GEORGE MASON UNIVERSITY

SWE 621

FALL 2022

ARCHITECTURAL STYLES

LOGISTICS

- HW2 due today
- Midterm in class next week
  - **Monday classes meet on Tuesday**
  - **Exam will be 4:30 - 7:10 on Tuesday, same room**
- HW3 due in 3 weeks (10/24)
  - Will be released next week after midterm

MIDTERM

- 200 points / 20% of course grade
- Closed book / closed notes
- ~80% based on lecture (including ideas covered in lecture and textbook)
- ~20% based on readings

MIDTERM REVIEW

- Examples of questions
  - Questions on concepts, definitions, and process advice
    - e.g., What are the characteristics of a good abstraction?
  - Questions applying concepts to real world examples
    - e.g., critique this code snippet as an abstraction, based on this code scenario.
    - e.g., for these requirements, design a solution and describe through a component and connector model

IN CLASS EXERCISE

- Why might one build a software system organized into layers?

SOFTWARE ARCHITECTURE

- Software architecture = { Elements, Constraints, Consequences }
- Elements: the set of structures needed to reason about the system
- Constraints: the ways in which functionality is assigned to elements and elements can be composed
- Consequences: the resulting properties of systems which conform to the constraints

FREQUENT ARCHITECTURAL REQUIREMENTS

- Performance: how fast is the system
- Reliability: how likely is the system to be available
- Scalability: how well does adding more computing resources translate to better performance
- Maintainability: how hard is system to change
- Extensibility: in what ways can new components be added without changing existing components
- Configurability: how easily can the system behavior be changed by end-users
- Portability: in what environments can the system be used
- Testability: how easy is it to write tests of the system's behavior

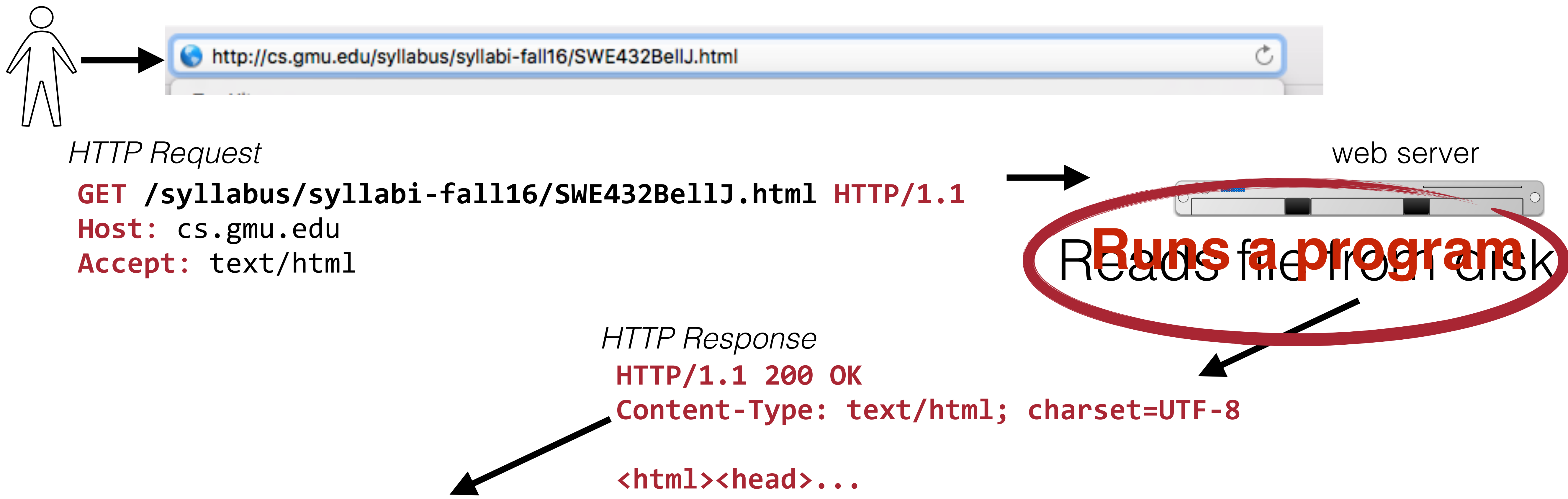
EXAMPLE OF ALTERNATIVE ARCHITECTURES: THE WEB

- Evolving competing architectures for organizing content and computation between browser (client) and web server
- 1990s: static web pages
- 1990s: server-side scripting (CGI, PHP, ASP, ColdFusion, JSP, …)
- 2000s: single page apps (JQuery)
- 2010s: front-end frameworks (Angular, Aurelia, React, …), microservices

STATIC WEB PAGES

- URL corresponds to directory location on server
  - e.g. http://domainName.com/img/image5.jpg maps to img/image5.jpg file on server
- Server responds to HTTP request by returning requested files
- Advantages
  - Simple, easily cacheable, easily searchable
- Disadvantages
  - No interactivity

DYNAMIC WEB PAGES



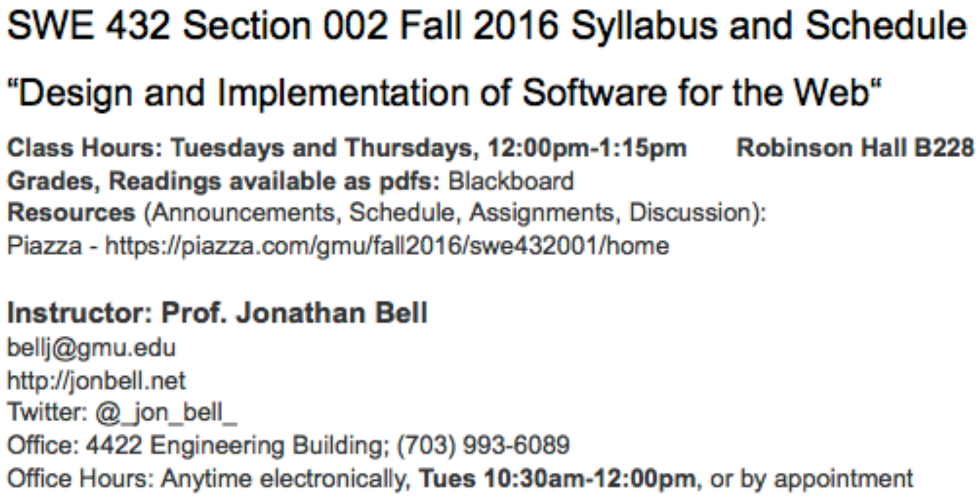
HTTP Request

```
GET /syllabus/syllabi-fall16/SWE432BellJ.html HTTP/1.1
Host: cs.gmu.edu
Accept: text/html
```

HTTP Response

```
HTTP/1.1 200 OK
Content-Type: text/html; charset=UTF-8

<html><head>...
```



