Principles of Software Construction: Objects, Design, and Concurrency

Introduction to GUIs

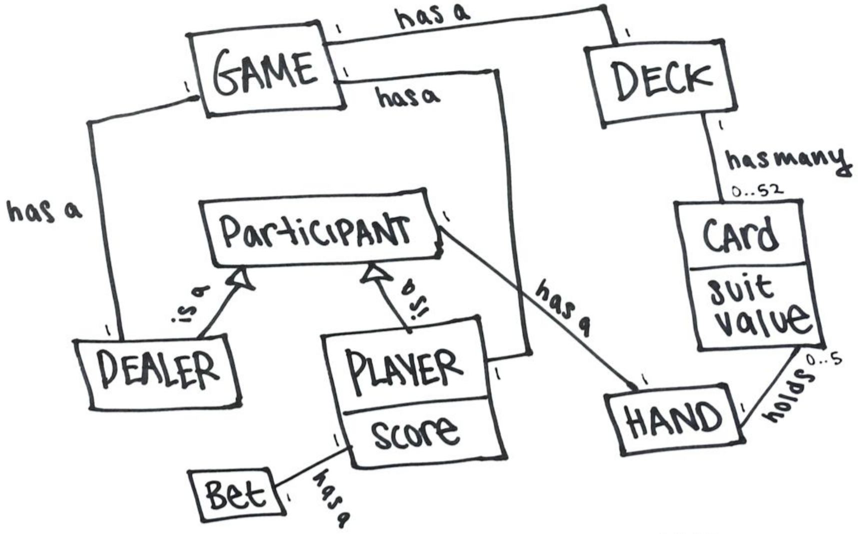
Claire Le Goues Vincent Hellendoorn

Administrivia

HW2 grades posted.

HW4 is released, due Wednesday (not Monday!).

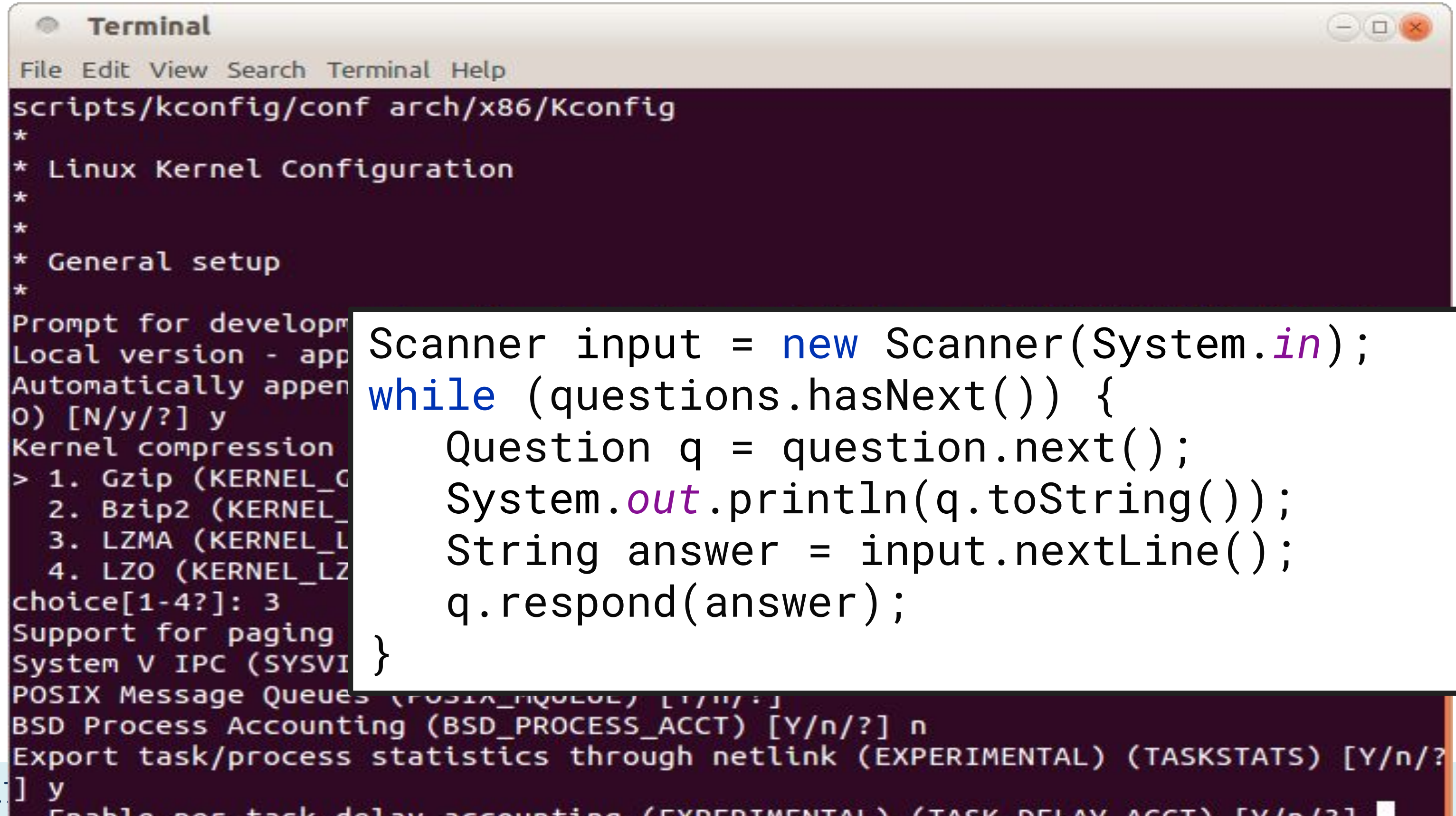
We have done: a backend with no explicit interaction



One Possible Domain model

this is Not a reference solution, it's an example of what a domain model looks like

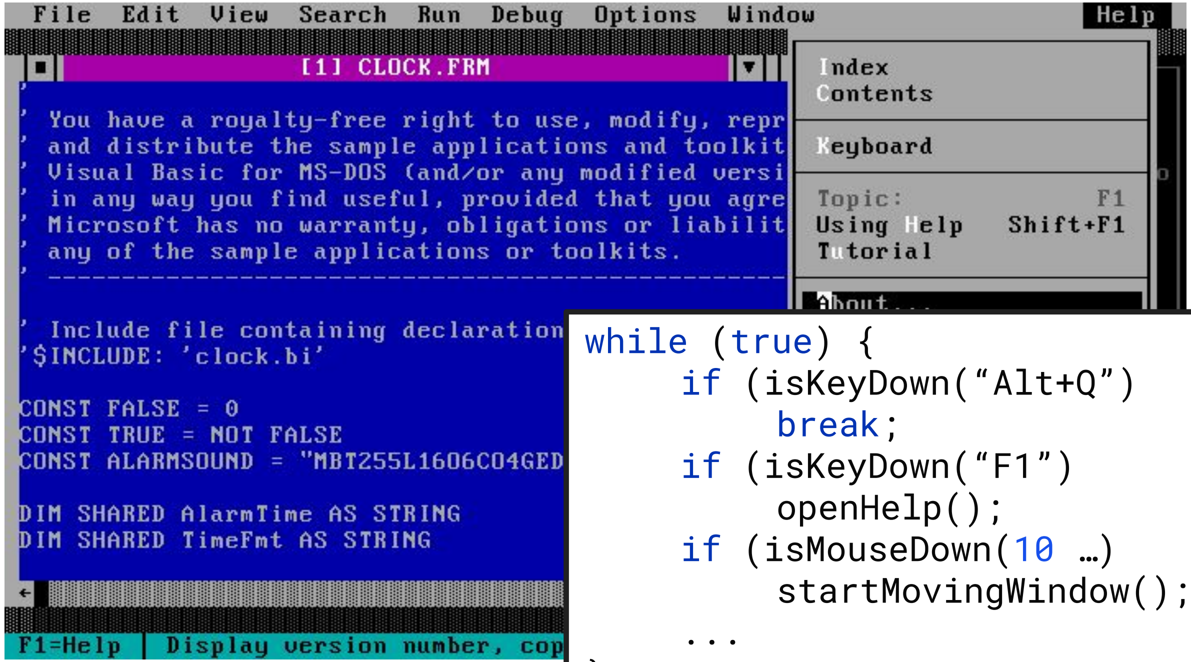
Interaction with CLI



```
scripts/kconfig/conf arch/x86/Kconfig
*
* Linux Kernel Configuration
*
*
* General setup
*
Prompt for developm
Local version - app
Automatically appen
o) [N/y/?] y
Kernel compression
> 1. Gzip (KERNEL_G
  2. Bzip2 (KERNEL_
  3. LZMA (KERNEL_L
  4. LZO (KERNEL_LZ
choice[1-4?]: 3
Support for paging
System V IPC (SYSVI
POSIX Message Queues (POSIX_MQUEUE) [Y/n/?]
BSD Process Accounting (BSD_PROCESS_ACCT) [Y/n/?] n
Export task/process statistics through netlink (EXPERIMENTAL) (TASKSTATS) [Y/n/?
] y
Enable per-task delay accounting (EXPERIMENTAL) (TASK_DELAY_ACCT) [Y/n/?]
```

```java
Scanner input = new Scanner(System.in);
while (questions.hasNext()) {
   Question q = question.next();
   System.out.println(q.toString());
   String answer = input.nextLine();
   q.respond(answer);
}
```

How do you wait?


File Edit View Search Run Debug Options Window Help
[1] CLOCK.FRM
Index
Contents
Keyboard
Topic: F1
Using Help Shift+F1
Tutorial
About...
F1=Help | Display version number, cop

```
'
' You have a royalty-free right to use, modify, repr
' and distribute the sample applications and toolkit
' Visual Basic for MS-DOS (and/or any modified versi
' in any way you find useful, provided that you agre
' Microsoft has no warranty, obligations or liabilit
' any of the sample applications or toolkits.
'
' -----------------------------------------------

' Include file containing declaration
'$INCLUDE: 'clock.bi'

CONST FALSE = 0
CONST TRUE = NOT FALSE
CONST ALARMSOUND = "MBT255L1606C04GED

DIM SHARED AlarmTime AS STRING
DIM SHARED TimeFmt AS STRING
```

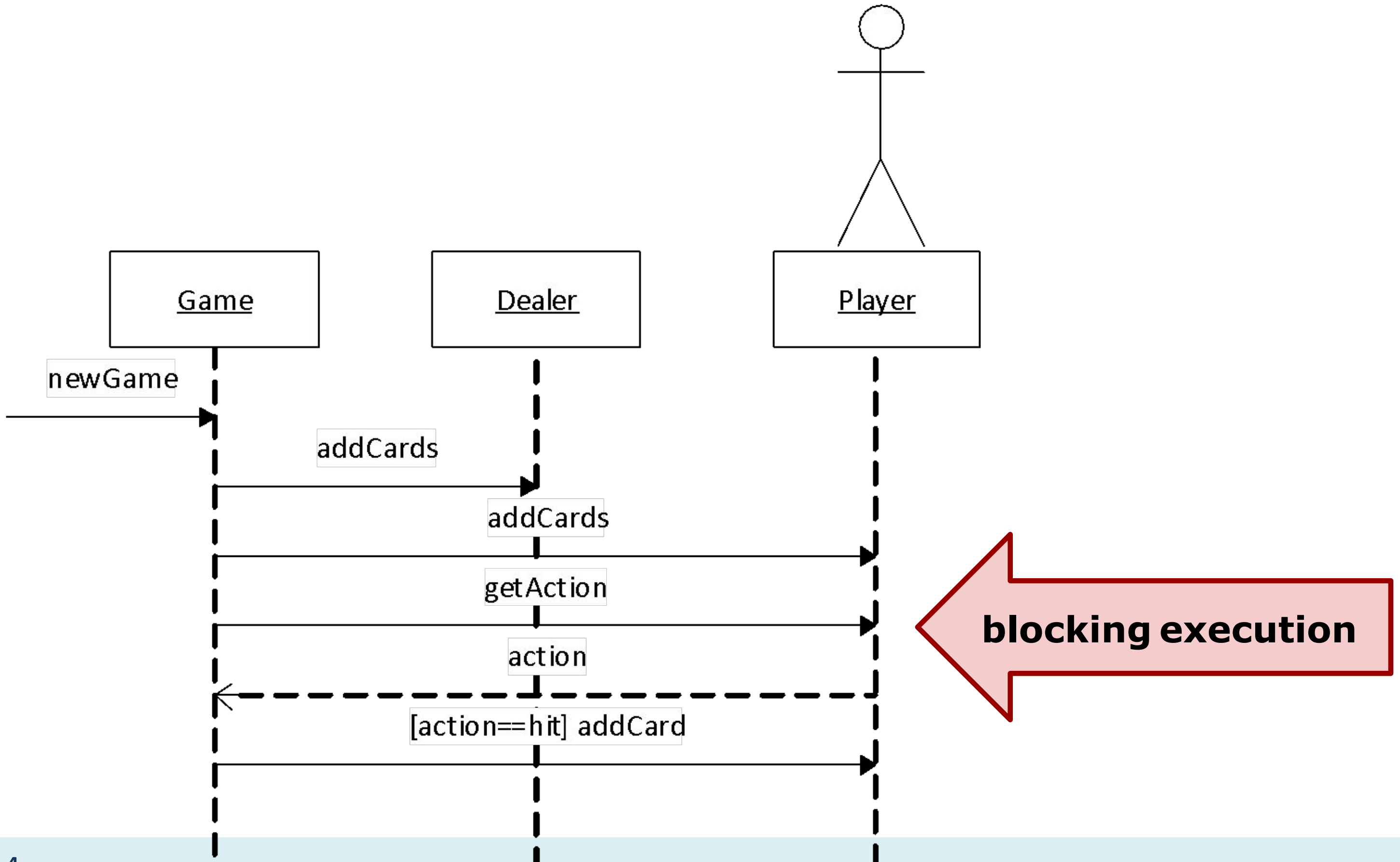
```
while (true) {
    if (isKeyDown("Alt+Q")
        break;
    if (isKeyDown("F1")
        openHelp();
    if (isMouseDown(10 …)
        startMovingWindow();
    ...
}
```

