
CSE 331
Software Design & Implementation

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Callbacks, Events, and Event-Driven Programs

The limits of scaling

What prevents us from building huge, intricate structures that work perfectly and indefinitely?

- No friction
- No gravity
- No wear-and-tear

... it's the difficulty of *understanding* them

So we split designs into sensible parts and reduce interaction among the parts

- More *cohesion* within parts
- Less *coupling* across parts



Design exercise

We will extend and modify this example throughout this lecture

- Provided code shows *skeletal versions that compile*

Our application has various *styled words*

- A mutable word with a color (and font, size, weight, ...)
- Some styled words are spell-checked against a dictionary
- Automatically link to things that look like URLs

Want good coupling, cohesion, and reuse

Available libraries

To set up the example, we assume we have:

1. **StringBuffer** to hold mutable text (in standard library)
 - Methods **insert**, **delete**, and much more
2. A **Dictionary** class with a static method providing dictionaries for available languages

```
class Dictionary {  
    public static Dictionary findDictionary(String lang) {...}  
    public boolean contains(String s) {...}  
    ...  
}
```

3. Classes for all the styling of words
 - Skeletal code just assumes a **Color** class
 - E.g., **new Color("red")**

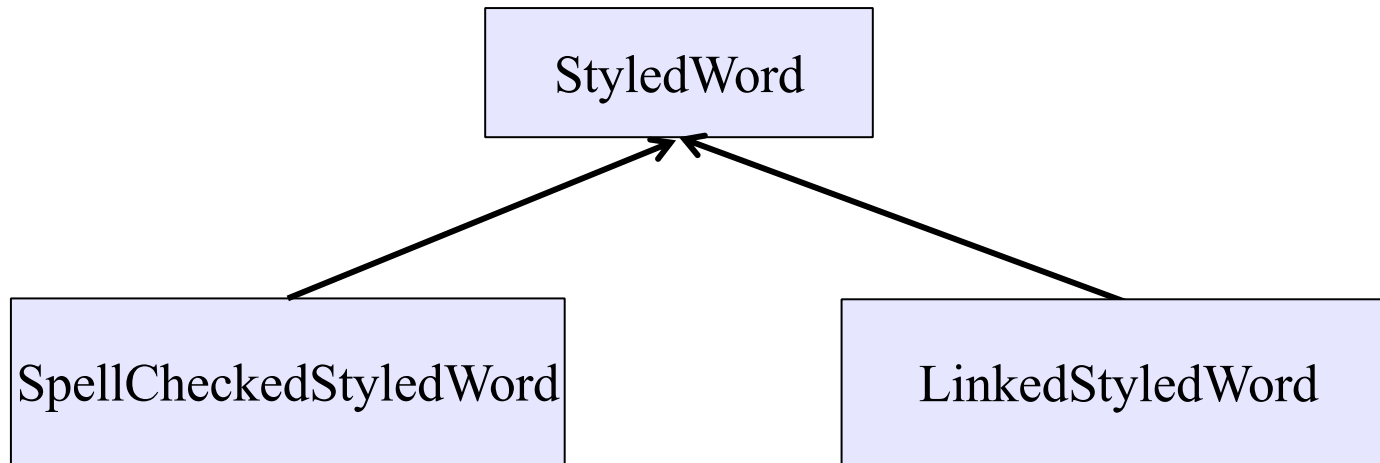
A direct approach

Version 1 (see `v1.java`)

Three new classes:

- **StyledWord**
 - Contains a **StringBuffer** and a **Color**
- **SpellCheckedStyledWord**
 - Contains a **StyledWord** and a **Dictionary**
- **LinkedStyledWord**
 - Contains a **StyledWord**

Module dependency diagram (MDD)



What's wrong with v1?

Cohesion: Seems fine – each class has 1 purpose

Reuse: So-so

- Subclassing would avoid all those *forwarding methods*
 - but **SpellCheckedStyledWord** / **LinkedStyledWord** might not be true subtypes
- No way to spell-check *and* add links
 - important if we want **StyledWord** to be a public library

Coupling: Problematic...

