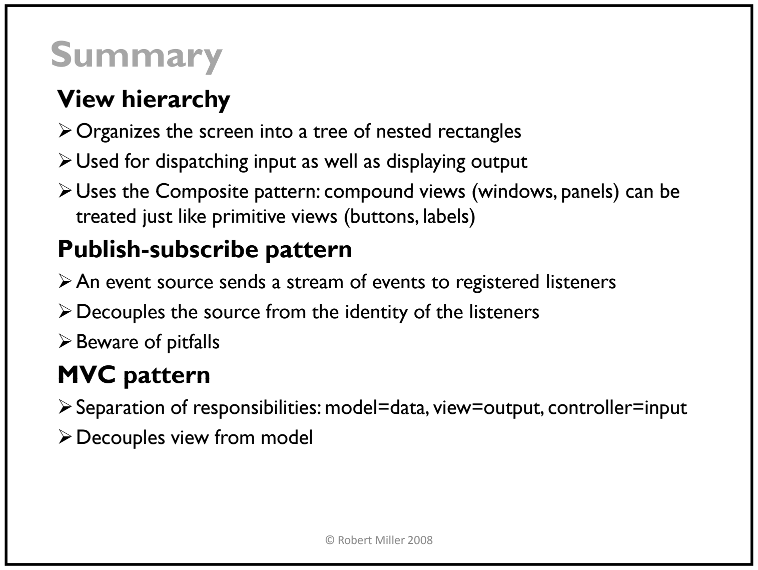
What happens if listeners[i] removes itself here?

- Java collections (Set, List, etc) have the same problem:

  It's not safe to mutate a collection while you're iterating over it

Solution

- fire events by iterating over a **copy** of the listeners data structure
- or use javax.swing.EventListenerList which copies only when necessary



Summary

View hierarchy

- Organizes the screen into a tree of nested rectangles
- Used for dispatching input as well as displaying output
- Uses the Composite pattern: compound views (windows, panels) can be treated just like primitive views (buttons, labels)

Publish-subscribe pattern

- An event source sends a stream of events to registered listeners
- Decouples the source from the identity of the listeners
- Beware of pitfalls

MVC pattern

- Separation of responsibilities: model=data, view=output, controller=input
- Decouples view from model