How do you GUI? Multiplayer?

```
while (true) {
    if (player === “player1”) {
        hasWon = play(“player1”);
        if (hasWon) break;
        player = “player2”;
    } else (player === “player2”) {
        hasWon = play(“player2”)
        if (hasWon) break;
        player = “player1”;
    }
}
```

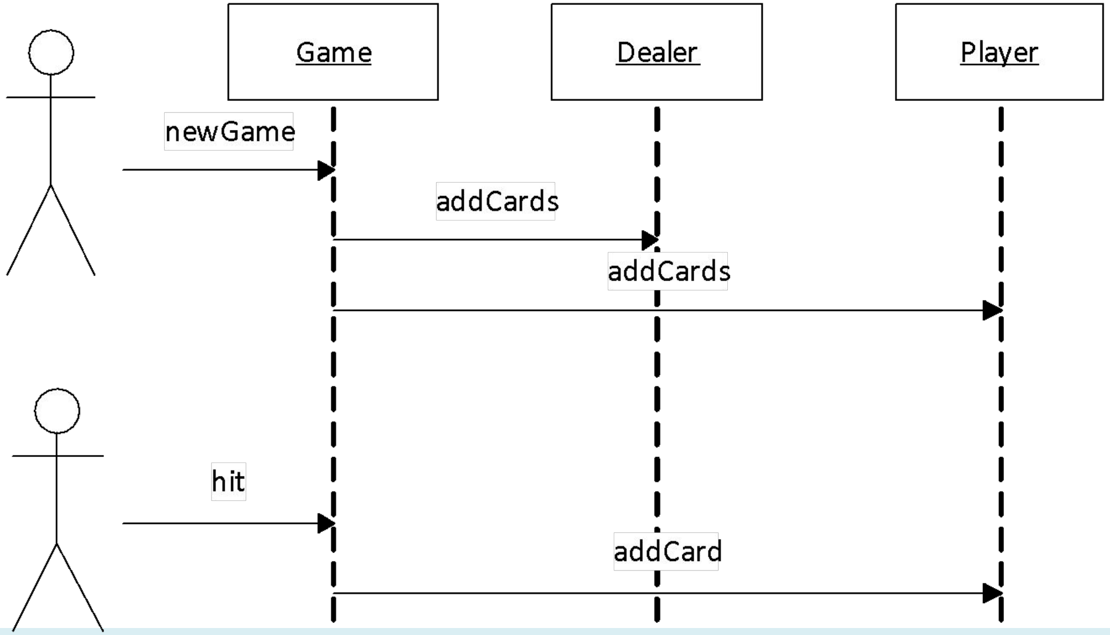
https://www.cloudsavvyit.com/2586/how-to-build-your-multiplayer-games-server-architecture/

Potential issue: Blocking interactions with users



Interactions with users through events

- Do not block waiting for user response
- Instead, react to user events



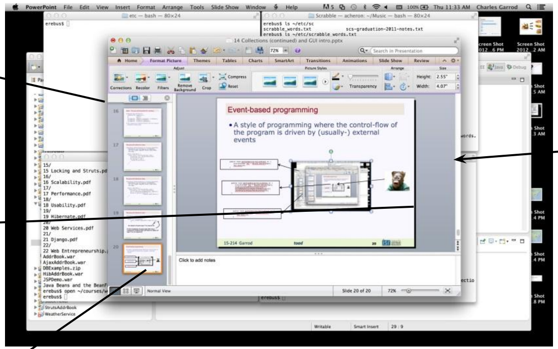
Event-based programming

Style of programming where control-flow is driven by (usually external) events

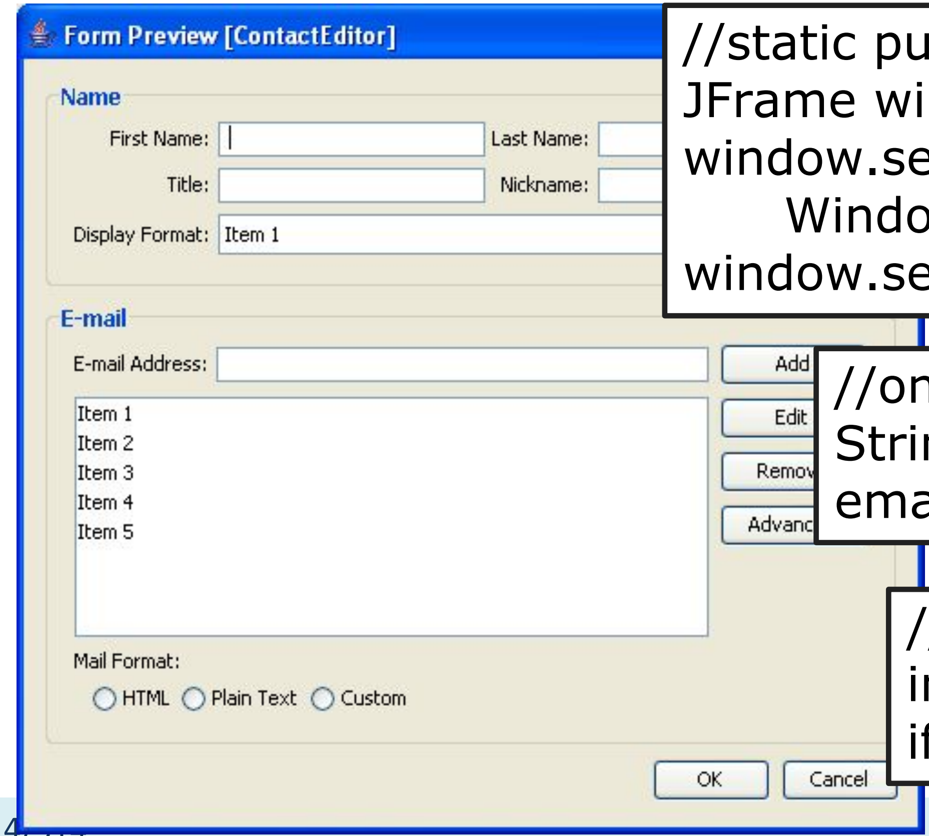
```
public void performAction(ActionEvent e) {
    List<String> lst = Arrays.asList(bar);
    foo.peek(42)
}
```

```
public void performAction(ActionEvent e) {
    bigBloatedPowerPointFunction(e);
    withANameSoLongIMadeItTwoMethods(e);
    yesIKnowJavaDoesntWorkLikeThat(e);
}
```

```
public void performAction(ActionEvent e) {
    List<String> lst = Arrays.asList(bar);
    foo.peek(40)
}
```


Event-based programming
• A style of programming where the control-flow of the program is driven by (usually-) external events
Click to add notes
Slide 20 of 20

Event-based GUIs



```
//static public void main…
JFrame window = …
window.setDefaultCloseOperation(
      WindowConstants.EXIT_ON_CLOSE);
window.setVisible(true);
```

```
//on add-button click:
String email = emailField.getText();
emaillist.add(email);
```

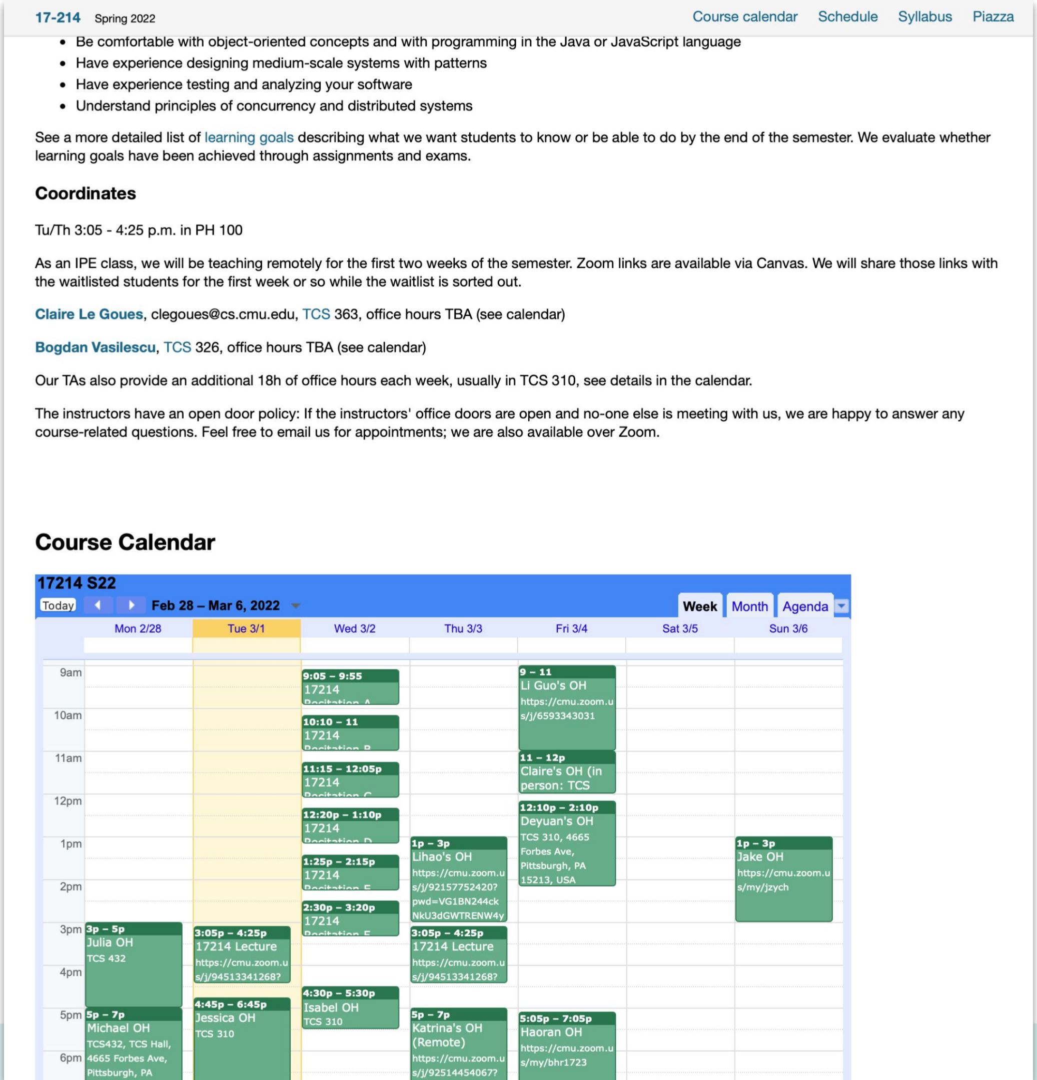
```
//on remove-button click:
int pos = emaillist.getSelectedItem(
if (pos>=0) emaillist.delete(pos);
```

So, what about a frontend?

…in fact, let's start with basically just a frontend without an explicit backend.

(and we'll come back to that backend later.)

How To Make This Happen?



17-214 Spring 2022 | Course calendar | Schedule | Syllabus | Piazza

- Be comfortable with object-oriented concepts and with programming in the Java or JavaScript language
- Have experience designing medium-scale systems with patterns
- Have experience testing and analyzing your software
- Understand principles of concurrency and distributed systems

See a more detailed list of learning goals describing what we want students to know or be able to do by the end of the semester. We evaluate whether learning goals have been achieved through assignments and exams.