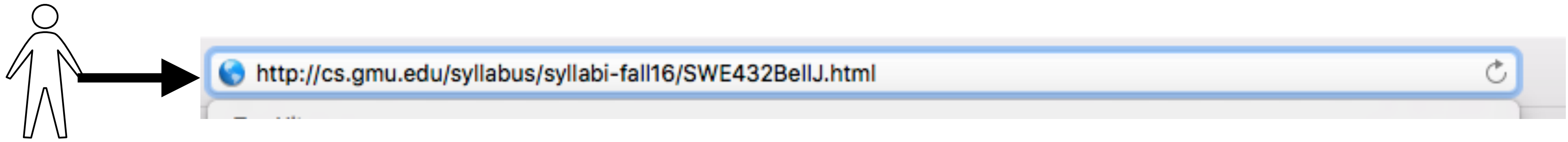
SWE 432 Section 002 Fall 2016 Syllabus and Schedule

“Design and Implementation of Software for the Web“

Class Hours: Tuesdays and Thursdays, 12:00pm-1:15pm **Robinson Hall B228**
Grades, Readings available as pdfs: Blackboard
Resources (Announcements, Schedule, Assignments, Discussion):
Piazza - https://piazza.com/gmu/fall2016/swe432001/home

Instructor: Prof. Jonathan Bell
bellj@gmu.edu
http://jonbell.net
Twitter: @_jon_bell_
Office: 4422 Engineering Building; (703) 993-6089
Office Hours: Anytime electronically, **Tues 10:30am-12:00pm**, or by appointment

DYNAMIC WEB PAGES



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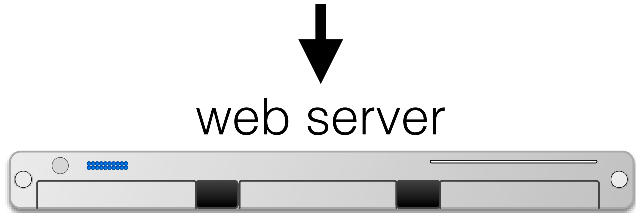
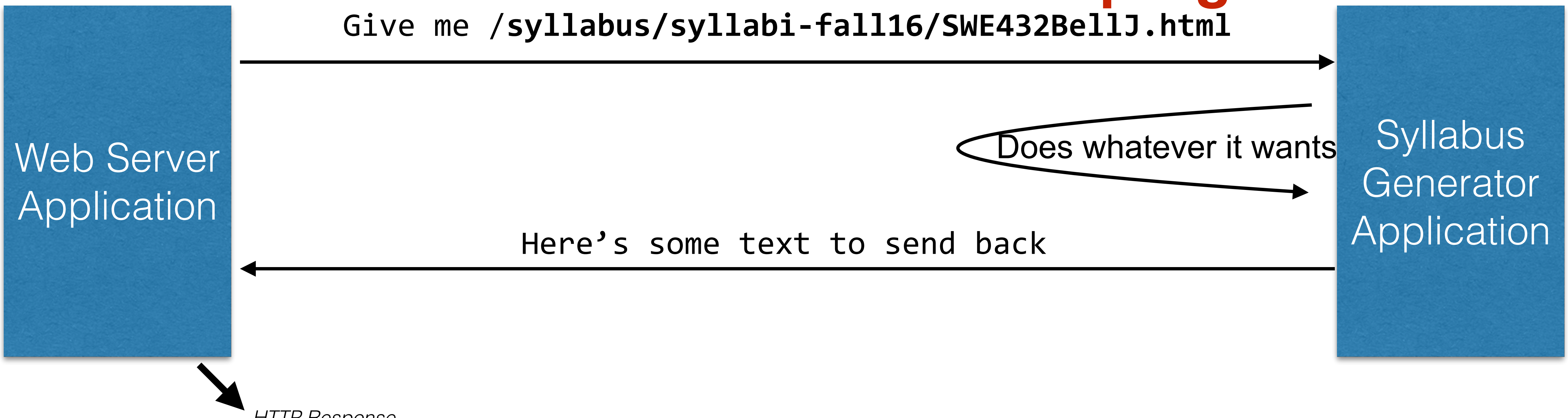
Host: cs.gmu.edu
Accept: text/html
```



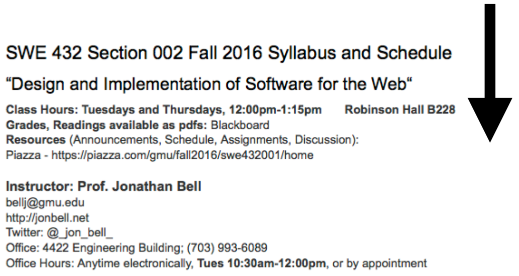
Runs a program


Web Server Application
Give me /syllabus/syllabi-fall16/SWE432BellJ.html
Does whatever it wants
Here's some text to send back
Syllabus Generator Application

HTTP Response

