GEORGE MASON UNIVERSITY

SWE 621

SPRING 2025

ARCHITECTURAL STYLES

LOGISTICS

- HW2 due today
- Next week is spring break, no class
- Midterm in class in **two weeks**
- HW3 due in 4 weeks (3/31)

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 DISCUSSION

- 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

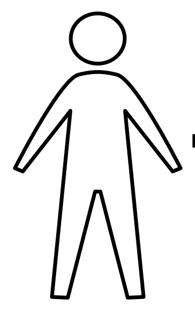
EXAMPLE OF ALTERNATIVE ARCHITECTURES: THE WEB

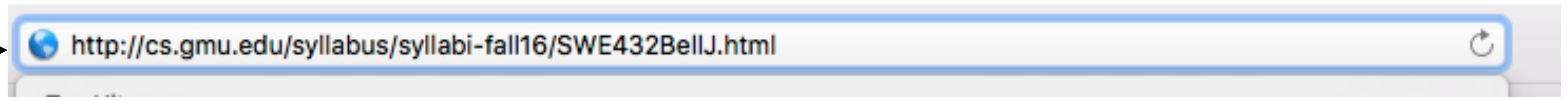
- Evolving competing architectures for organizing content and computation between browser (client) and web server
- 1990s: static web pages
- 1990s: server-side scripting (CGI, PHP, ASP, ColdFusion, JSP, …)
- 2000s: single page apps (JQuery)
- 2010s: front-end frameworks (Angular, Aurelia, React, …),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