“When the text changes”

```
class SpellcheckedStyledWord {
    ...
    private void performSpellcheck() {...}
    public void addLetter(char c, int pos) {
        word.addLetter(c, position);
        performSpellcheck();
    }
}
```

`SpellCheckedStyledWord` and `LinkedStyledWord` need to know whenever the text changes

- `addLetter` and `deleteLetter`
- Hopefully no other ones we forgot!
- But concept of “text changed” is something we want to leave to `StyledWord`
- To avoid this coupling, want the “text changed” *event* to be managed by `StyledWord`

Moving “when the text changes”

Version 2 (see `v2.java`)

- (Not good but a stepping-stone to version 3)

Let’s make `StyledWord` responsible for any necessary spell-checking or link adding

- A `StyledWord`’s state now includes:
 - a `Spellchecker` if there is one
 - a `LinkUpdater` if there is one
- When the word changes, pass `this` to the spell-checker and/or link updater

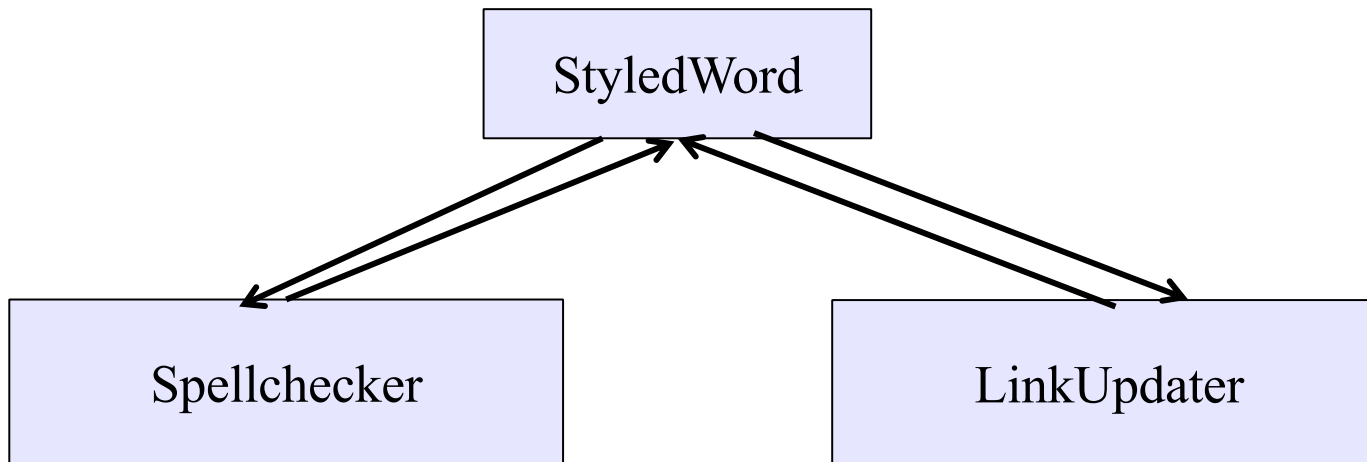
What is right in v2?

Reuse: solves the problems with v1

Coupling:

- removes *some* dependence of SpellChecker / LinkUpdater on the details of StyledWord
- but on the other hand...

Version 2 MDD



What's wrong with v2?

Reuse: A bit better, but work-in progress

- No more forwarding methods
- Can spellcheck or update links or both
- But what if there's a third (or fourth or...) thing we want to do later when some words change

Cohesion: Worse: **StyledWord** shouldn't be directly tracking what needs spellchecking or link-updating

Coupling: Solved our V1 coupling problem, but made our MDD worse

V2 uses callbacks

```
class StyledWord {
    ...
    private void afterWordChange() {
        if (spellchecker != null)
            spellchecker.performSpellcheck(this);
        if (linkUpdater != null)
            linkUpdater.updateLink(this);
    }
}
```

- `performSpellcheck` & `updateLink` passed to constructor
- All the `StyledWord` does with those objects is call `performSpellcheck(this)` or `updateLink(this)`
- `spellchecker` and `linkUpdater` are *callbacks* – code passed in for the purpose of being called some time later

Callbacks

Callback: “Code” provided by client to be used by library

- In Java, pass an object with the “code” in a method

Synchronous callbacks:

- Examples: **HashMap** calls its client’s **hashCode**, **equals**
- Useful when library needs the callback result immediately

Asynchronous callbacks:

- *Register* to indicate interest and where to call back
- Useful when the callback should be performed later, when some interesting event occurs
- UIs, servers, etc.

The key decoupling insight

- **StyledWord** depends on **Spellchecker** and **LinkUpdater** in v2, but does *not* need to know *anything* about what these classes do
 - just needs to call the call-backs when an event occurs (the text changes)
- Weaken the dependency by introducing a much weaker specification in the form of an interface or abstract class
 - The interface implemented by things that can be *notified* when the text changes

```
interface WordChangeListener {  
    public void onWordChange(StyledWord w);  
}
```

v3: take a WordChangeListener

```
class StyledWord {
    ...
    private List<WordChangeListener> listeners;
    public StyledWord(Collection<WordChangeListener> ls) {
        this.listeners = new ArrayList<>(ls);
    }

    public void addLetter(char c, int position) {
        text.insert(position, c);
        afterWordChange();
    }

    private void afterWordChange() {
        for (WordChangeListener listener : listeners)
            listener.onWordChange(this);
    }
}
```