```
HTTP/1.1 200 OK
Content-Type: text/html; charset=UTF-8

<html><head>...
```



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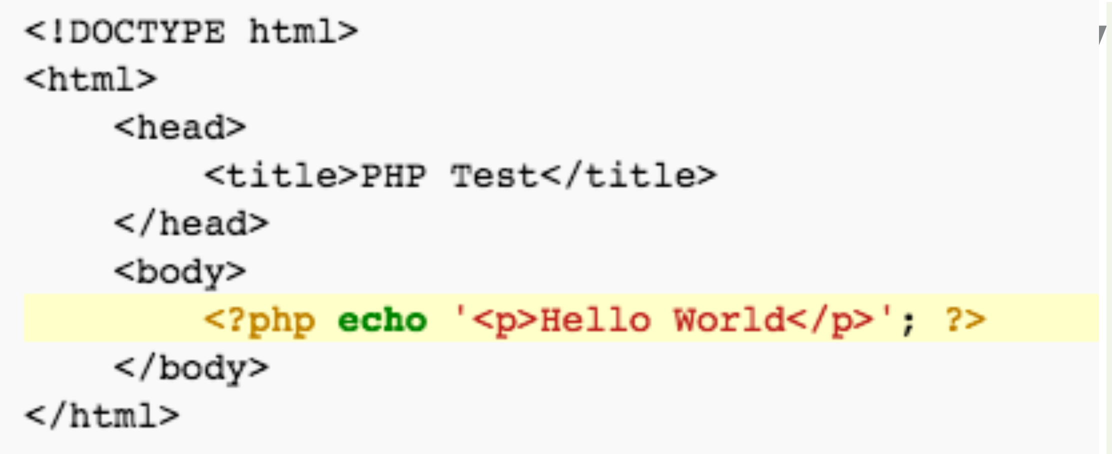
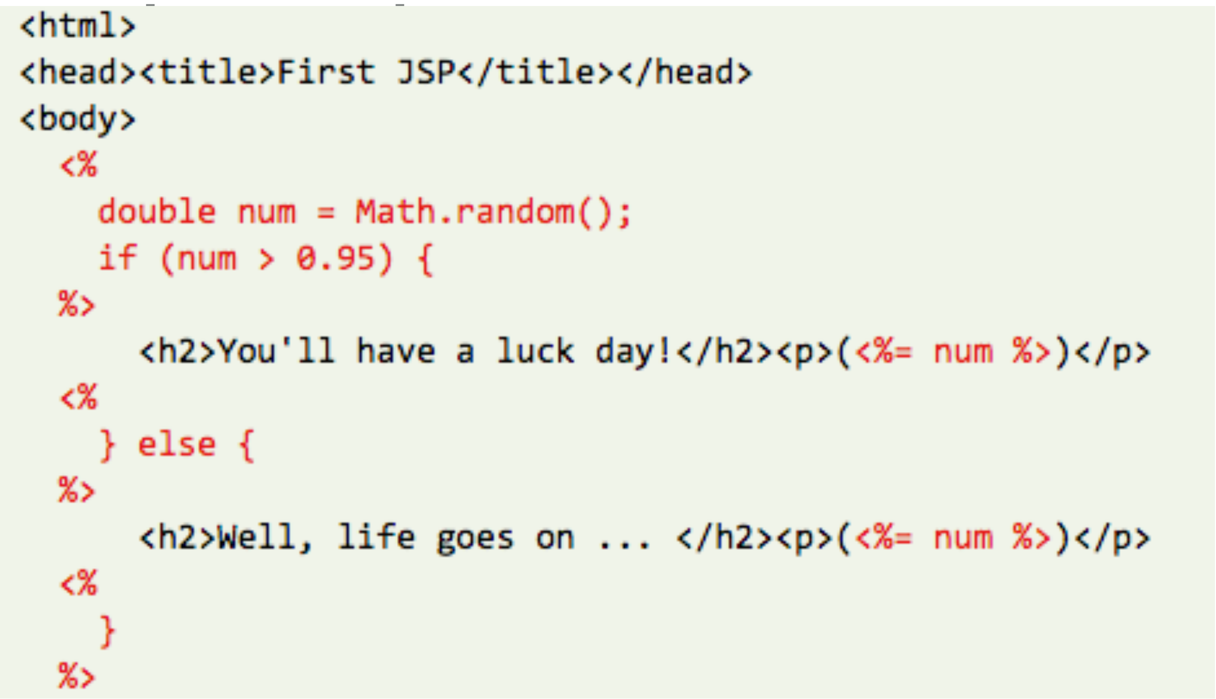
There's a standard mechanism to talk to these auxiliary applications, called CGI (Common Gateway Interface)

SERVER SIDE SCRIPTING

- (



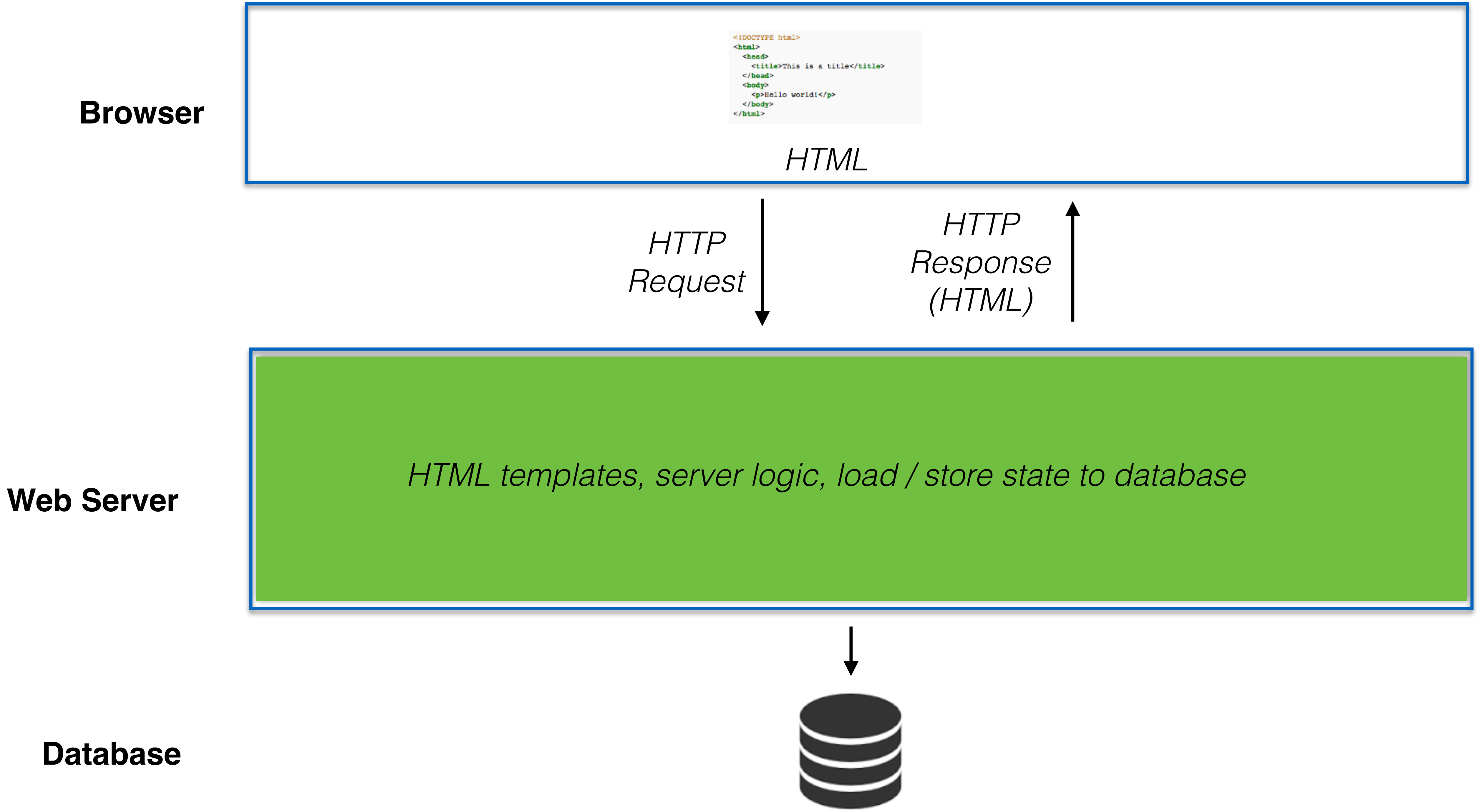
```
<!DOCTYPE html>
<html>
    <head>
        <title>PHP Test</title>
    </head>
    <body>
        <?php echo '<p>Hello World</p>'; ?>
    </body>
</html>
```



```
<html>
<head><title>First JSP</title></head>
<body>
  <%
    double num = Math.random();
    if (num > 0.95) {
  %>
      <h2>You'll have a luck day!</h2><p>(<%= num %>)</p>
  <%
    } else {
  %>
      <h2>Well, life goes on ... </h2><p>(<%= num %>)</p>
  <%
    }
  %>
```

- Early approaches emphasized embedding server code *inside* html pages
- Examples: CGI

SERVER SIDE SCRIPTING SITE



Browser