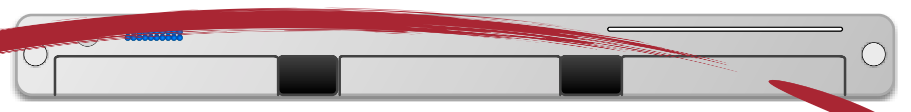


http://cs.gmu.edu/syllabus/syllabi-fall16/SWE432BellJ.html

HTTP Request

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

web server



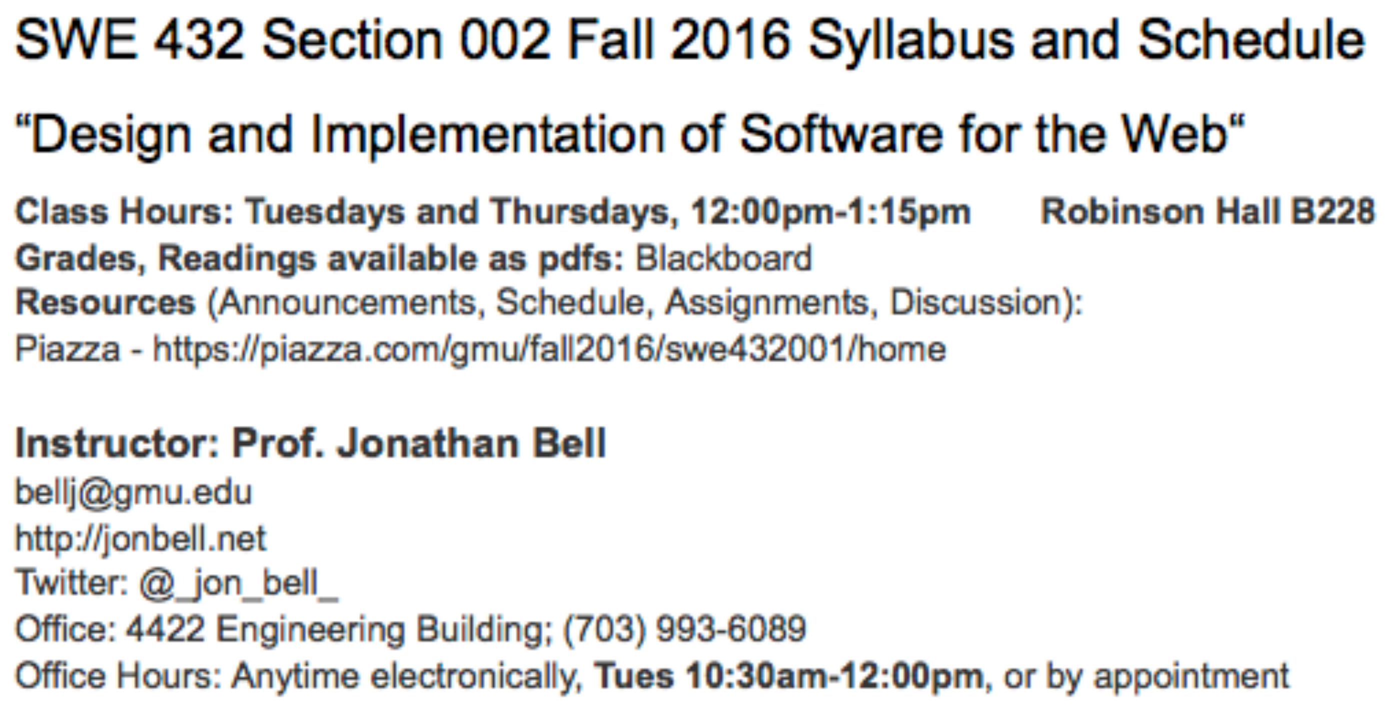
Reads file from disk

Runs a program

HTTP Response

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

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



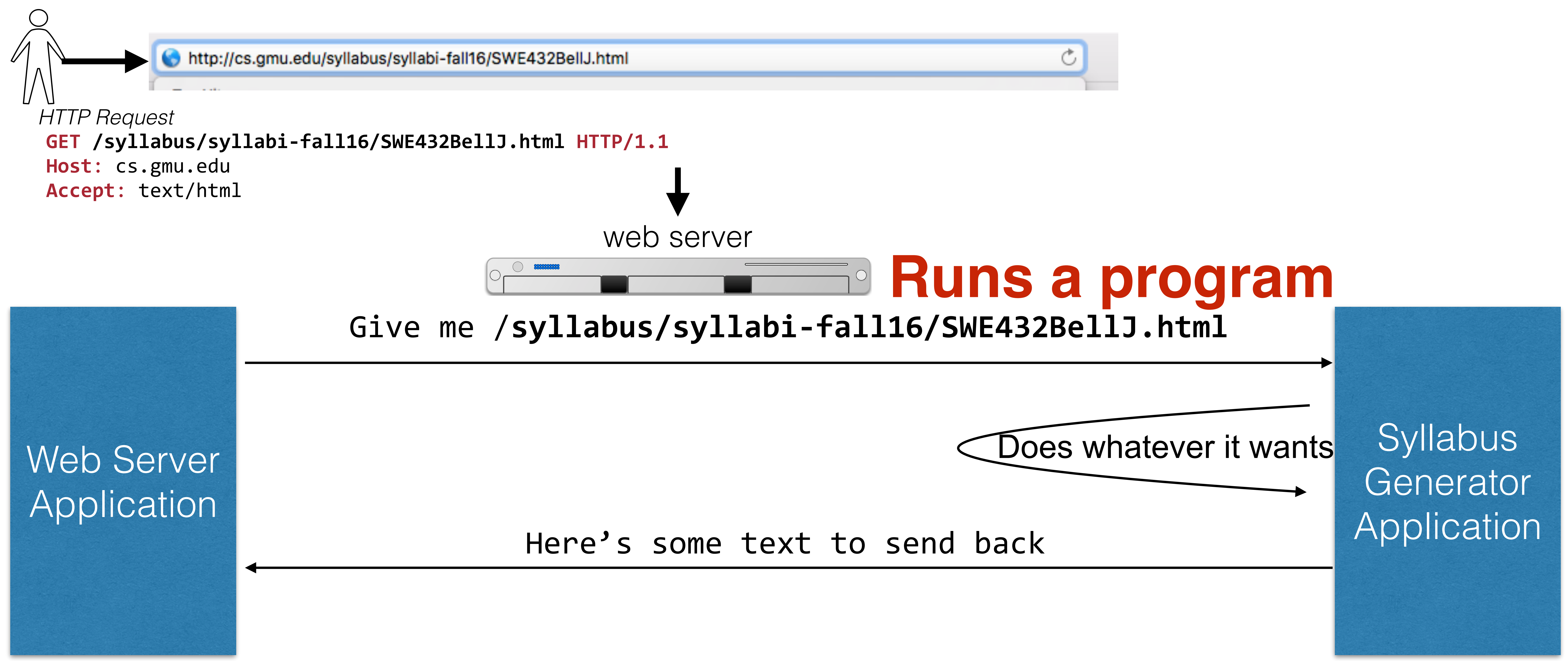
SWE 432 Section 002 Fall 2016 Syllabus and Schedule