Coordinates

Tu/Th 3:05 - 4:25 p.m. in PH 100

As an IPE class, we will be teaching remotely for the first two weeks of the semester. Zoom links are available via Canvas. We will share those links with the waitlisted students for the first week or so while the waitlist is sorted out.

Claire Le Goues, clegoues@cs.cmu.edu, TCS 363, office hours TBA (see calendar)

Bogdan Vasilescu, TCS 326, office hours TBA (see calendar)

Our TAs also provide an additional 18h of office hours each week, usually in TCS 310, see details in the calendar.

The instructors have an open door policy: If the instructors' office doors are open and no-one else is meeting with us, we are happy to answer any course-related questions. Feel free to email us for appointments; we are also available over Zoom.

Course Calendar

17214 S22

Today | Feb 28 – Mar 6, 2022 | Week | Month | Agenda

Mon 2/28
- 3p – 5p Julia OH TCS 432
- 5p – 7p Michael OH TCS432, TCS Hall, 4665 Forbes Ave, Pittsburgh, PA

Tue 3/1
- 3:05p – 4:25p 17214 Lecture https://cmu.zoom.us/j/94513341268?
- 4:45p – 6:45p Jessica OH TCS 310

Wed 3/2
- 9:05 – 9:55 17214
- 10:10 – 11 17214
- 11:15 – 12:05p 17214
- 12:20p – 1:10p 17214
- 1:25p – 2:15p 17214
- 2:30p – 3:20p 17214
- 4:30p – 5:30p Isabel OH TCS 310

Thu 3/3
- 1p – 3p Lihao's OH https://cmu.zoom.us/j/92157752420?pwd=VG1BN244ckNkU3dGWTRENW4y
- 3:05p – 4:25p 17214 Lecture https://cmu.zoom.us/j/94513341268?
- 5p – 7p Katrina's OH (Remote) https://cmu.zoom.us/j/92514454067?

Fri 3/4
- 9 – 11 Li Guo's OH https://cmu.zoom.us/j/6593343031
- 11 – 12p Claire's OH (in person: TCS
- 12:10p – 2:10p Deyuan's OH TCS 310, 4665 Forbes Ave, Pittsburgh, PA 15213, USA
- 5:05p – 7:05p Haoran OH https://cmu.zoom.us/my/bhr1723

Sat 3/5

Sun 3/6
- 1p – 3p Jake OH https://cmu.zoom.us/my/jzych

GUI Design: what do we want?

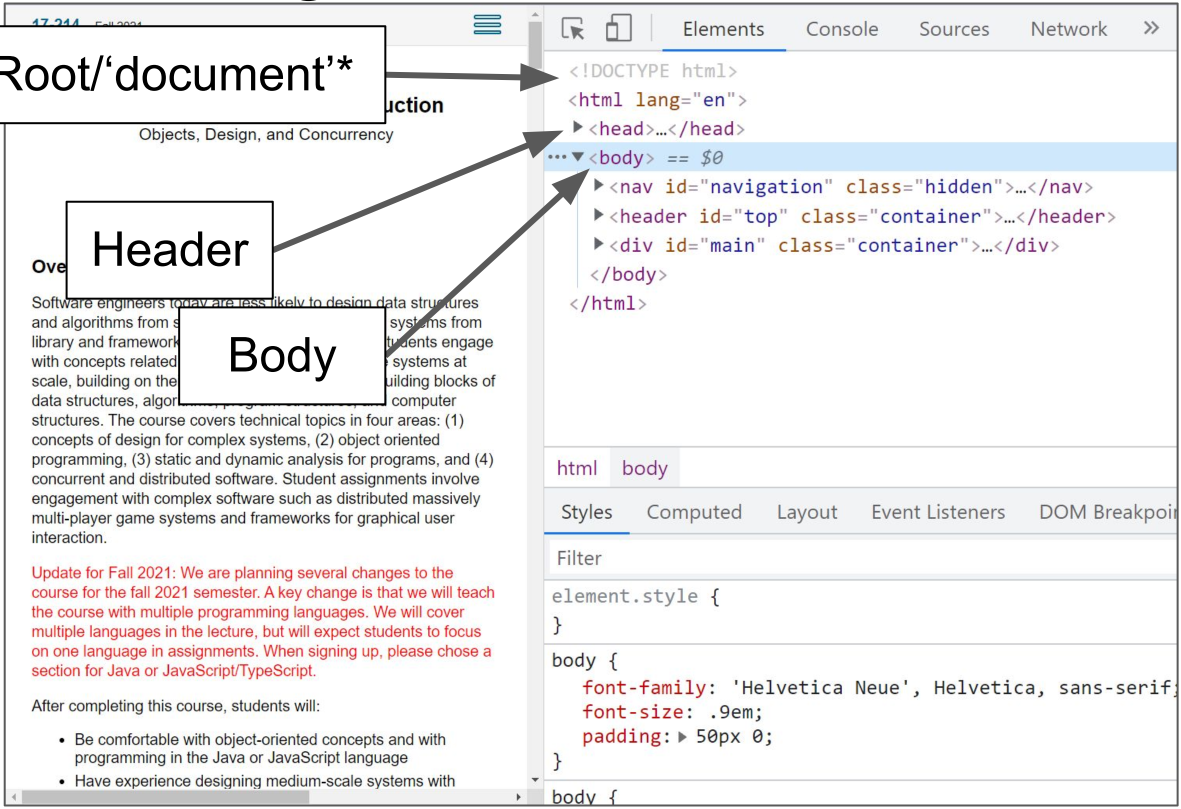
- Nested Elements
- Style Vocabulary
- Interactivity

GUI Design: what do we want?

- Nested Elements
  - HTML
- Style Vocabulary
  - CSS
- Interactivity
  - JavaScript

Anatomy of an HTML Page

Predefined elements



```
<!DOCTYPE html>
<html lang="en">
▶<head>…</head>
▼<body> == $0
  ▶<nav id="navigation" class="hidden">…</nav>
  ▶<header id="top" class="container">…</header>
  ▶<div id="main" class="container">…</div>
  </body>
</html>
```

```
element.style {
}
body {
  font-family: 'Helvetica Neue', Helvetica, sans-serif;
  font-size: .9em;
  padding: ▶ 50px 0;
}
body {
```

Objects, Design, and Concurrency

Software engineers today are less likely to design data structures and algorithms from s… systems from library and framework… students engage with concepts related… systems at scale, building on the… building blocks of data structures, algor… computer structures. The course covers technical topics in four areas: (1) concepts of design for complex systems, (2) object oriented programming, (3) static and dynamic analysis for programs, and (4) concurrent and distributed software. Student assignments involve engagement with complex software such as distributed massively multi-player game systems and frameworks for graphical user interaction.

Update for Fall 2021: We are planning several changes to the course for the fall 2021 semester. A key change is that we will teach the course with multiple programming languages. We will cover multiple languages in the lecture, but will expect students to focus on one language in assignments. When signing up, please chose a section for Java or JavaScript/TypeScript.

After completing this course, students will:

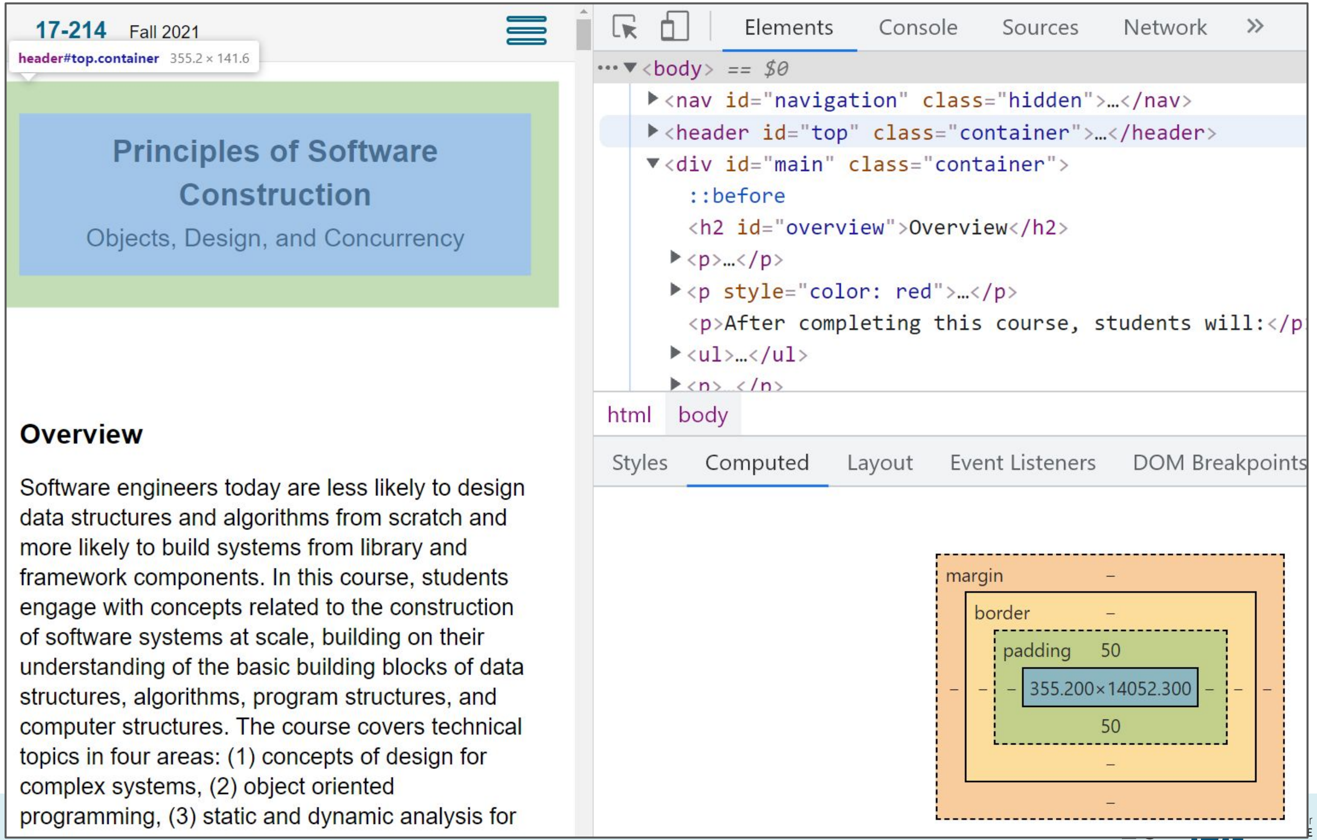
- Be comfortable with object-oriented concepts and with programming in the Java or JavaScript language
- Have experience designing medium-scale systems with

Technically, 'document' is the root with HTML as its only child

Anatomy of an HTML Page

Nested elements

- Sizing
- Attributes
- Text



17-214 Fall 2021

header#top.container 355.2 × 141.6

Principles of Software Construction

Objects, Design, and Concurrency

Overview

Software engineers today are less likely to design data structures and algorithms from scratch and more likely to build systems from library and framework components. In this course, students engage with concepts related to the construction of software systems at scale, building on their understanding of the basic building blocks of data structures, algorithms, program structures, and computer structures. The course covers technical topics in four areas: (1) concepts of design for complex systems, (2) object oriented programming, (3) static and dynamic analysis for

```
<body> == $0
  <nav id="navigation" class="hidden">…</nav>
  <header id="top" class="container">…</header>
  <div id="main" class="container">
    ::before
    <h2 id="overview">Overview</h2>
    <p>…</p>
    <p style="color: red">…</p>
    <p>After completing this course, students will:</p
    <ul>…</ul>
    <p>…</p>
```