```
<!DOCTYPE html>
<html>
  <head>
    <title>This is a title</title>
  </head>
  <body>
    <p>Hello world!</p>
  </body>
</html>
```

HTML

HTTP Request

HTTP Response (HTML)

Web Server

HTML templates, server logic, load / store state to database

Database

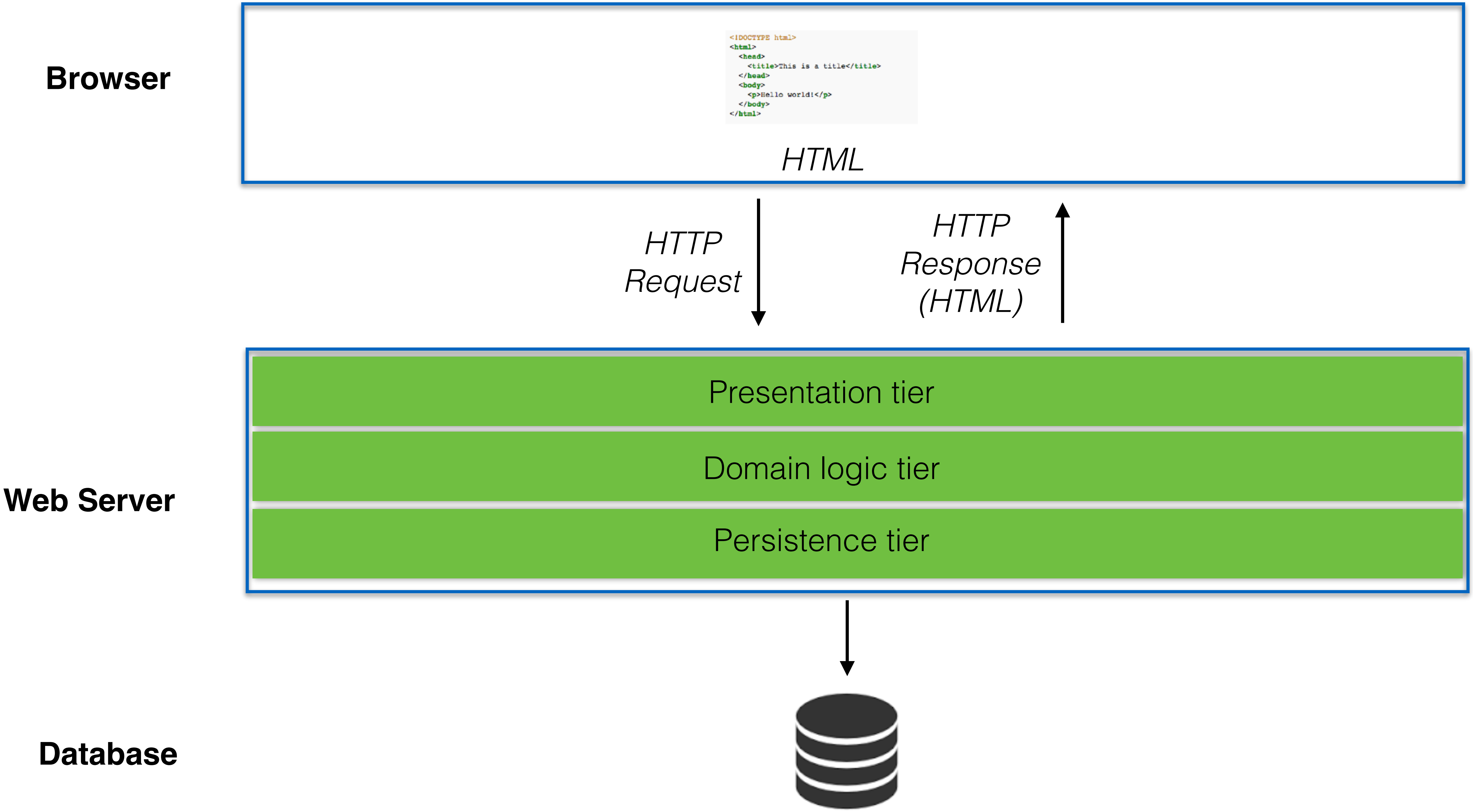
LIMITATIONS

- Poor **modularity**
  - Code representing logic, database interactions, generating HTML presentation all tangled
  - Hard to understand, difficult to maintain
- Still a step up over static pages!

SERVER SIDE FRAMEWORKS

- Framework that structures server into tiers, organizes logic into classes
- Create separate tiers for presentation, logic, persistence layer
- Can understand and reason about domain logic without looking at presentation (and vice versa)
- Examples: ASP.NET, JSP

SERVER SIDE FRAMEWORK SITE