"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

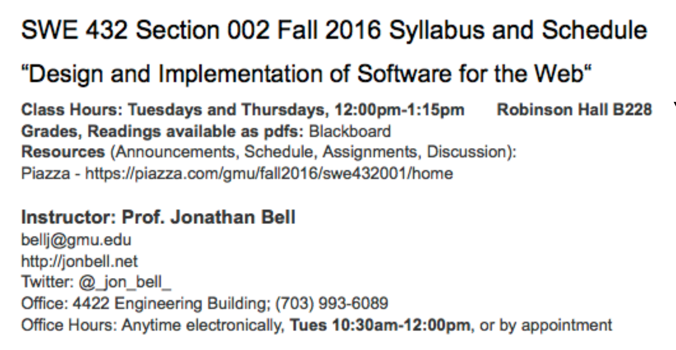

http://cs.gmu.edu/syllabus/syllabi-fall16/SWE432BellJ.html
HTTP Request
web server
Runs a program
Give me /syllabus/syllabi-fall16/SWE432BellJ.html
Web Server Application
Does whatever it wants
Syllabus Generator Application
Here’s some text to send back

```
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>...
```



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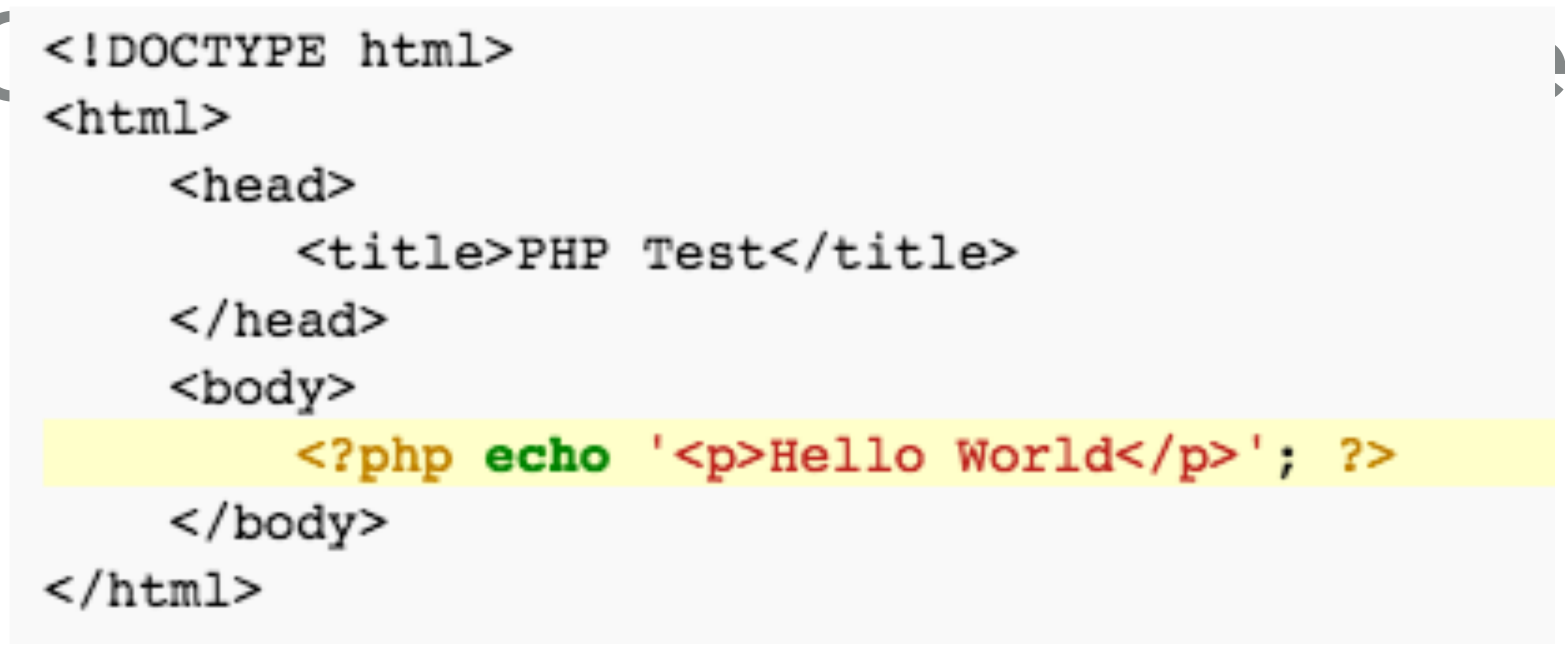
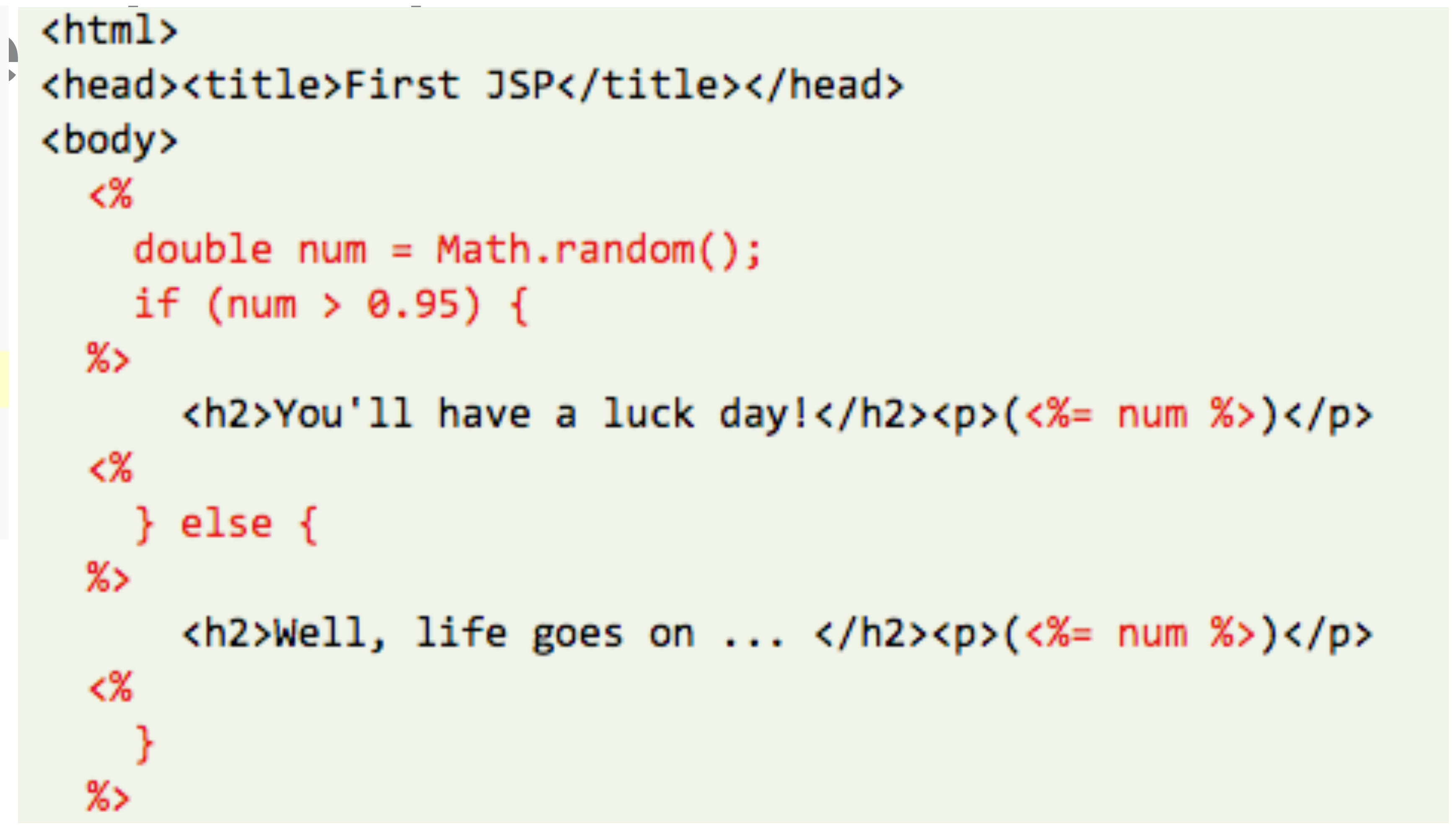
There’s a standard mechanism to talk to these auxiliary applications, called CGI (Common Gateway Interface)