margin –, border –, padding 50, 355.200×14052.300, 50

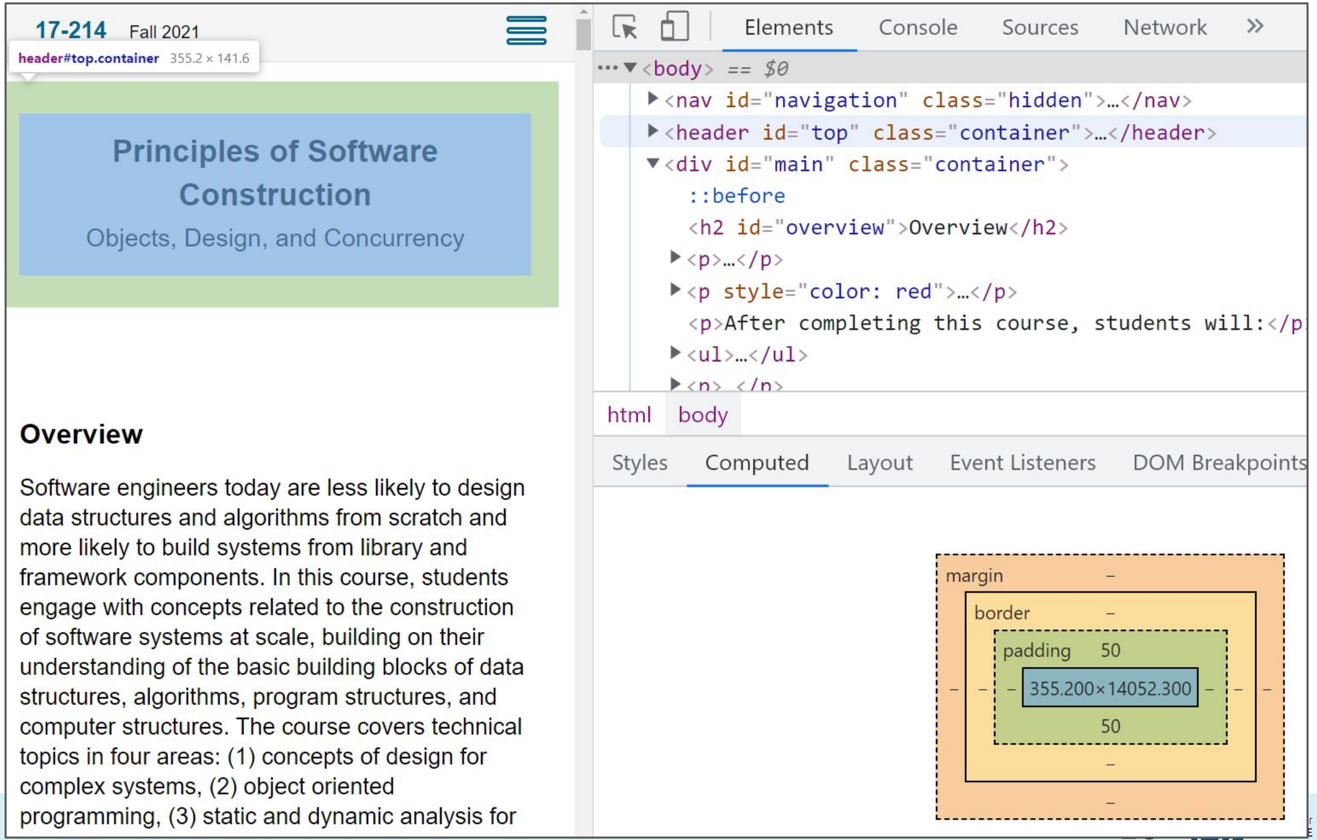
A few Tags

- <html>
  - The root of the visible page
- <head>
  - Stores metadata, imports
- <p>
  - A paragraph
- <button>
  - Attributes include `name`, `type`, `value`
- <div>
  - Generic section -- very useful
- <table>
  - The obvious
- Many more; dig into a real page!

Anatomy of an HTML Page

Nested elements
- Sizing
- Attributes
- Text

You can write these out directly, or compose and modify them programmatically!
- Or, both! (we'll see in a minute).



Overview

Software engineers today are less likely to design data structures and algorithms from scratch and more likely to build systems from library and framework components. In this course, students engage with concepts related to the construction of software systems at scale, building on their understanding of the basic building blocks of data structures, algorithms, program structures, and computer structures. The course covers technical topics in four areas: (1) concepts of design for complex systems, (2) object oriented programming, (3) static and dynamic analysis for

```
••• ▼<body> == $0
      ▶<nav id="navigation" class="hidden">…</nav>
      ▶<header id="top" class="container">…</header>
      ▼<div id="main" class="container">
          ::before
          <h2 id="overview">Overview</h2>
        ▶<p>…</p>
        ▶<p style="color: red">…</p>
          <p>After completing this course, students will:</p
        ▶<ul>…</ul>
        ▶<p>…</p>
```

Anatomy of a GUI/HTML Page

GUIs are typically <u>trees</u>

- Nested elements, recursively
- Some fixed positions (html, body)

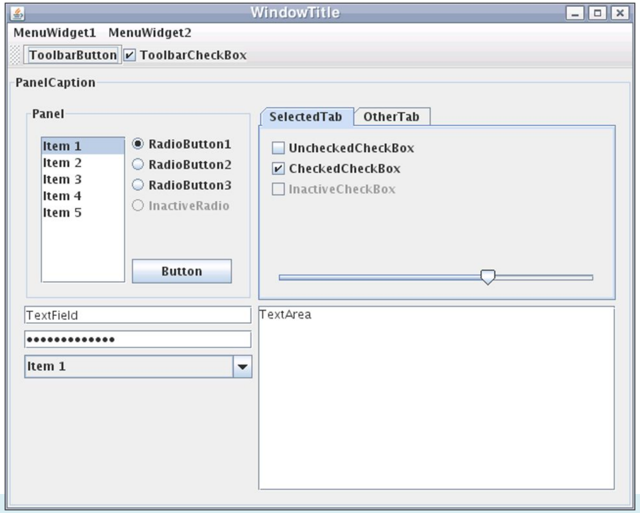
How to implement this?

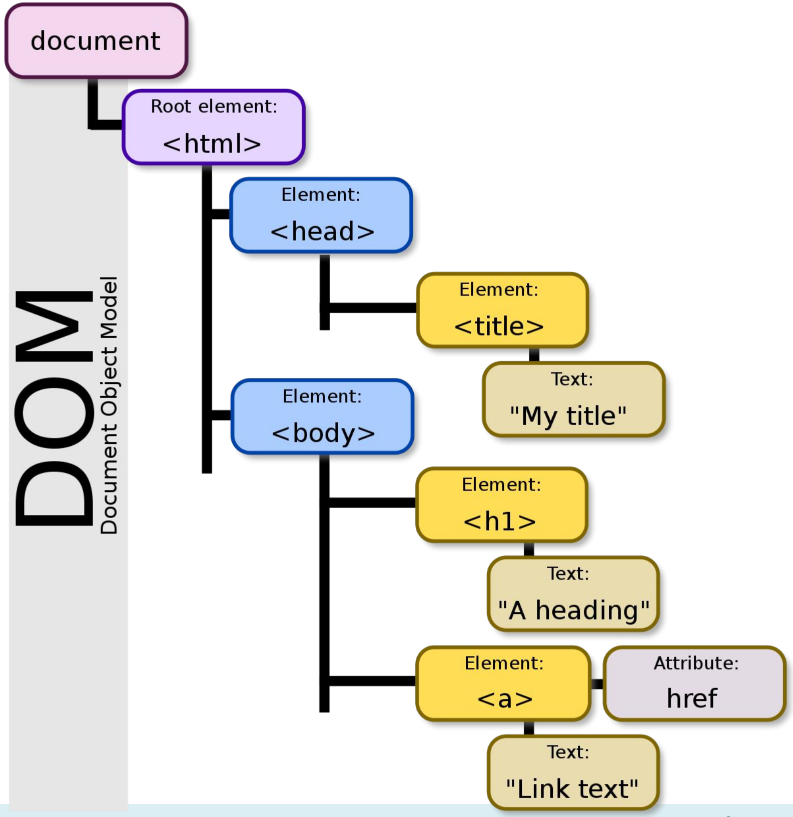
JFrame

JPanel

JTextField

…





https://en.wikipedia.org/wiki/Document_Object_Model

The composite pattern

- Problem: Collection of objects has behavior similar to the individual objects
- Solution: Have collection of objects and individual objects implement the same interface
- Consequences:
  - Client code can treat collection as if it were an individual object
  - Easier to add new object types
  - Design might become too general, interface insufficiently useful

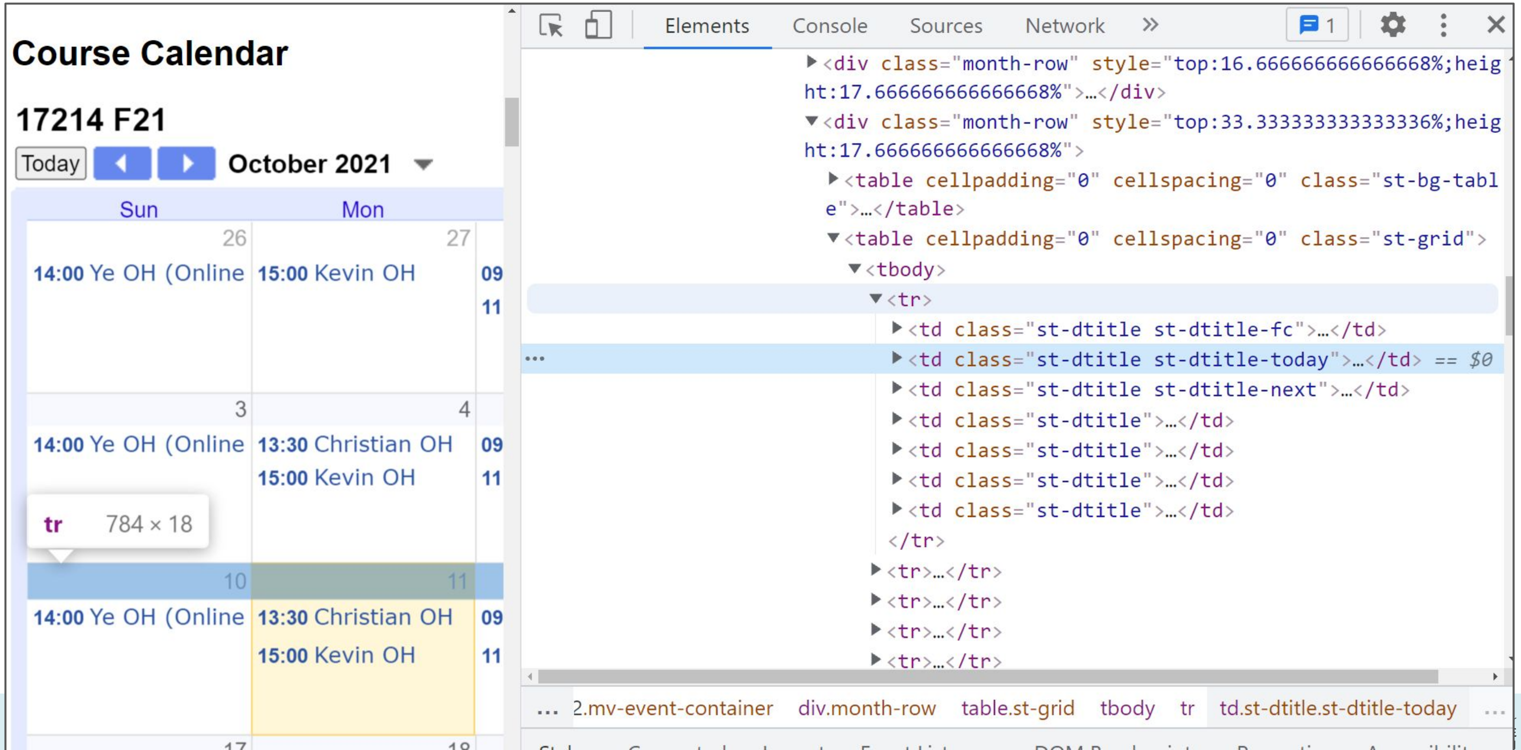
Composite

- Elements can contain elements
  - With restrictions
  - Need to deal with style, interaction
- In JS: HTMLElement
  - With child-classes e.g. HTMLDivElement, HTMLBodyElement
  - Navigation:
    - getElement*: locate by tag name, id, class, etc.
    - next/prev(Element)Sibling
    - childNodes, parent

Let’s start with a very simple example.

Style: not only leaf-nodes have appearance.

Note the column, here.



```
▶<div class="month-row" style="top:16.666666666666668%;height:17.666666666666668%">…</div>
▼<div class="month-row" style="top:33.333333333333336%;height:17.666666666666668%">
  ▶<table cellpadding="0" cellspacing="0" class="st-bg-table">…</table>
  ▼<table cellpadding="0" cellspacing="0" class="st-grid">
    ▼<tbody>
      ▼<tr>
        ▶<td class="st-dtitle st-dtitle-fc">…</td>
        ▶<td class="st-dtitle st-dtitle-today">…</td> == $0
        ▶<td class="st-dtitle st-dtitle-next">…</td>
        ▶<td class="st-dtitle">…</td>
        ▶<td class="st-dtitle">…</td>
        ▶<td class="st-dtitle">…</td>
        ▶<td class="st-dtitle">…</td>
       </tr>
      ▶<tr>…</tr>
      ▶<tr>…</tr>
      ▶<tr>…</tr>
      ▶<tr>…</tr>
```

… 2.mv-event-container div.month-row table.st-grid tbody tr td.st-dtitle.st-dtitle-today …

Style

Tags come with inherent & customizable style

- Inherent:
  - <div> is a `block` (full-width, with margin)
  - <span> is in-line
  - <h1> is large
- Customizable: add and override styles
  - Change font-styles, margins, widths
  - Modify groups of elements

Style: CSS

- Cascading Style Sheets
  - Reuse: styling rules for tags, classes, types
  - Reuse: not just at the leafs!

```
<span style="font-weight:bold">Hello again!</span>
```

vs.

```
<style type="text/css">
    span {
        font-family: arial
    }
</style>
```

Style: CSS

- Cascading Style Sheets
  - Reuse: styling rules for tags, classes, types
  - Reuse: not just at the leafs!
- What if there are conflicts?