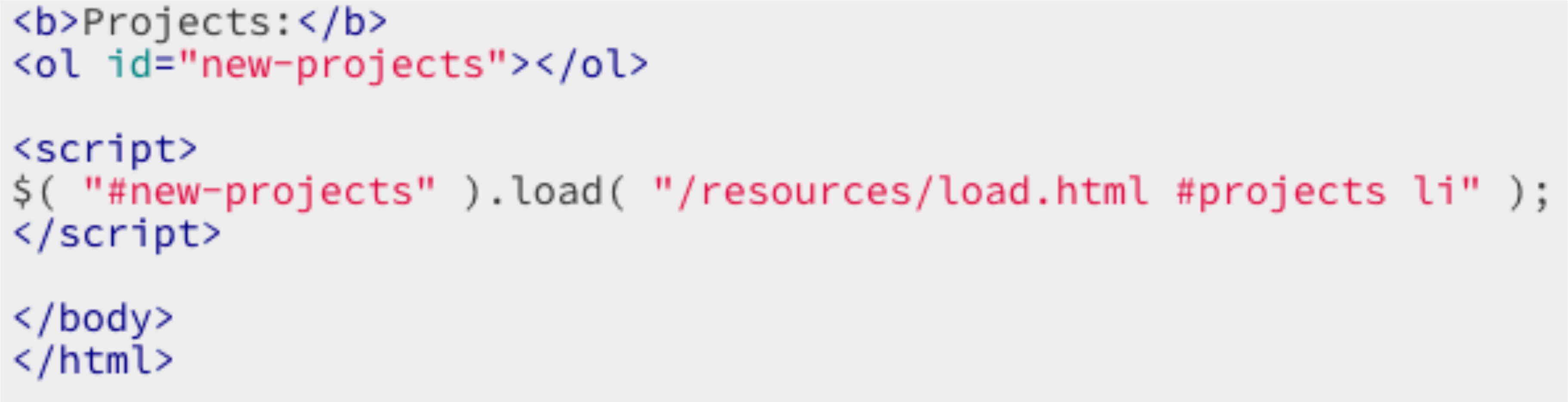
```
<!DOCTYPE html>
<html>
  <head>
    <title>This is a title</title>
  </head>
  <body>
    <p>Hello world!</p>
  </body>
</html>
```

LIMITATIONS

- Need to load a whole new web page to get new data
  - Users must *wait* while new web page loads, decreasing responsiveness & interactivity
  - If server is slow or temporarily non-responsive, ***whole user interface hangs!***
  - Page has a discernible *refresh*, where old content is replaced and new content appears rather than seamless transition

SINGLE PAGE APPLICATION (SPA)

- Client-side logic sends messages to server, receives response
- Logic is associated with a single HTML pages, written in Javascript
- HTML elements dynamically added and removed through DOM manipulation



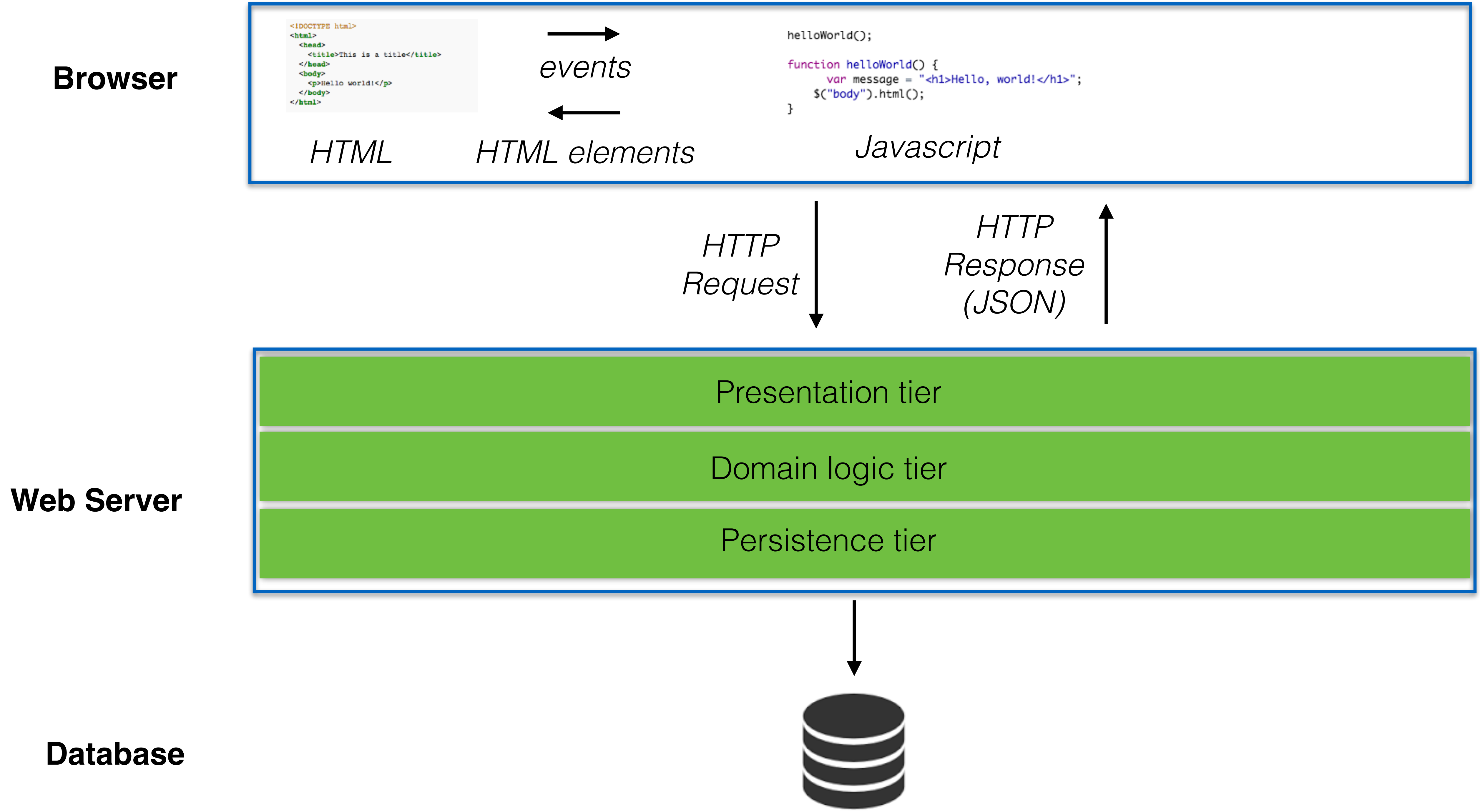
```
<b>Projects:</b>
<ol id="new-projects"></ol>