SERVER SIDE SCRIPTING



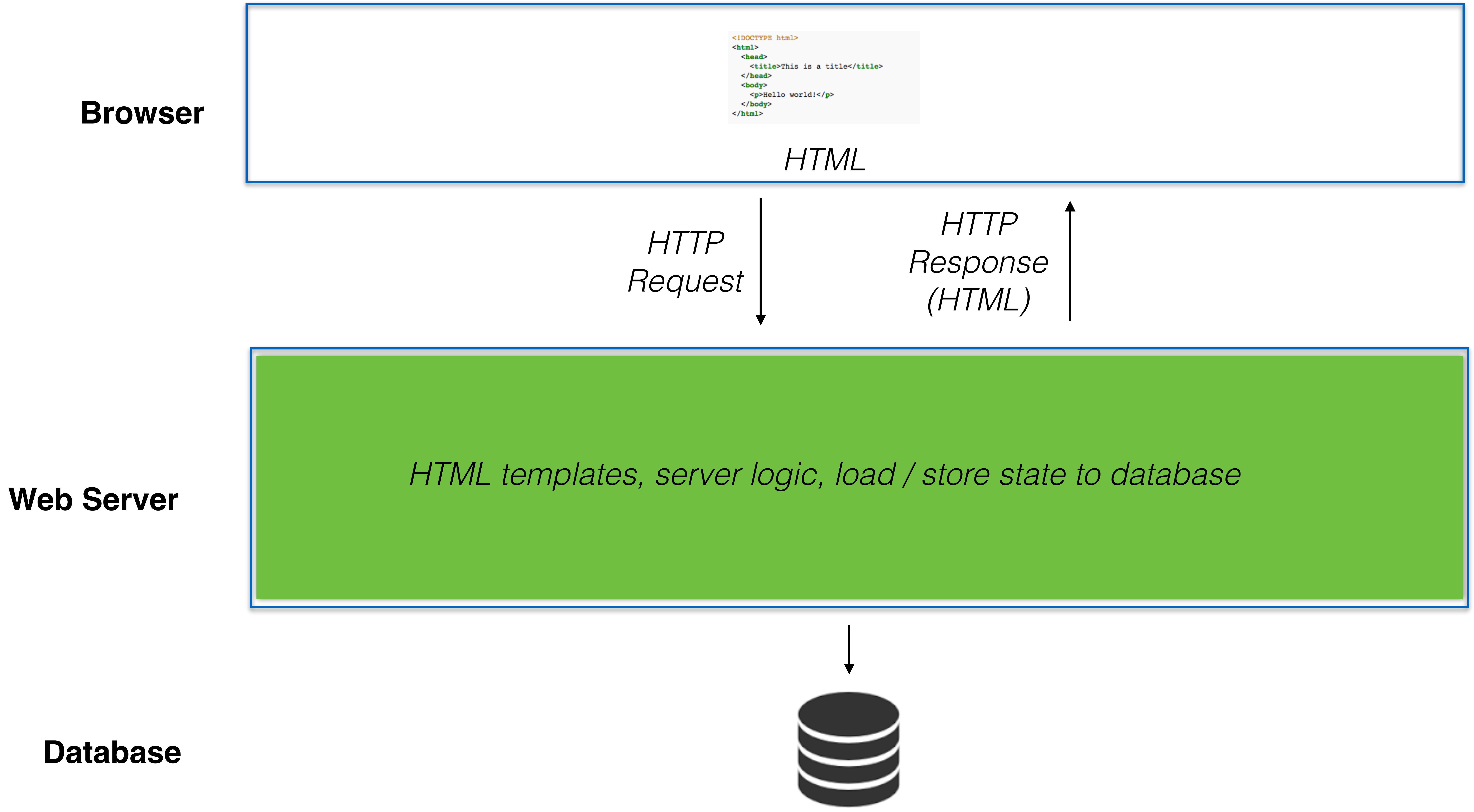
```
<!DOCTYPE html>
<html>
    <head>
        <title>PHP Test</title>
    </head>
    <body>
        <?php echo '<p>Hello World</p>'; ?>
    </body>
</html>
```



```