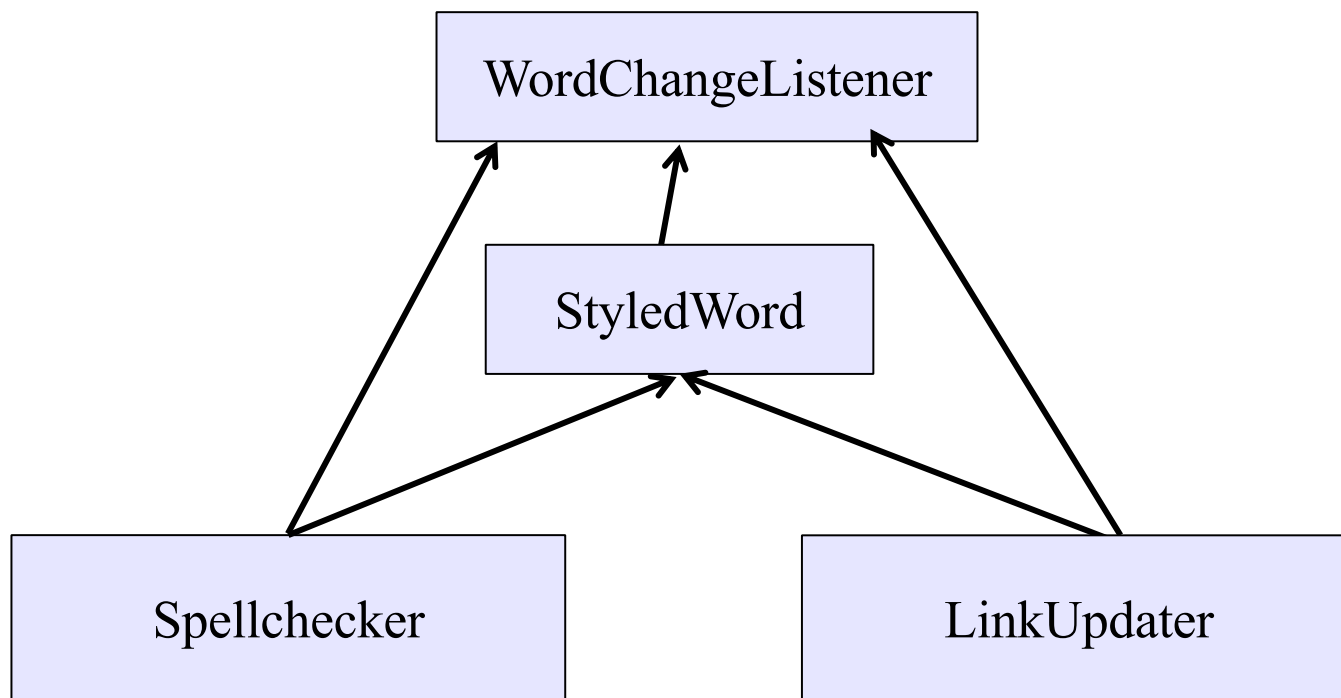

v3: implement WordChangeListener

```
class Spellchecker implements WordChangeListener {
    ...
    public void onWordChange(StyledWord word) {
        performSpellcheck(word); // as before
    }
}
```

```
class LinkUpdater implements WordChangeListener {
    ...
    public void onWordChange(StyledWord word) {
        updateLink(word); // as before
    }
}
```

A better MDD

- `WordChangeListener` is simple and weak



Judging v3

Cohesion: Good!

Coupling: Good!

Reuse: Good!

- Better than v2: can use *any* `WordChangeListener` -- no need for to know what they are
 - See `ChangeCounter` in `v3.java`

Achievement unlocked: Observer Pattern

- v3 allows any number of listeners
- Cohesion: **StyledWord** handles styled text while supporting listeners; each listener does its thing
- Coupling: Only via the weakly specified listener interface

This is the *observer pattern*

- Words can be *observed* via *observers/listeners* that are *notified* via *callbacks* when an *event* (of interest) occurs
- **Pattern**: Something used over-and-over in software, worth recognizing when appropriate and using common terms
- Widely used in public libraries

Could be further improved...

- **StyledWord** v3 is reusable enough to be a public library
- But it is not as easy to use as it could be:
 - listeners are only notified that a change has occurred
 - it is up to them to figure out what changed
 - (listener could do this by keeping a copy of the last version for comparison, but that is hard word)
- Easy solution: **StyledWord** should pass a description of what changed to listeners

Improved WordChangeListener

```
interface WordChangeListener {
    public void onWordChange(WordChangeEvent e);
}

class WordChangeEvent {
    public final StyledWord target;
    public int position; // where it changed
    public String textAdded;
    public String textRemoved;
}
```

Allows even more flexibility for `StyledWord` without any changes needed for listeners (e.g., remove and add text in one operation).