<script>
$( "#new-projects" ).load( "/resources/load.html #projects li" );
</script>

</body>
</html>
```

- Processing that does not require server may occur entirely client side, dramatically increasing responsiveness & reducing needed server resources
- Classic example: Gmail

SINGLE PAGE APPLICATION SITE



Browser

```
<!DOCTYPE html>
<html>
  <head>
    <title>This is a title</title>
  </head>
  <body>
    <p>Hello world!</p>
  </body>
</html>
```

HTML

events

HTML elements

```
helloWorld();

function helloWorld() {
      var message = "<h1>Hello, world!</h1>";
    $("body").html();
}
```

Javascript

HTTP Request

HTTP Response (JSON)

Web Server

Presentation tier

Domain logic tier

Persistence tier

Database

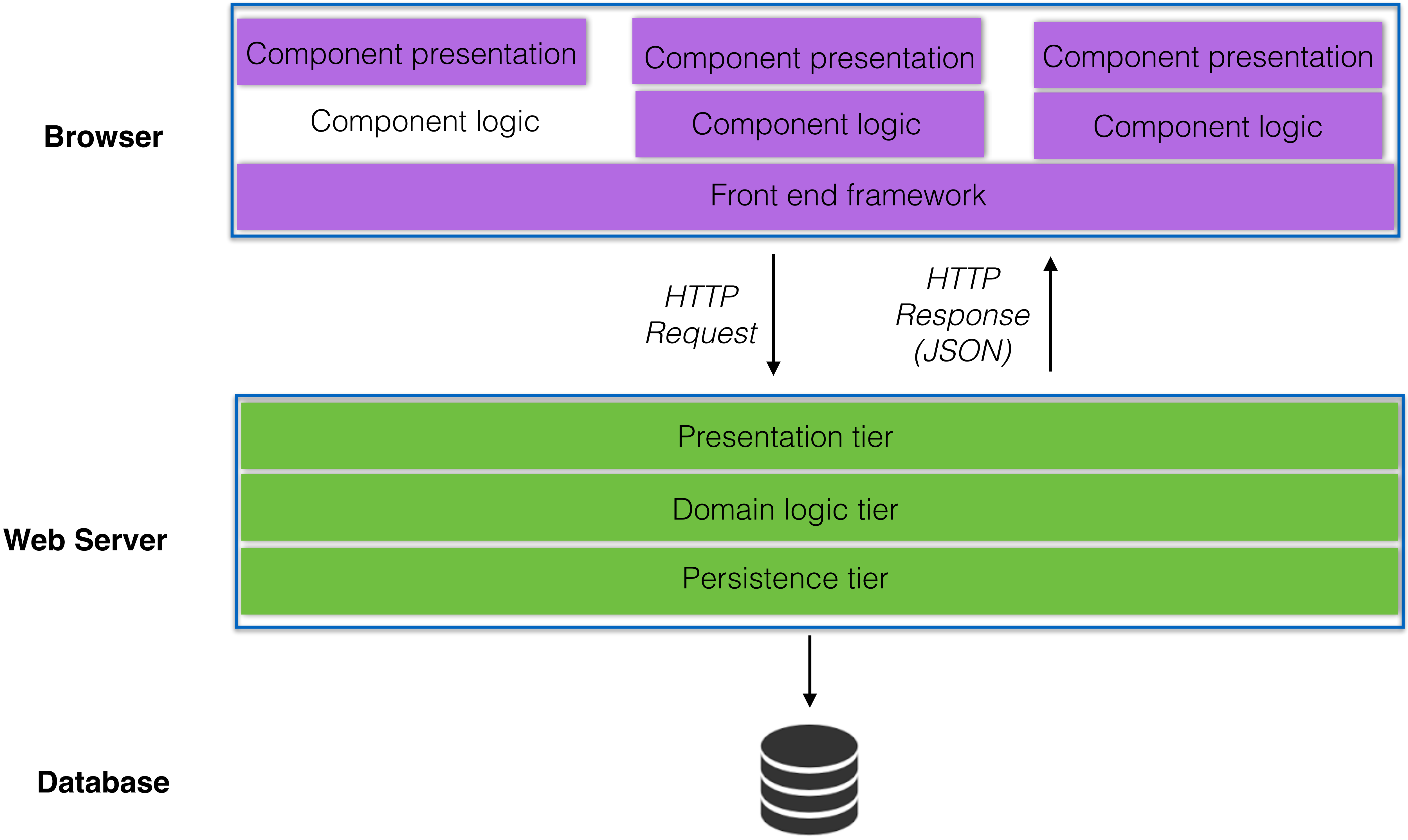
LIMITATIONS

- Poor modularity *client-side*
    - As logic in client grows increasingly large and complex, becomes Big Ball of Mud
    - Hard to understand & maintain
    - DOM manipulation is *brittle* & *tightly coupled*, where small changes in HTML may cause unintended changes (e.g., two HTML elements with the same id)
    - Poor reuse: logic tightly coupled to individual HTML elements, leading to code duplication of similar functionality in many places

FRONT END FRAMEWORKS

- Client is organized into separate *components,* capturing model of web application data
- Components are reusable, have encapsulation boundary (e.g., class)
- Components separate *logic* from *presentation*
- Components dynamically generate corresponding code based on component state
    - In contrast to HTML element manipulation, *framework* generates HTML, not user code, decreasing coupling
- Examples: Meteor, Ember, Angular, Aurelia, React

FRONT END FRAMEWORK SITE



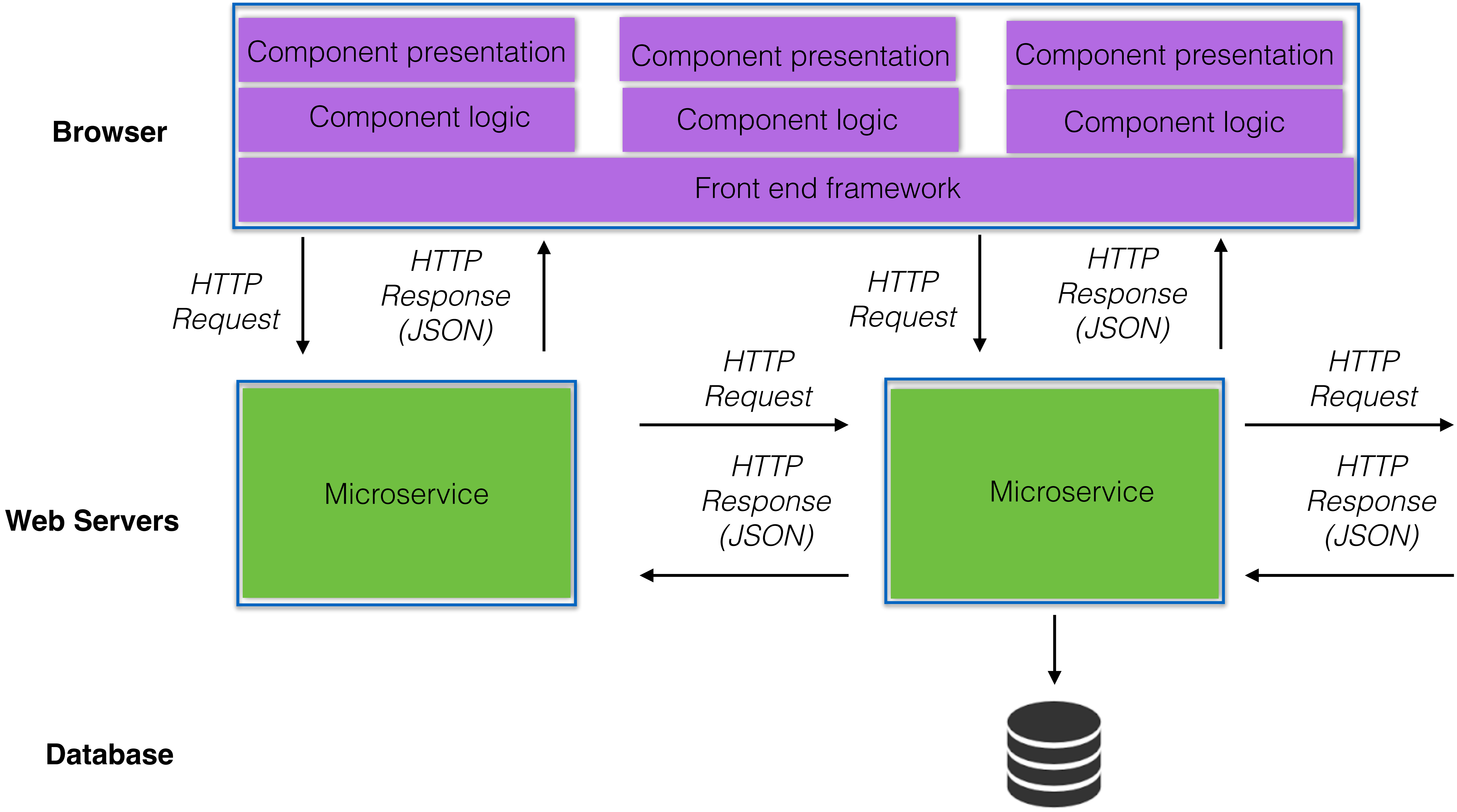
LIMITATIONS

- Duplication of logic in client & server
  - As clients grow increasingly complex, must have logic in both client & server
  - May even need to be written twice in different *languages*! (e.g., Javascript, Java)
  - Server logic closely coupled to corresponding client logic. Changes to server logic require corresponding client logic change.
  - Difficult to reuse server logic

MICROSERVICES

- Small, focused web server that communicates through *data* requests & responses
  - Focused *only* on logic, not presentation
- Organized around capabilities that can be reused in multiple context across multiple applications
- Rather than horizontally scale identical web servers, vertically scale server infrastructure into many, small focused servers

MICROSERVICE SITE



Browser

Component presentation

Component logic

Component presentation

Component logic

Component presentation

Component logic

Front end framework

HTTP Request

HTTP Response (JSON)

HTTP Request

HTTP Response (JSON)

Web Servers

Microservice

HTTP Request

HTTP Response (JSON)

Microservice

HTTP Request

HTTP Response (JSON)

Database

CAN WE DRAW MORE GENERAL LESSONS?

- Lots of different ways to organize a web app
  - Keep inventing new ones that are better by having some new properties
  - But may sometimes sacrifice others
- Can we draw any more general lessons about how to organize software?

ARCHITECTURAL STYLES

- Architectural style specifies
  - how to partition a system