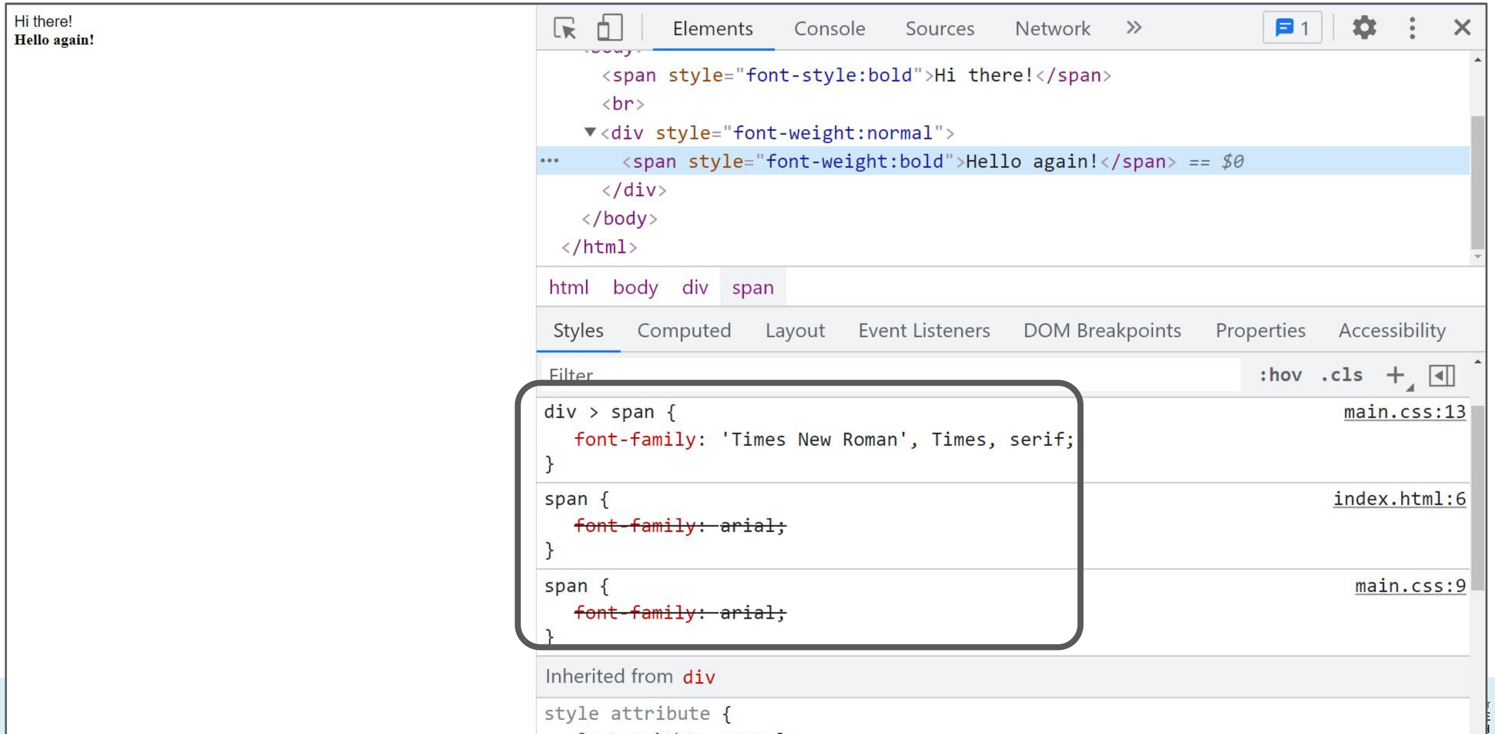
```
<div style="font-weight:normal">
  <span style="font-weight:bold">Hello again!</span>
</div>
```

  - Lowest element wins*

*Technically, there's a whole scoring system

Style: CSS

What is happening here?


Hi there!
Hello again!

```
    <span style="font-style:bold">Hi there!</span>
    <br>
  ▼<div style="font-weight:normal">
      <span style="font-weight:bold">Hello again!</span> == $0
    </div>
  </body>
</html>
```

```
div > span {                                            main.css:13
  font-family: 'Times New Roman', Times, serif;
}
span {                                                  index.html:6
  ~~font-family: arial;~~
}
span {                                                  main.css:9
  ~~font-family: arial;~~
}
Inherited from div
style attribute {
```

Style: CSS

- Cascading Style Sheets
  - Reuse: styling rules for tags, classes, types
  - Reuse: not just at the leafs!
- What if there are no conflicts?

```
<div style="font-family:arial">
  <span style="font-weight:bold">Hello again!</span>
</div>
```

  - How would you implement this?

Decorator

What is happening here?

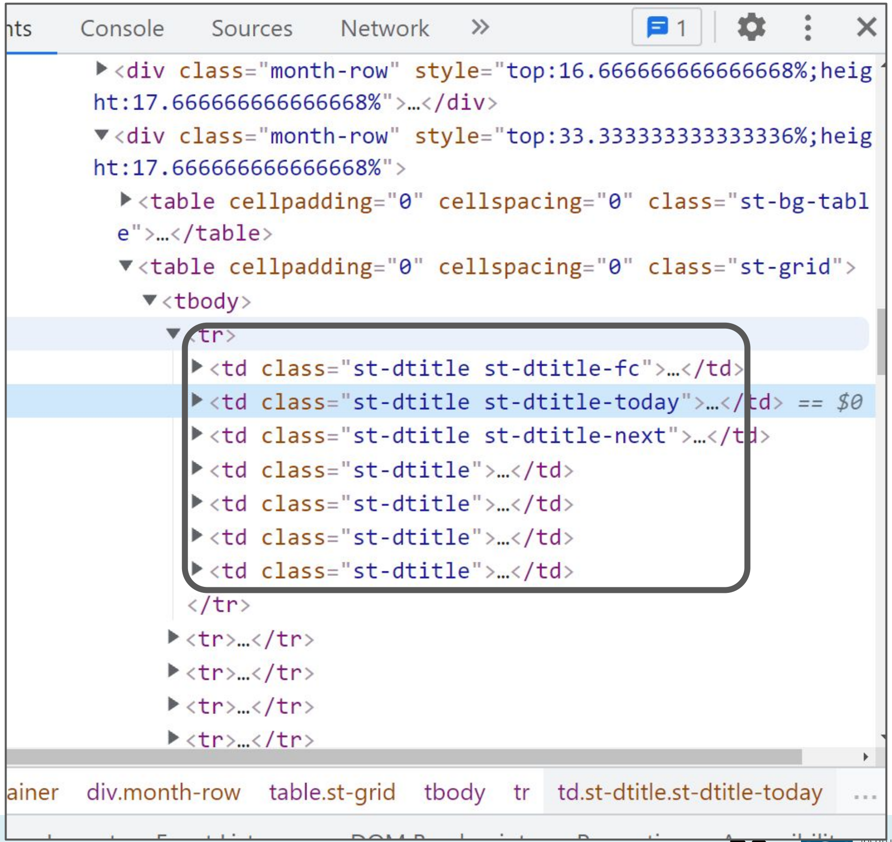
- To compute the style of an element:
  - Apply its tag-default style
  - **Wrap** in added style rules (tag-specific or general)
    - Text: font-family, weight, etc.
  - Inherit parents’ style
    - Conflicts lead to overrides
- Makes *themes* really powerful

Technically, HTML is streamed top-to-bottom; CSS works bottom-up

CSS: classes

Let's not repeat custom style

- Use any nr. of class label(s)
- Class styles get added
- Facilitates reuse


nts
Console
Sources
Network
»
1

```
▶<div class="month-row" style="top:16.666666666666668%;heig
ht:17.666666666666668%">…</div>
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        ▶<td class="st-dtitle">…</td>
        ▶<td class="st-dtitle">…</td>
        ▶<td class="st-dtitle">…</td>
        ▶<td class="st-dtitle">…</td>
       </tr>
      ▶<tr>…</tr>
      ▶<tr>…</tr>
      ▶<tr>…</tr>
      ▶<tr>…</tr>
```
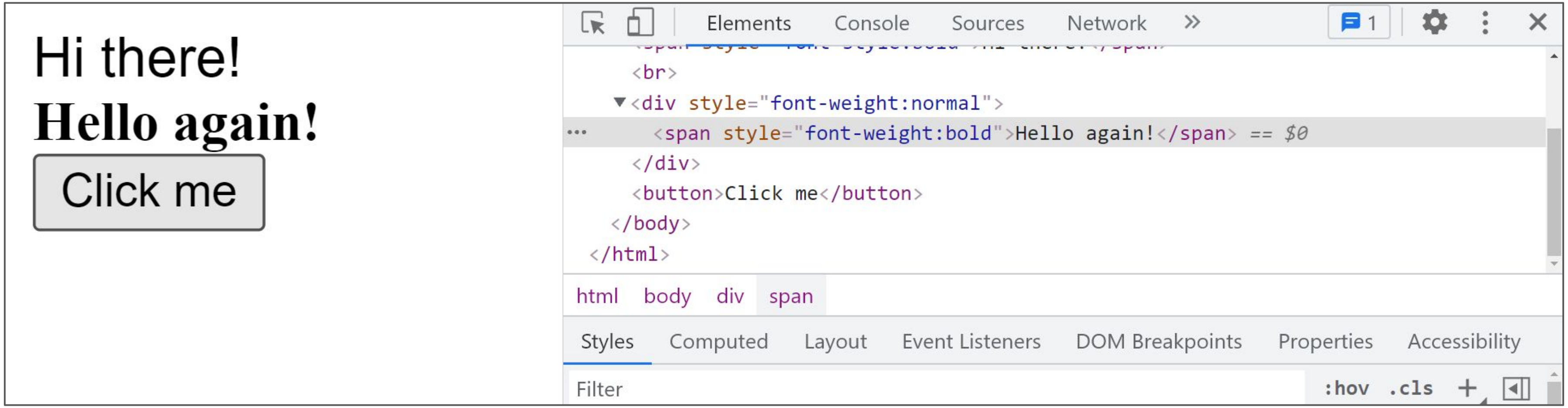

ainer div.month-row table.st-grid tbody tr td.st-dtitle.st-dtitle-today …

Interactivity: A GUI is more than just a document

- How do we make it “work”?
- This is a two-part answer: (1) we can attach scripts to elements, but (2) …how? [Design question!]



```
      <br>
    ▼<div style="font-weight:normal">
        <span style="font-weight:bold">Hello again!</span> == $0
      </div>
      <button>Click me</button>
    </body>
  </html>
```

That's extremely simple, let's try something *slightly* more complicated.

Consider: TicTacToe

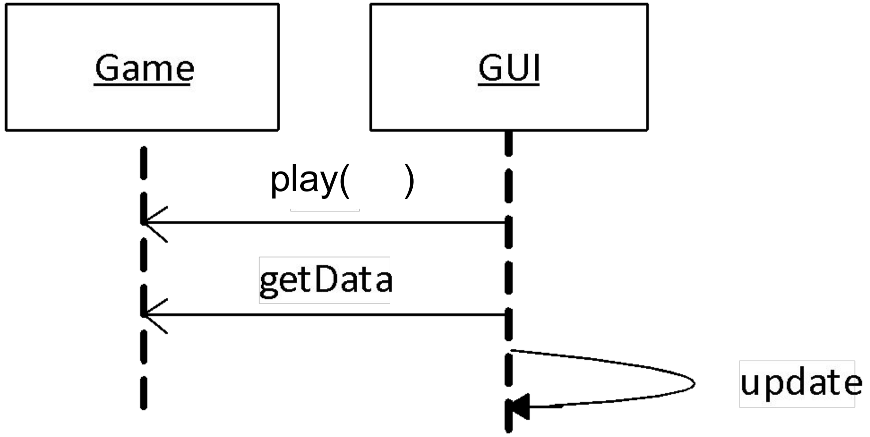
(note that this is NOT the same code you'll see in recitation next week, but the game itself will look basically the same.)