<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



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

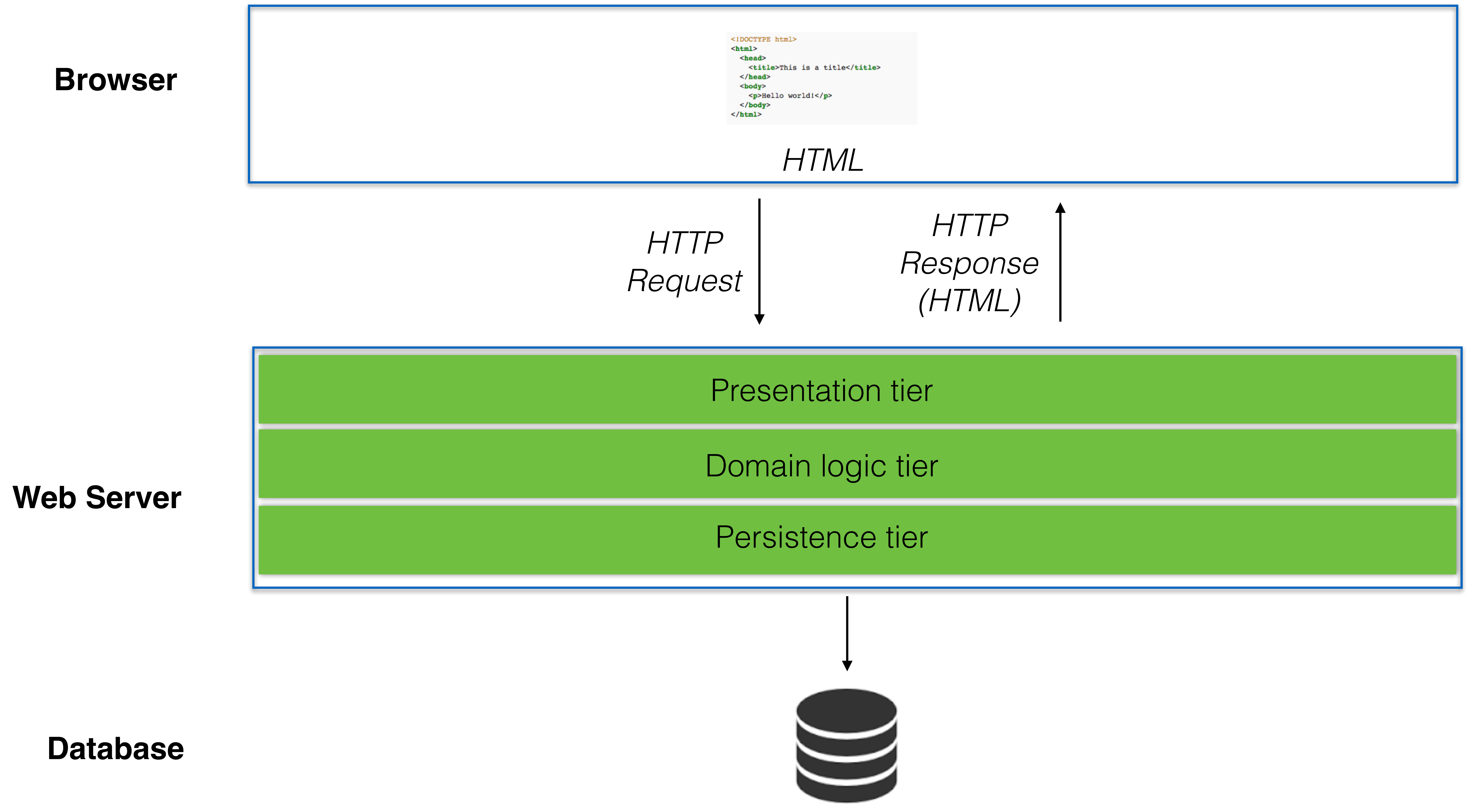
LIMITATIONS

- 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

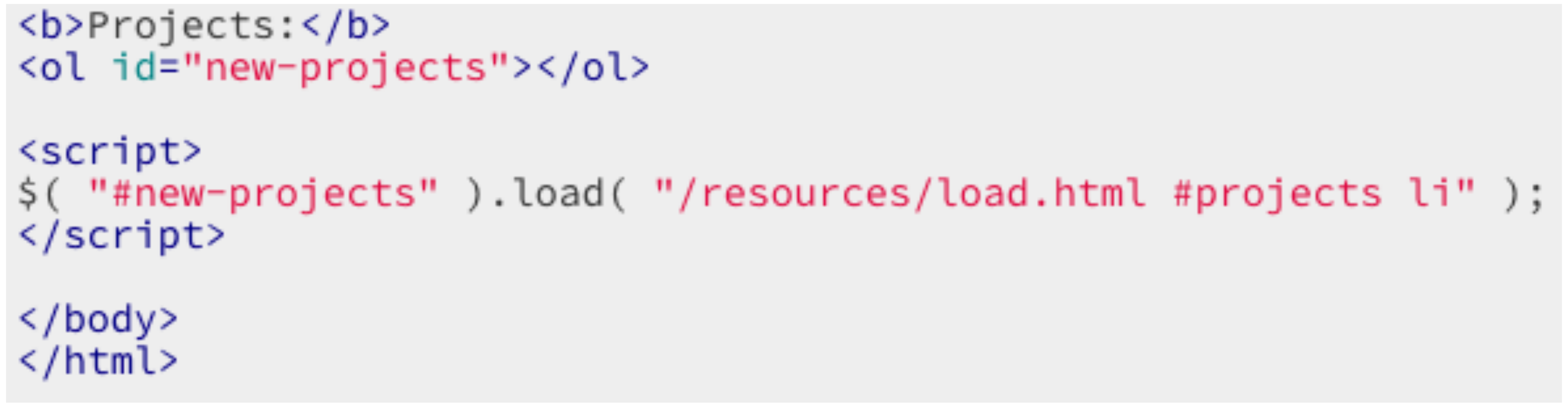