  - how components identify and communicate with each other
  - how information is communicated
  - how elements of a system can evolve independently

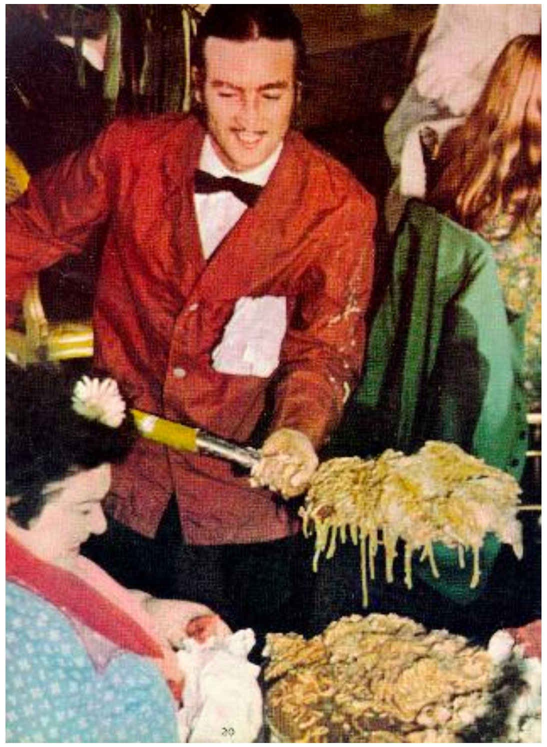
ARCHITECTURAL STYLES

- Can also be characterized by one or more architectural decisions
  - e.g., elements in component A can send messages to elements in component B but not vice versa (i.e., layers)
- Making this decision(s) immediately has one or more consequences on architectural requirements
- Often binary
  - Either code conforms to the constraints and gains the consequences or has at least one violation and does not get the consequences

SOME COMMON ARCHITECTURAL STYLES

- Big ball of mud
- Layered
- Model-centered
- Publish/subscribe
- Pipe and filter
- REST
- Functional reactive programming

BIG BALL OF MUD



http://www.laputan.org/mud/

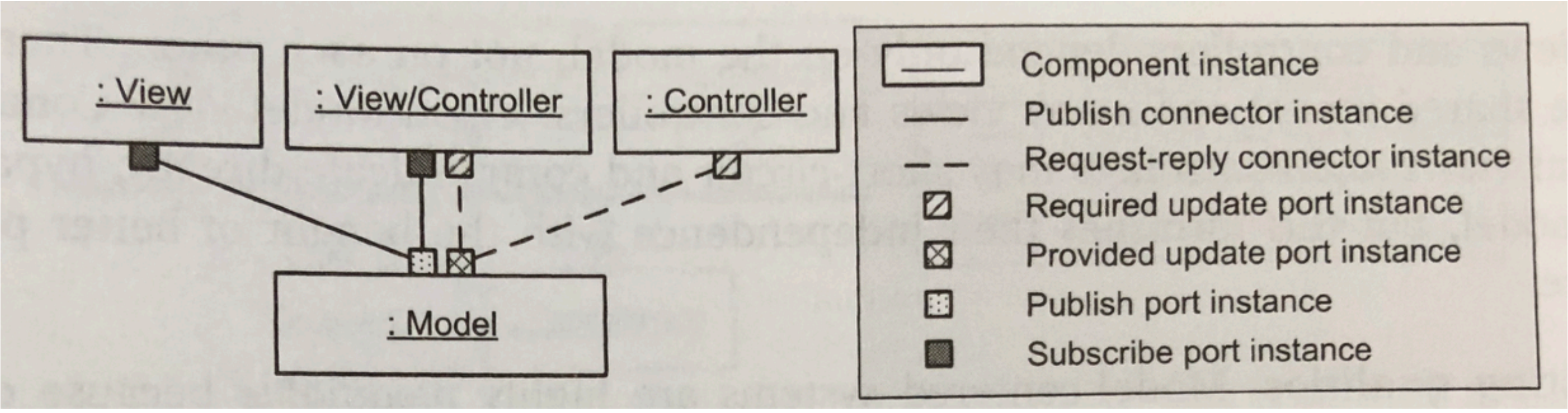
- Forces
  - Insufficient time to build the "right" way, with consideration of how design decisions impact maintainability
- Constraints: none
  - Anything can go anywhere.
  - Anything can be written in any way.
- Consequences
  - Leads to system that is disorganized.
  - Makes it hard to find where to make change, understand implications of change.
  - Decreases maintainability

http://www.laputan.org/mud/

LAYERED ARCHITECTURE

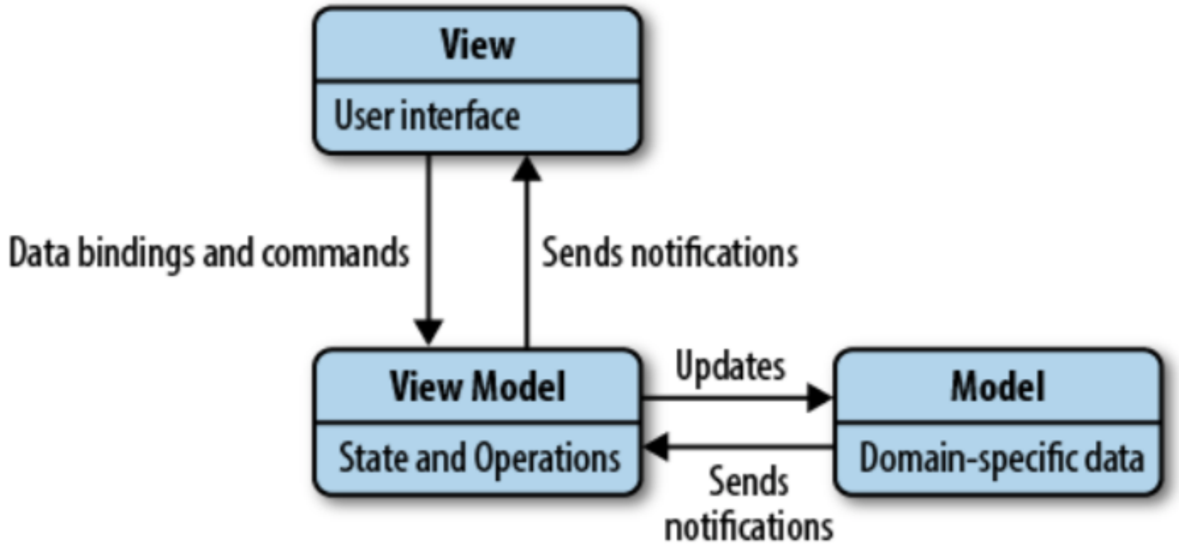
- Elements: layers
- Constraints: can only use lower layers
  - Strictly layered: can only use adjacent lower layer
- Consequences
  - Supports maintability by making it easier to find functionality
  - Supports portability and reusability by enabling layers to be swapped out

MODEL-CENTERED


: View
: View/Controller
: Controller
: Model
Component instance
Publish connector instance
Request-reply connector instance
Required update port instance
Provided update port instance
Publish port instance
Subscribe port instance

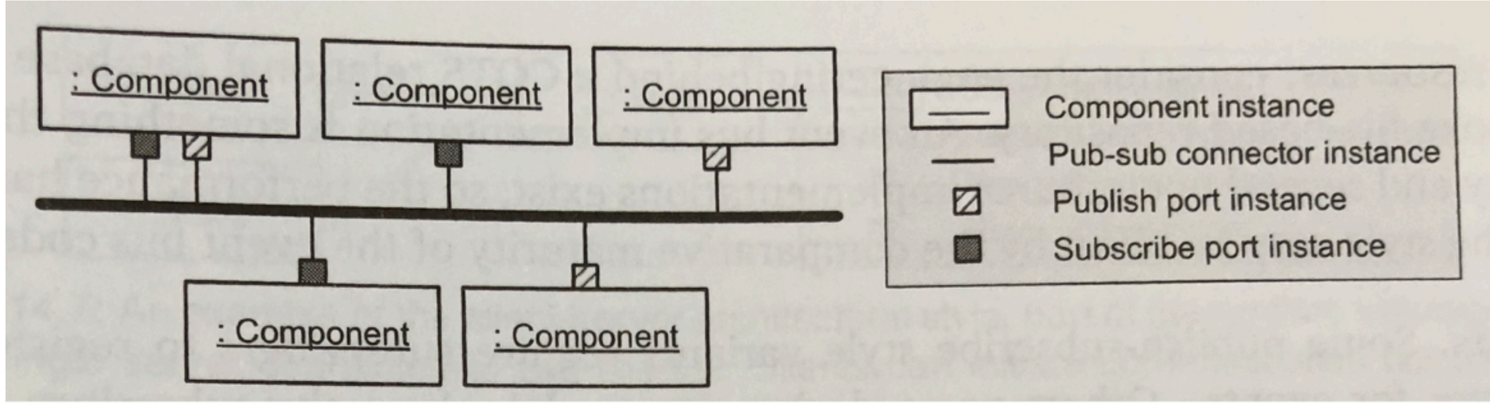
- Elements: model, view (optional), controller (optional), view-controller (optional)
- Constraints
  - Components interact with a central model rather than each other
  - Changes originates outside of model, propagate to model, trigger notifications to elements depending on model
- Synonyms: repository, shared-data, data-centered
- Consequences
  - Maintainable: can write data processing in terms of model rather than in terms of UI abstractions
  - Extensible: easy to add views, controllers, view/models without changing model
  - Scalability: can run each element in a separate thread

EXAMPLE: ANGULAR 1.0 -- MVVM



- Model: domain-specific data, doesn't matter how much it's interact with
- View
  - Visual representation of current state of model
  - View does not communicate with model directly Models are much more dumb: no formatting, etc
- ViewModel: processes user input, translates into format which work for model

PUBLISH/SUBSCRIBE

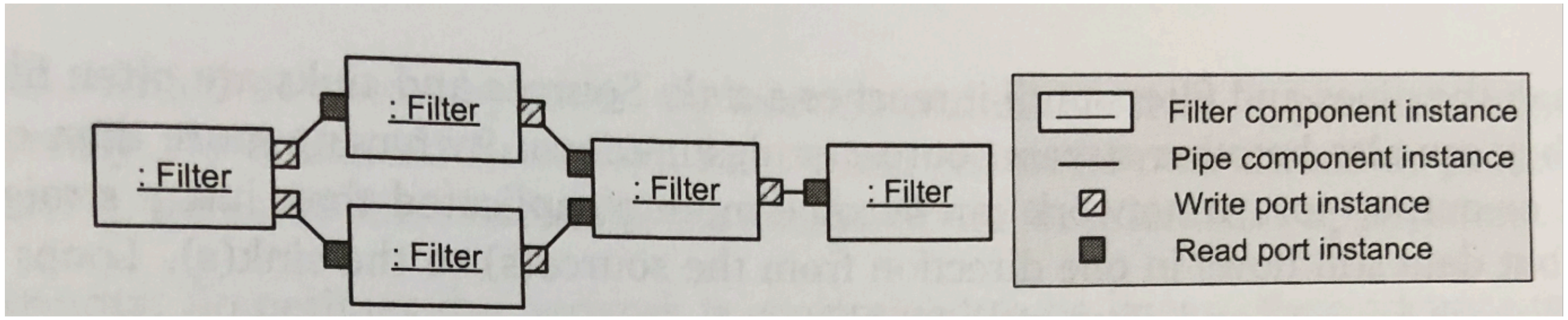


- Elements: component, event bus
  - Components broadcast events to listeners on event bus
- Constraints
  - Components do not know why an event is published
  - Subscribing components do not know **who** published event, depending on event type rather than specific publisher
- Synonyms: event-based, pub/sub
- Consequences