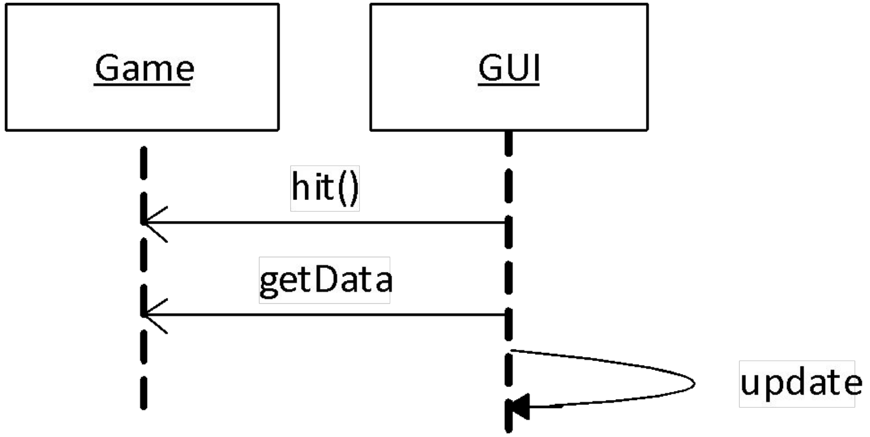
A design challenge

DECOUPLING THE GUI

GUI design challenge

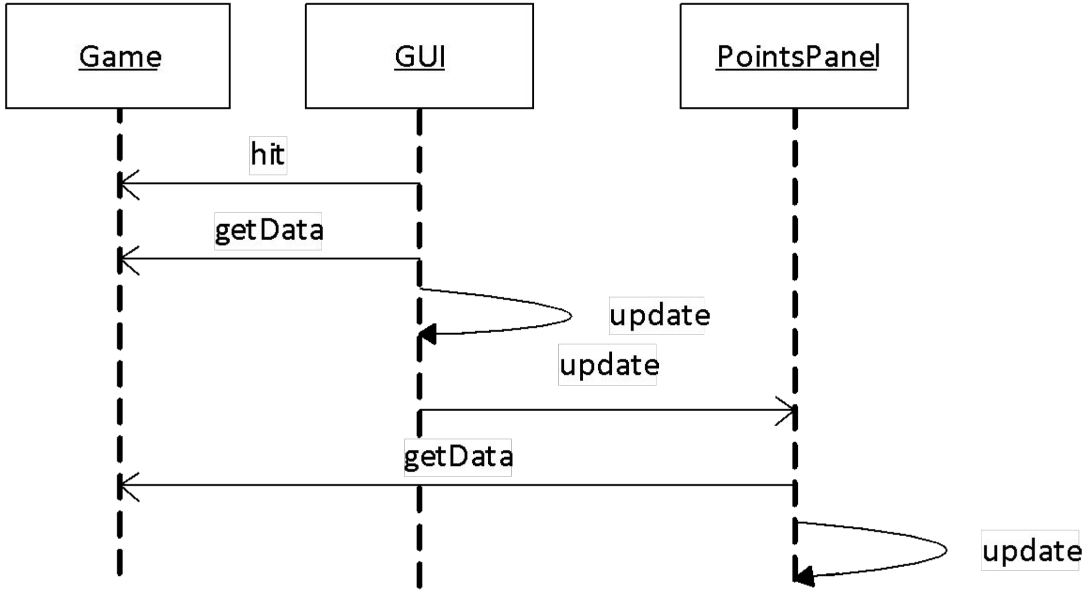
- Consider TicTacToe or Blackjack game, implemented by `Game` class:
  - Player clicks a space, expects it to update; clicks “hit” and expects a new card
  - When should the GUI update the screen?





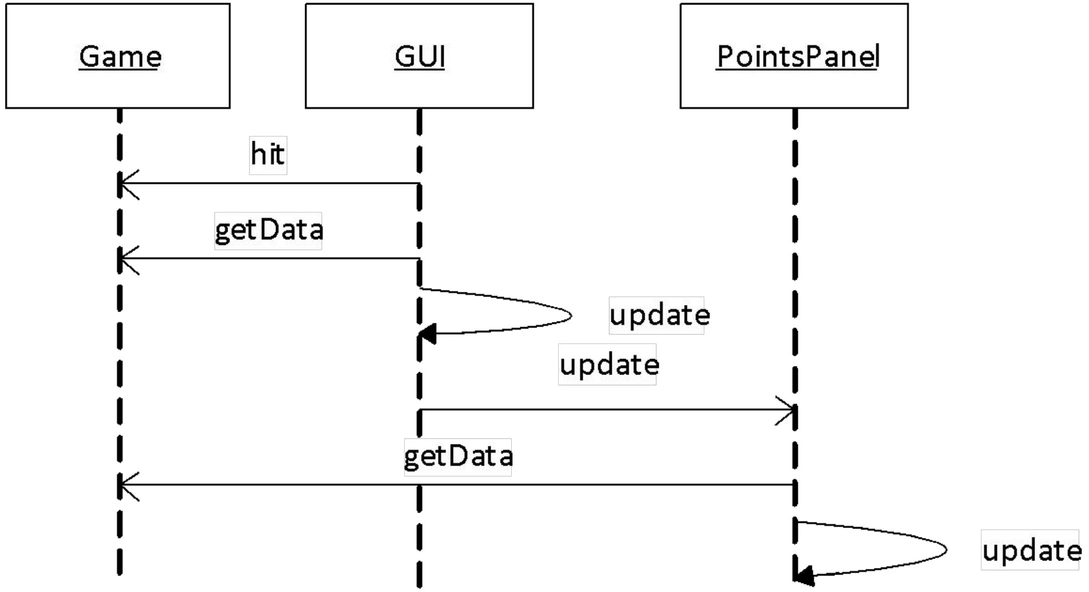
A GUI design challenge, extended

- What if we want to show the points won?



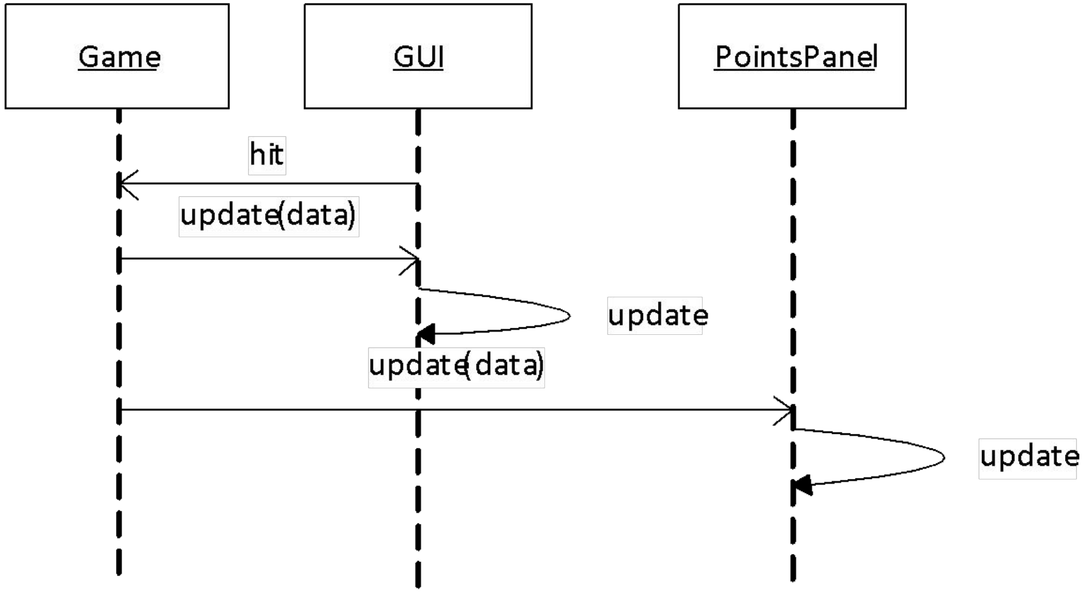
Game updates GUI?

- What if points change for reasons not started by the GUI? (or computations take a long time and should not block)



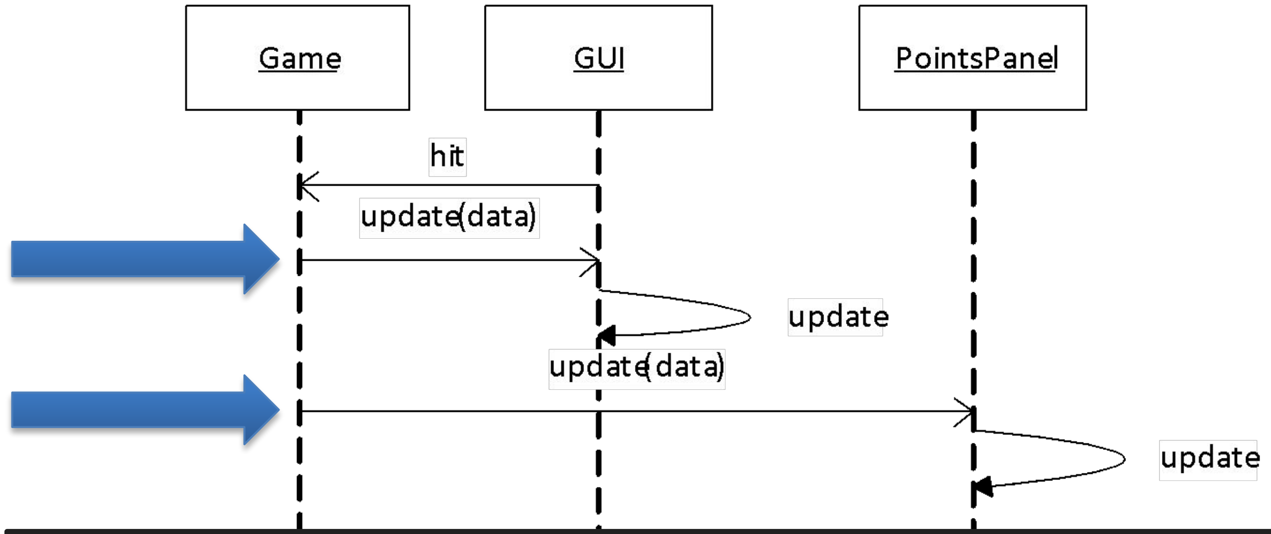
Game updates GUI?

- Let the Game tell the GUI that something happened



Game updates GUI?

- Let the Game tell the GUI that something happened



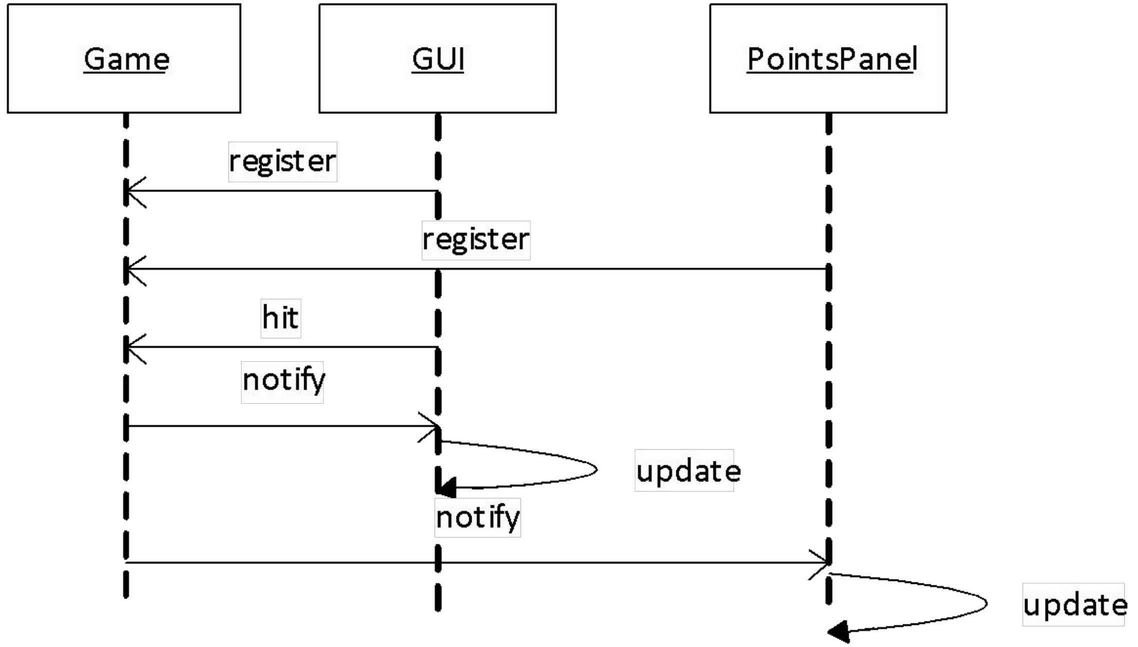
Problem: This couples the `World` to the GUI implementation.