Final version of `StyledWord`

- Observable with events is **widely** used by important libraries
 - network & file I/O libraries on servers
 - user interface libraries on clients
- In fact, the fundamental structure of these programs is built around processing events & notifying listeners
 - the “main” of these programs is a loop that waits for events and, when they arrive, notifies the appropriate listeners

Event-driven programming

An *event-driven* program is designed to wait for events:

- program initializes then enters the *event loop*
- abstractly:

```
do {  
    e = getNextEvent();  
    process event e;  
} while (e != quit);
```

Contrast with most programs we have written so far

- they perform specified steps in order and then exit
- that style is still used, just not as frequently
 - example: computing Page Rank or other Big Data work

Server Programming

- Servers sit around waiting for events like:
 - new client connections
 - new data from the client (large scale servers)
- Simple version (normal scale):

```
while (true) {  
    wait for a client to connect  
    process the request; send a response back  
}
```

- (might want to use a new thread for processing)
- web servers usually look like this (easiest solution)

Advanced Server Programming

- Large scale servers usually do not have one thread per client
 - it would be hard to scale that past hundreds of clients
 - (need a more complex solution to scale)
- Instead, they have a small number (1?) of threads that simultaneously wait on events from all sockets
 - new connections on the server socket
 - new data to read on any client socket
 - finish writing to any client socket
 - (can then write more)
 - handlers do not make any calls that might wait for something
- These servers look much more like GUI clients...

GUI Client Programming

- Clients sit around waiting for events like:
 - mouse move/drag/click, button press, button release
 - keyboard: key press or release, sometimes with modifiers like shift/control/alt/etc.
 - finger tap or drag on a touchscreen
 - window resize/minimize/restore/close
 - timer interrupt (including animations)
 - network activity or file I/O (start, done, error)
 - (we will see an example of this shortly)

Events in Java AWT/Swing/Android

AWT & Swing are the native Java libraries for writing GUIs
Android apps are also GUIs and written in Java

Most of the GUI widgets can generate events

- button clicks, menu picks, key press, etc.

Events are handled using the Observer Pattern:

- objects wishing to handle events register as observers with the objects that generate them
- when an event happens, appropriate method in each observer is called
- as expected, multiple observers can watch for and be notified of an event generated by an object

Likewise, advanced servers register handlers on each socket

Event listeners / handlers

Event listeners must implement the proper interface. AWT/Swing:

KeyListener – handle key press

ActionListener – handle button press

MouseListener – handle mouse clicks

MouseMotionListener – handle mouse move/drag

When an event occurs

- the appropriate method specified in the interface is called:
actionPerformed, **keyPressed**, **mouseClicked**,
mouseDragged, ...
- an event object is passed to the listener method

Interfaces are different in Android but all conceptually the same

Event objects

GUI event is represented by an *event object*

- passes information often needed by the handler

In AWT/Swing, the superclass is **AWTEvent**. Some subclasses are:

ActionEvent – GUI-button press

KeyEvent – keyboard

MouseEvent – mouse move/drag/click/button

In Android, the superclass is **InputEvent**.

Event objects contain

- UI object that triggered the event
- other information depending on event. Examples:

ActionEvent – text string from a button

MouseEvent – mouse coordinates

Example: button

Create a `JButton` and add it to a window

- (we will talk about windows next time)

Create an object that implements `ActionListener`

- contains an `actionPerformed` method

Add the listener object to the button's listeners

- then it will be called when the button is pressed

`ButtonDemo1.java`

Listener classes

`ButtonDemo1.java` defines a class that is used only **once** to create a listener for a single button.

Not ideal in a couple of respects:

- listener code is far away from where it's used
 - that makes it a little harder to understand
- it's a lot of code for just one listener
 - imagine doing this in a UI with thousands of components

A more convenient shortcut: *lambdas*

- in Java 8+, you can use lambdas to create anonymous methods instead of creating a class that only exists to house one method.

Example: button

`ButtonDemo2.java`

Android similarities

- Events and listeners work in the same manner
- Here is code that listens for a button click:

```
Button btn = ...;
btn.setOnClickListener(new OnClickListener() {
    @Override
    public void onClick(View v) {
        Log.d("My Button", "You pressed it");
    }
});
```

- Many of the same widgets as in AWT/Swing

UI Thread

- Where is the event loop in these Swing programs?
- The library creates a separate thread that runs that event loop
 - the “UI thread”
 - created when the **JFrame** is made visible
 - application does not exit until this thread also finishes
 - that happens automatically when the window is closed