```
<!DOCTYPE html>
<html>
  <head>
    <title>This is a title</title>
  </head>
  <body>
    <p>Hello world!</p>
  </body>
</html>
```

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



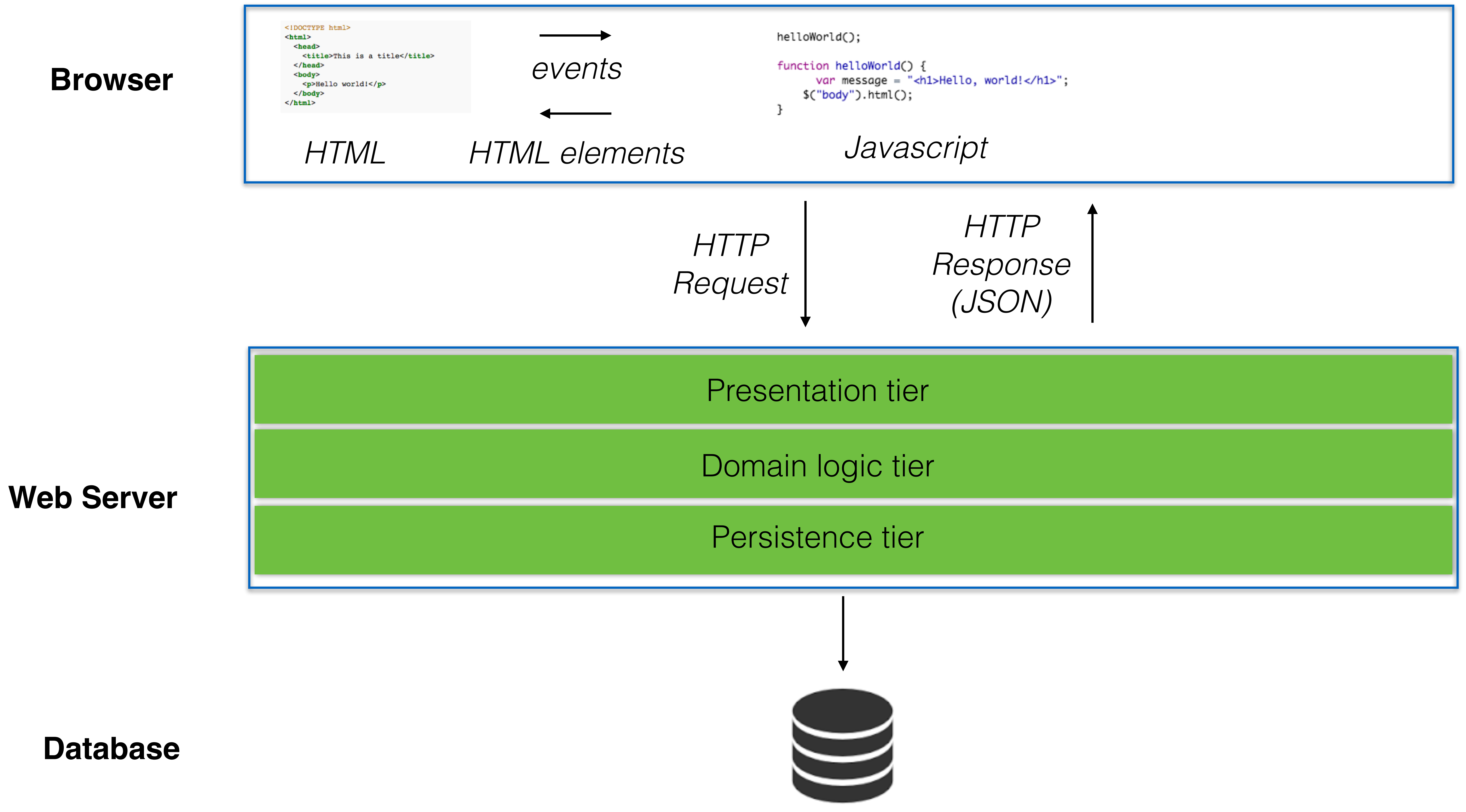
```
<b>Projects:</b>
<ol id="new-projects"></ol>