Core implementation vs. GUI

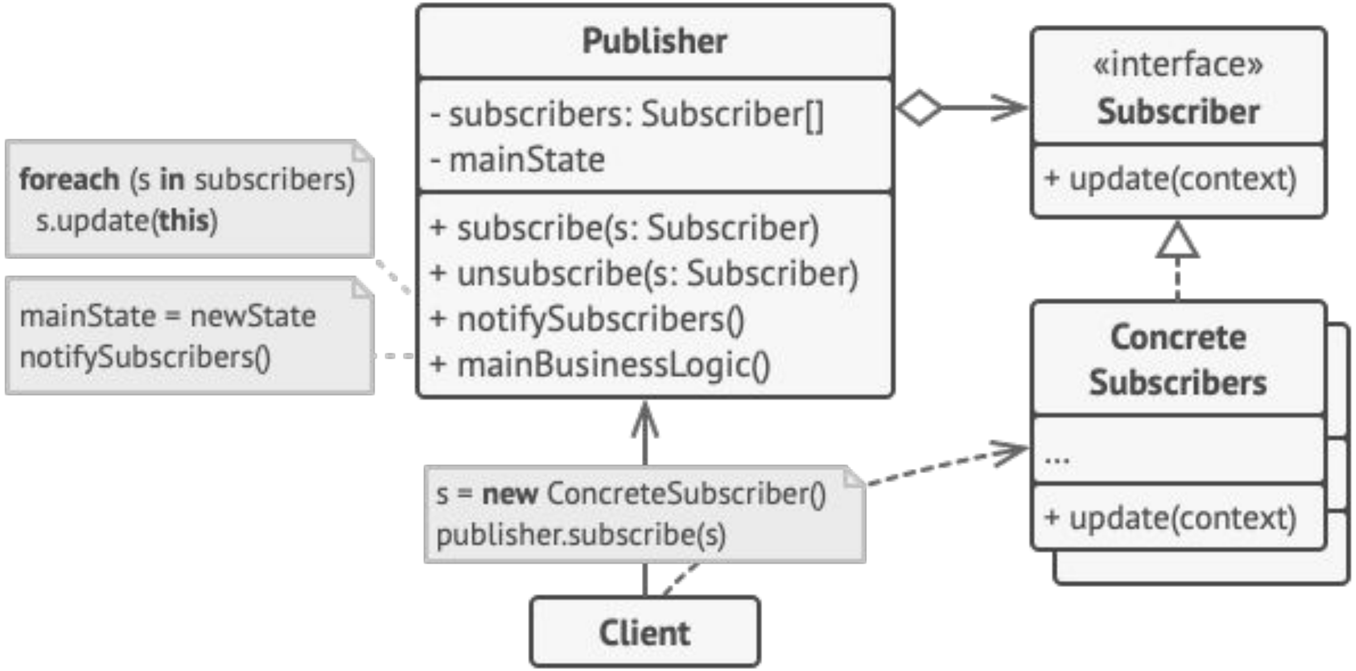
- Core implementation: Application logic
    - Computing some result, updating data
- GUI
    - Graphical representation of data
    - Source of user interactions
- Design guideline: *Avoid coupling the GUI with core application*
    - Multiple UIs with single core implementation
    - Test core without UI
    - *Design for change, design for reuse, design for division of labor; low coupling, high cohesion*

Decoupling with the Observer pattern

- Let the Game tell *all* interested components about updates



Recall the Observer



```
foreach (s in subscribers)
  s.update(this)
```

```
mainState = newState
notifySubscribers()
```

```
s = new ConcreteSubscriber()
publisher.subscribe(s)
```

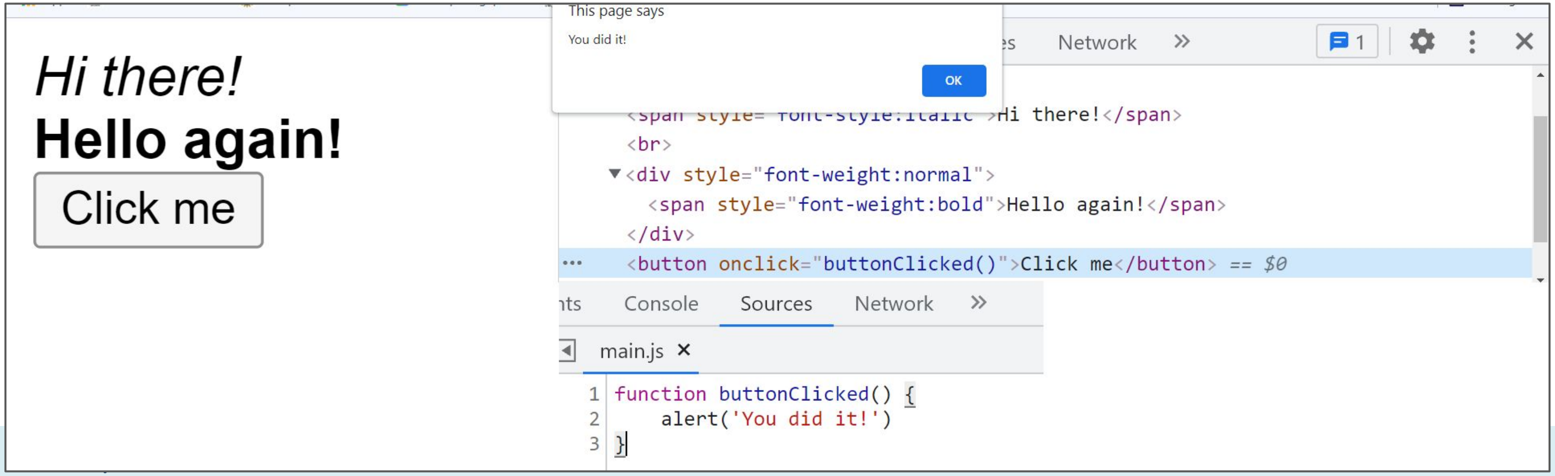
https://refactoring.guru/design-patterns/observer

Observer Pattern

- Manages publishers and subscribers
  - Here, button publishes its ‘click’ events
  - `buttonClicked` subscribes to 1+ updates
- Flexibility and Reuse
  - Multiple observers per element
  - Shared observers across elements

Actions: JavaScript

- Key: event listeners/the Observer Pattern
- (frontend) JS is highly event-driven
  - Respond to window `onLoad` event, content loads (e.g., ads)
  - Respond to clicks, moves
- This is what happened with our simple button!



Hi there!
Hello again!
Click me

```
<span style="font-style:italic">Hi there!</span>
<br>
▼<div style="font-weight:normal">
  <span style="font-weight:bold">Hello again!</span>
</div>
<button onclick="buttonClicked()">Click me</button> == $0
```

```
function buttonClicked() {
    alert('You did it!')
}
```

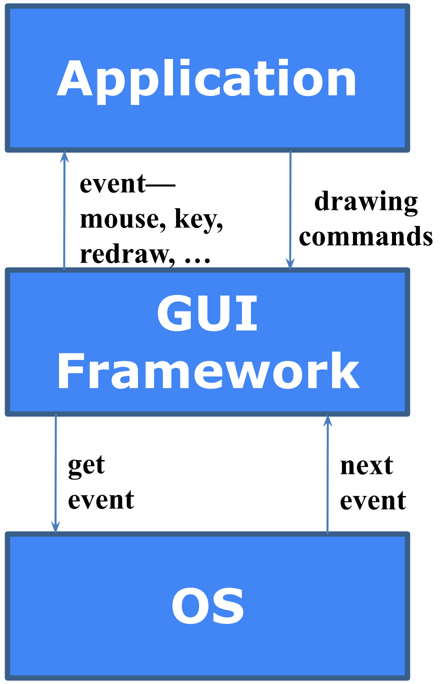
What does this look like in TicTacToe?

Let’s go look!

Important note! just because TTT is implemented in a static web page all in the frontend, does *not* mean that the GUI and the Game are hopelessly entangled or that we’re violating the design principle to keep them separate!

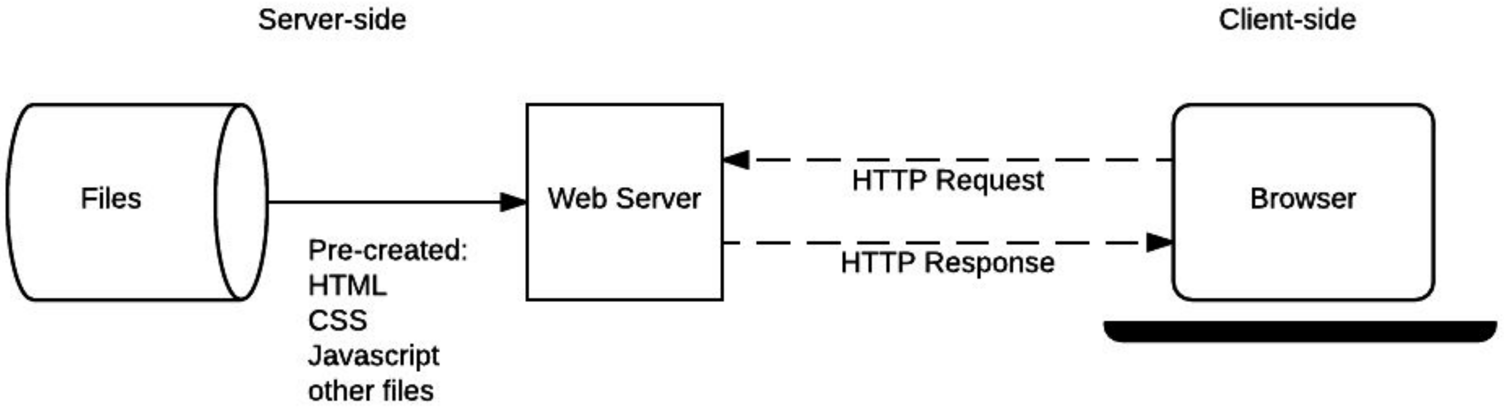
An event-based GUI with a GUI framework

- Setup phase
  - Describe how the GUI window should look
  - Register observers to handle events
- Execution
  - Framework gets events from OS, processes events
    - Your code is mostly just event handlers



Static Web Pages

- Delivered as-is, final
  - Consistent, often fast
  - Cheap, only storage needed
- “Static” a tad murky with JavaScript
  - We can still have buttons, interaction
  - But it won’t “go” anywhere -- the server is mum



https://developer.mozilla.org/en-US/docs/Learn/Server-side/First_steps/Client-Server_overview#anatomy_of_a_dynamic_request

Static Web Pages

- Delivered as-is, final
  - Consistent, often fast
  - Cheap, only storage needed
- Can be maintained with *static website generators*
  - Or you'll be doing a lot of copying
  - Coupled with themes => rapid development, deployment
  - Quite popular, e.g. hosting on GH Pages
  - (remember: HW4!)

