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
- Some styled words forbid the letter ‘Q’ [toy example ☺]

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")`**

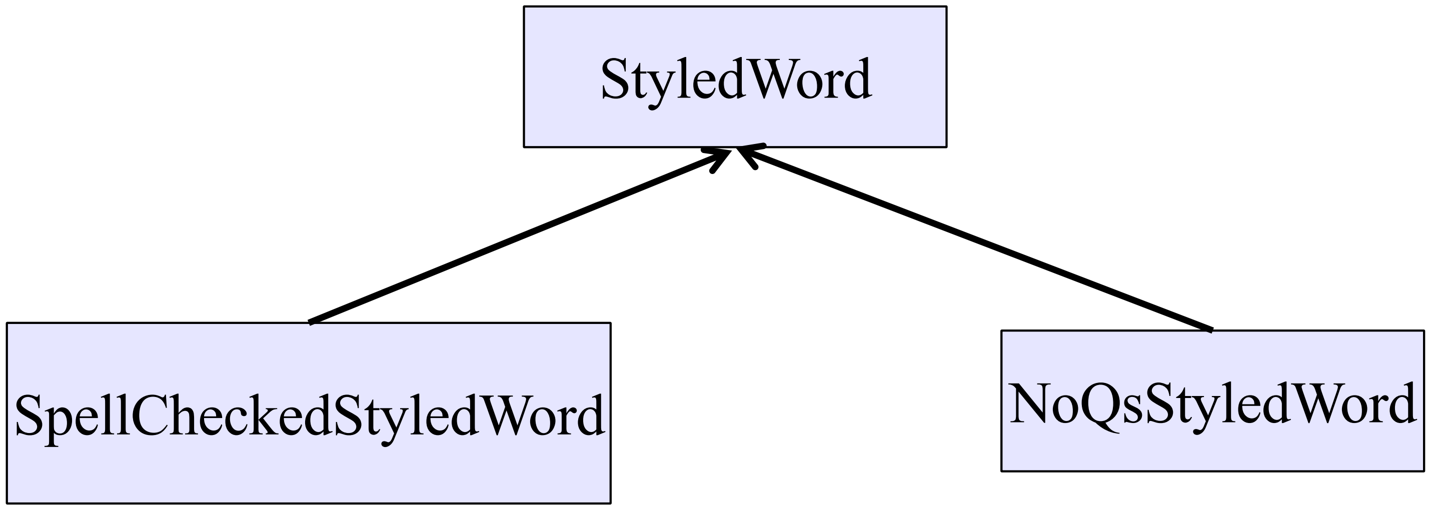
A direct approach

Version 1 (see **`v1.java`**)

Three new classes:

- **`StyledWord`**
  - Contains a **`StringBuffer`** and a **`Color`**
- **`SpellCheckedStyledWord`**
  - Contains a **`StyledWord`** and a **`Dictionary`**
- **`NoQsStyledWord`**
  - 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`** / **`NoQsStyledWord`** might not be true subtypes
- No way to spell-check *and* forbid ‘Q’
  - 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 **`NoQsStyledWord`** 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 Q-removal

- A **`StyledWord`**’s state now includes:
  - A **`Spellchecker`** if there is one
  - A **`QRemover`** if there is one
- When the word changes, pass **`this`** to the spell-checker and/or Q-remover

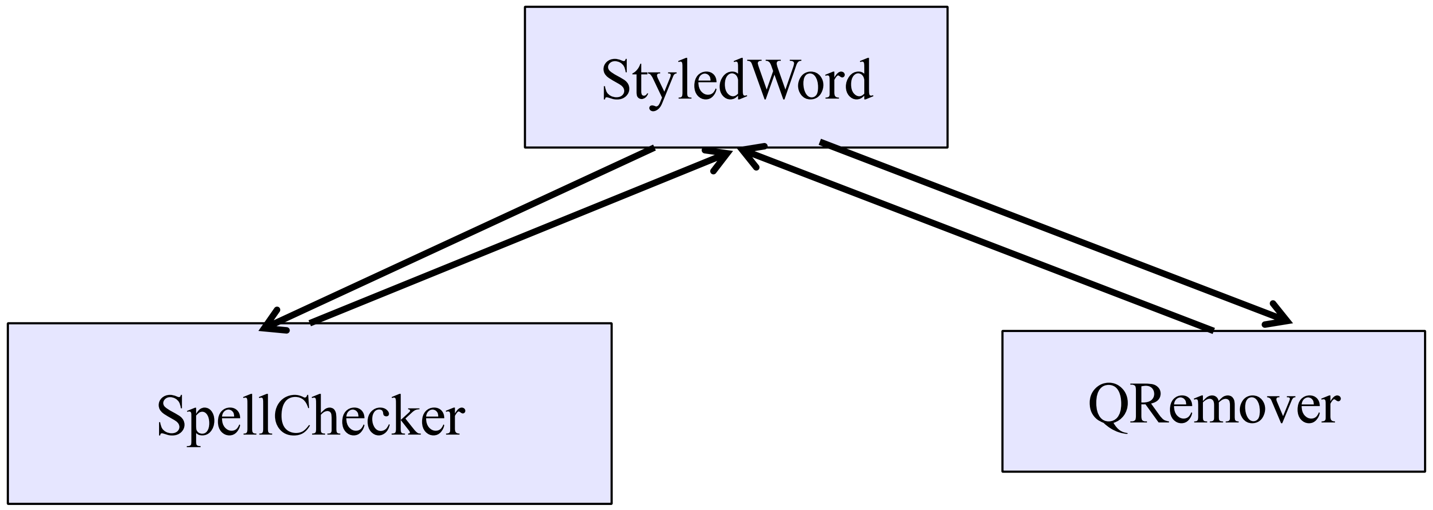
What is right in v2?