  - Maintainability: can make changes to components without impacting others
  - Performance: can (sometimes) reduce performance due to indirection

REST (REPRESENTATIONAL STATE TRANSFER)

- Elements: HTTP server, request / response connector
- Constraints:
  - Stateless: each client request contains all information necessary to service request
  - Cacheable: clients and intermediaries may cache responses.
  - Layered: client cannot determine if it is connected to end server or intermediary along the way
  - Uniform interface for resources: a single uniform interface (URIs) simplifies and decouples architecture
- Consequences
  - Scalability and reliability: enables servers to be added and removed at will at runtime
  - Performance: enables caching
  - Modifiability: hides changes behind URIs

PIPE AND FILTER



- Elements: pipes, filters, read ports, write ports
- Constraints
  - Filters may only interact through pipes
  - Filters may not share any global state
  - Filters may not make any assumptions about what happens upstream or downstream
  - Filter should incrementally read input and generate output
- Consequences:
  - Configurability, extensibility: can swap and compose networks of filters together, even at runtime
  - Scalability: can do computation in different filters in parallel
  - Modifiability: can more easily make independent changes

FUNCTIONAL REACTIVE PROGRAMMING

- Elements: component, stream of events
- Constraints:
  - Component only gets input from rest of system through stream of events; cannot access or mutate data elsewhere
  - When event arrives, changes state (resulting in new output) and may emit event to other components
- Consequences
  - Maintainability: much easier to make changes to individual element without having to think about consequences of that change to rest of system

SUMMARY

- Architectural style offer specific ways to achieve architectural requirements
- Often offer ways to separate functionality into separate elements and constraints on how these elements can interact
- Violating constraints of an architectural style often means that the consequences of the architectural style will no longer be realized

IN CLASS ACTIVITY

DESIGN ACTIVITY: TODO APPLICATION

- Form group of 2 or 3
- Your goal: design an architecture for a todo application by applying an architectural style (see next slide)
- Todo application requirements
  - User interactions with todos: add, delete, rename, complete, copy
  - Display todos to user
  - Persist todos
- Deliverables:
  - component and connector model showing elements in your system
  - explanation of architectural style, including discussion of constraints imposed on elements
  - text explaining how 3 different scenarios (e.g., add todo, copy todo, persist todos) are handled by the system, describing each scenario with details of what each component does

LIST OF ARCHITECTURAL STYLES

- Each group should select one of the following architectural styles.
- Architectural styles
  - Big ball of mud
  - Layered
  - Model-centered
  - Publish/subscribe
  - Pipes and filters
  - REST
  - Functional reactive programming

DESIGN ACTIVITY: STEP 2: DISCUSSION

- Compare and contrast designs based on each architectural style