Static Web Pages

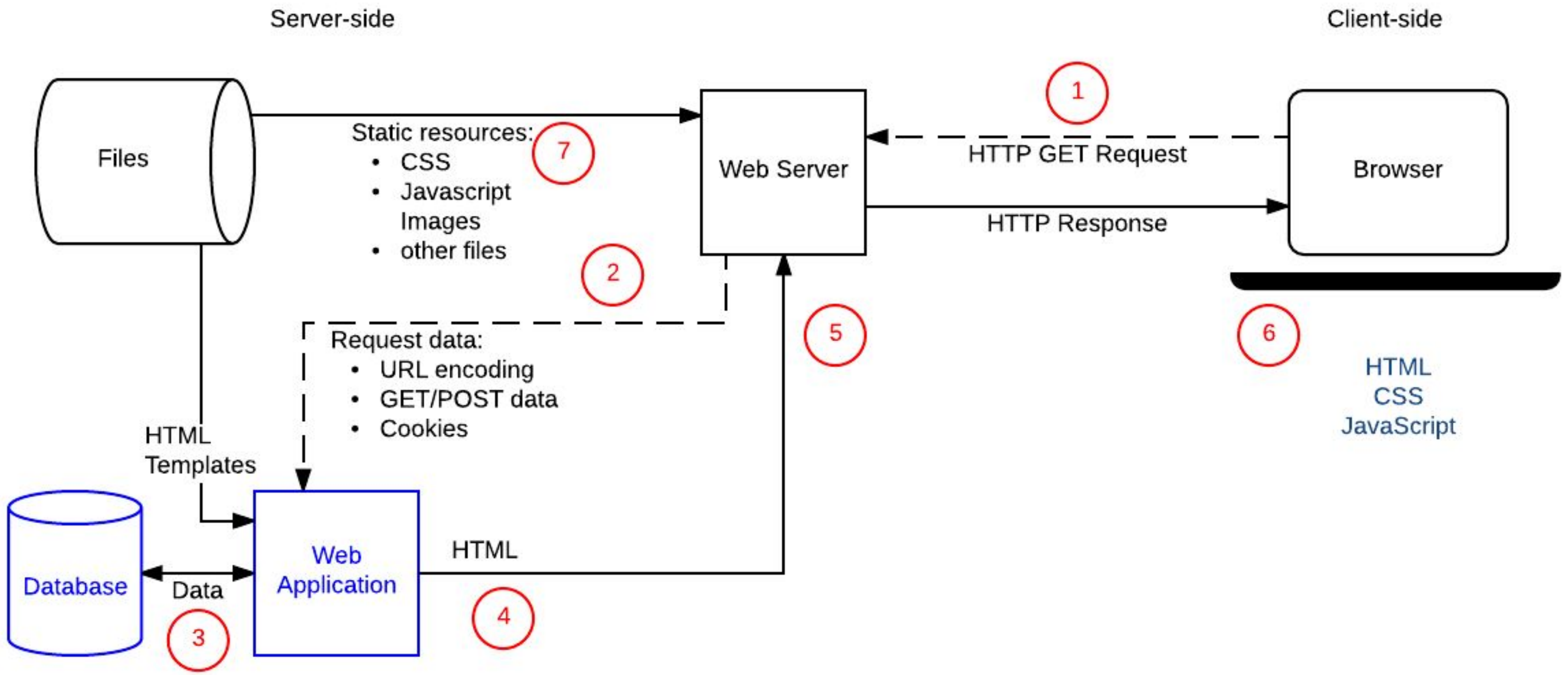
- But …
  - No data from elsewhere (where does your email come from?)
  - No persistence (at least, not obviously)
  - No customizability (e.g., accounts)
  - No communication (payment, chat, etc)
  - Realistically, no intensive jobs

Dynamic Web Pages

- Client/Server
  - Someone needs to answer the website's calls
    - Doesn't need to be us!
  - Host a webserver
    - Serves pages, handles calls
    - For static pages too!
- We'll show you more in recitation tomorrow (Wednesday)

Web Servers

Dynamic sites can do more *work*



https://developer.mozilla.org/en-US/docs/Learn/Server-side/First_steps/Client-Server_overview#anatomy_of_a_dynamic_request

Web Servers

- Communicate via HyperText Transfer Protocol
  - URL (the address)
  - Method:
    - GET: retrieve data. Parameters in URL `...?key=value&key2=value2` and message body
    - POST: store/create data. Parameters in request body
    - Several more, rarely used
  - Responses:
    - *Status Code*:
      - We probably all know 404.
      - 2XX family is OK.
    - And possible data. E.g., entire HTML page.

Web Servers

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    - Several more, rarely used
  - Responses:
    - *Status Code*. We all know 404. 2XX family is OK.
    - And possible data. E.g., entire HTML page.
  - POST makes no sense for static sites!
  - As do GETs with parameters

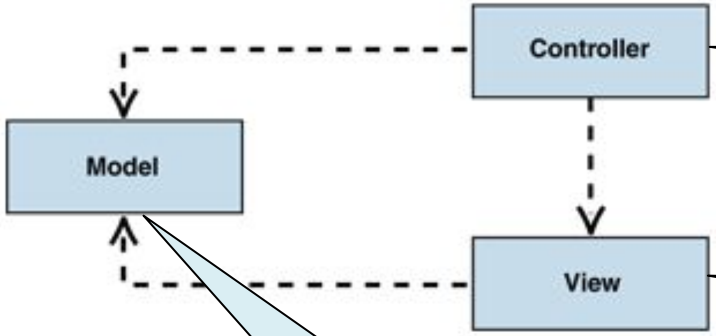
We can implement TicTacToe this way, too!

Let’s go see.

(network tab of inspect will show us messages!)

But notice we’ve begun to more explicitly separate out the HTML from the logic.

An architectural pattern: Model-View-Controller (MVC)



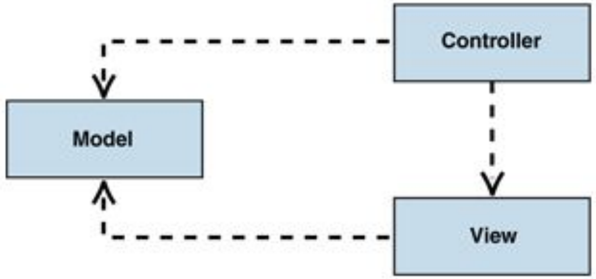
Manage inputs from user: mouse, keyboard, menu, etc.

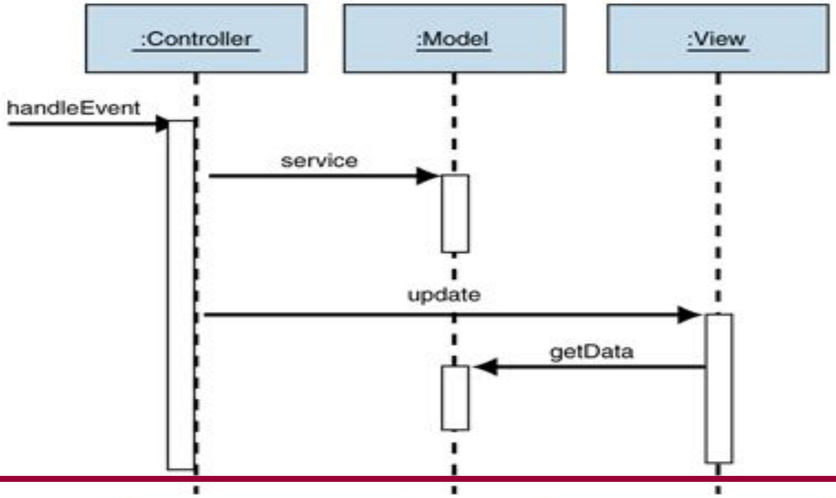
Manage display of information on the screen

Manage data related to the application domain

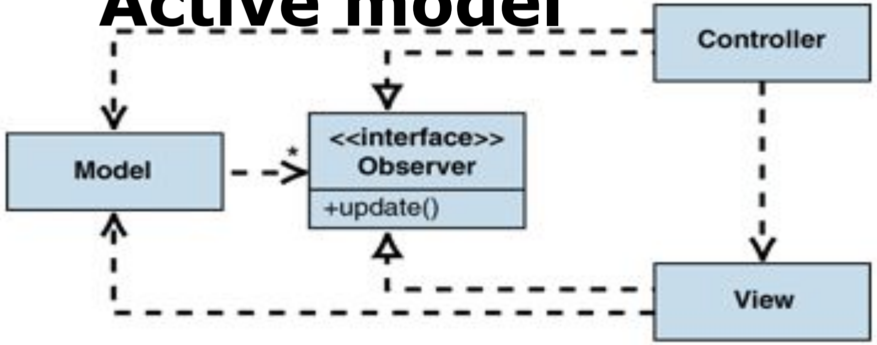
Model-View-Controller (MVC)

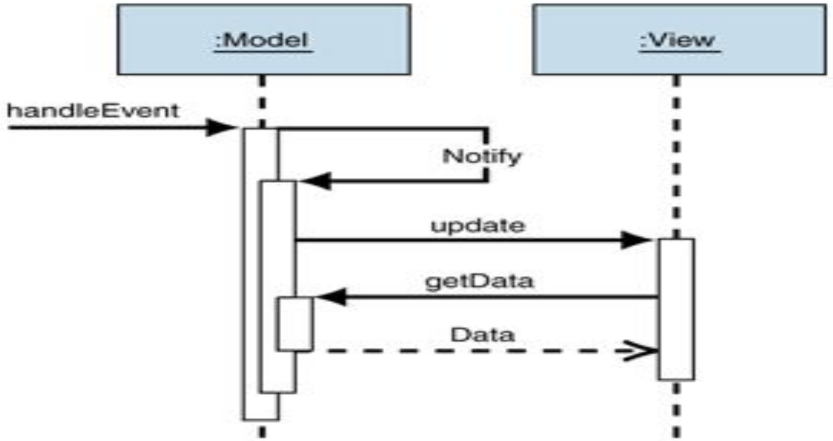
Passive model





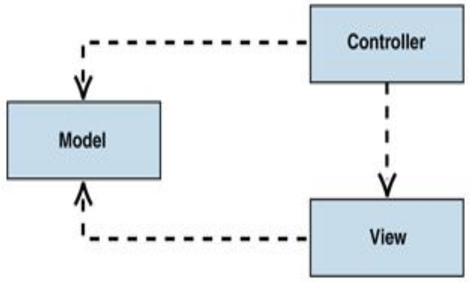
Active model

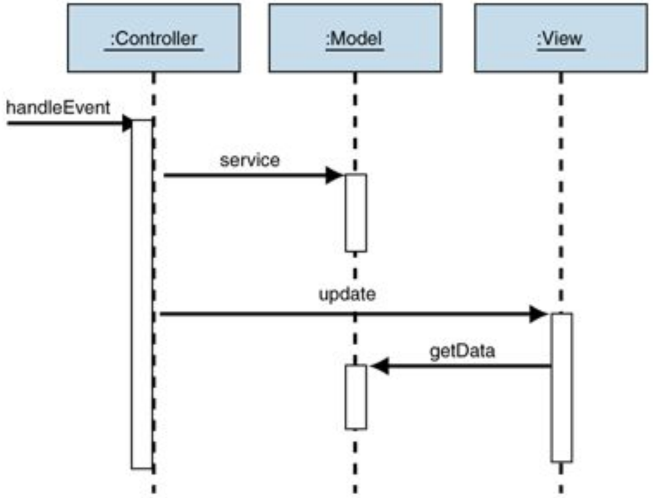




http://msdn.microsoft.com/en-us/library/ff649643.aspx

Model View Controller Dependencies





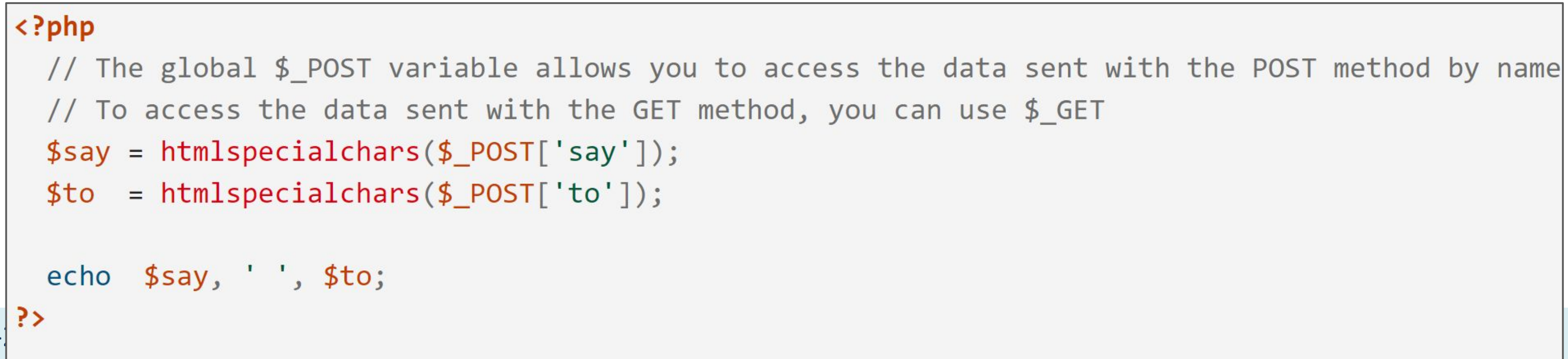
MVC is ubiquitous

Separates:

- Model: data organization
    - Interface to the database
- View: data representation (typically HTML)
    - Often called *templates* in web-dev; “view” is a bit overloaded
- Controller: intermediary between client and model/view
    - Typically asks model for data, view for HTML

How to Web App?

- Let’s avoid generating HTML from scratch on every call
  - Map requests to handler code
    - Fetch data, process
  - Generate and return HTML
- Historically: PHP
  - Modifies HTML pages server-side on request; strong ties to SQL



```php
<?php
  // The global $_POST variable allows you to access the data sent with the POST method by name
  // To access the data sent with the GET method, you can use $_GET
  $say = htmlspecialchars($_POST['say']);
  $to  = htmlspecialchars($_POST['to']);

  echo  $say, ' ', $to;
?>
```

Summary

- GUIs are full of design patterns
  - Helpful for reuse, delegation in complex environments
- Covered the basics of HTML, CSS, JS, servers
  - Needed for dynamic web pages
  - Decouple the GUI; architect your backend
  - A lot more to learn (security, performance, privacy), but this will do
- You will build this
  - At a small scale