Reuse: solves the problems with v1

Coupling:

- removes *some* dependence of SpellChecker / Q-Remover 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 spell-check or Q-remove 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 spell-checking or Q-removal

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 (qremover != null)
      qremover.removeQs(this);
 }
```

- **`performSpellcheck`** & **`removeQs`** passed to the constructor
- All the **`StyledWord`** does with those objects is call **`performSpellcheck(this)`** or **`removeQs(this)`**
- **`performSpellcheck`** and **`removeQs`** 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 **`Qremover`** 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);
  }
```

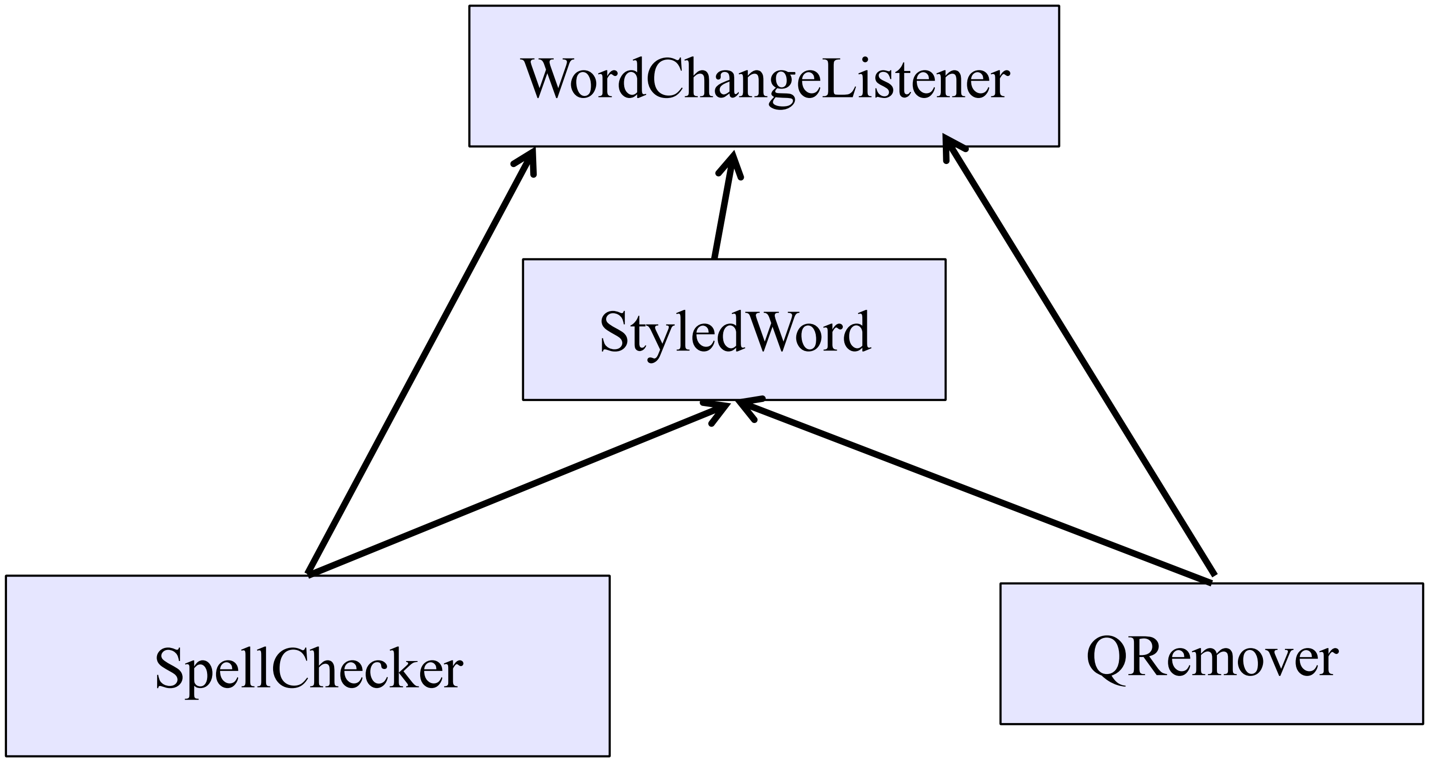
v3: implement **`WordChangeListener`**

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

class QRemover implements WordChangeListener {
  …
  public void onWordChange(StyledWord word) {
    removeQs(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