<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



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

```javascript
helloWorld();

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

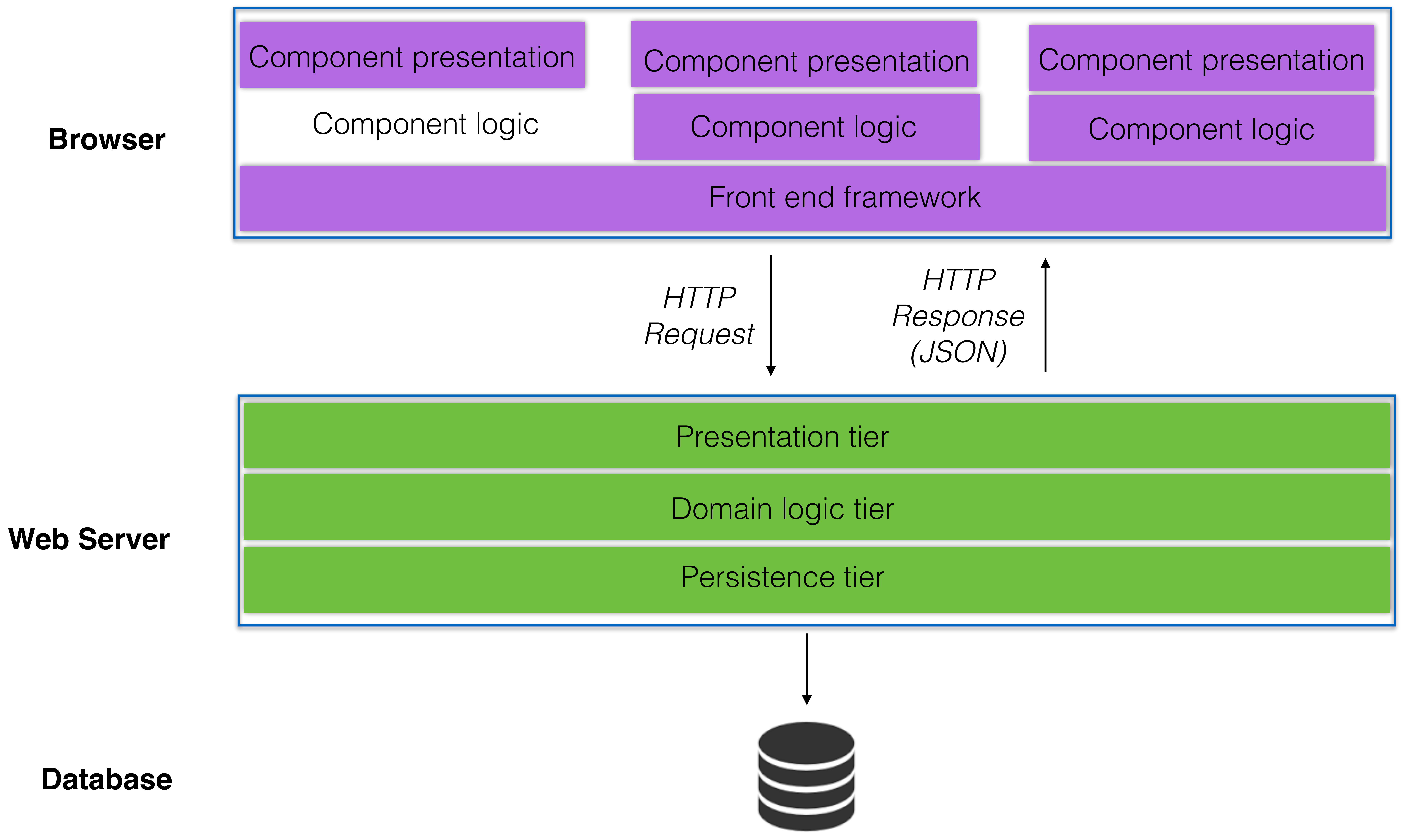
LIMITATIONS

- 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



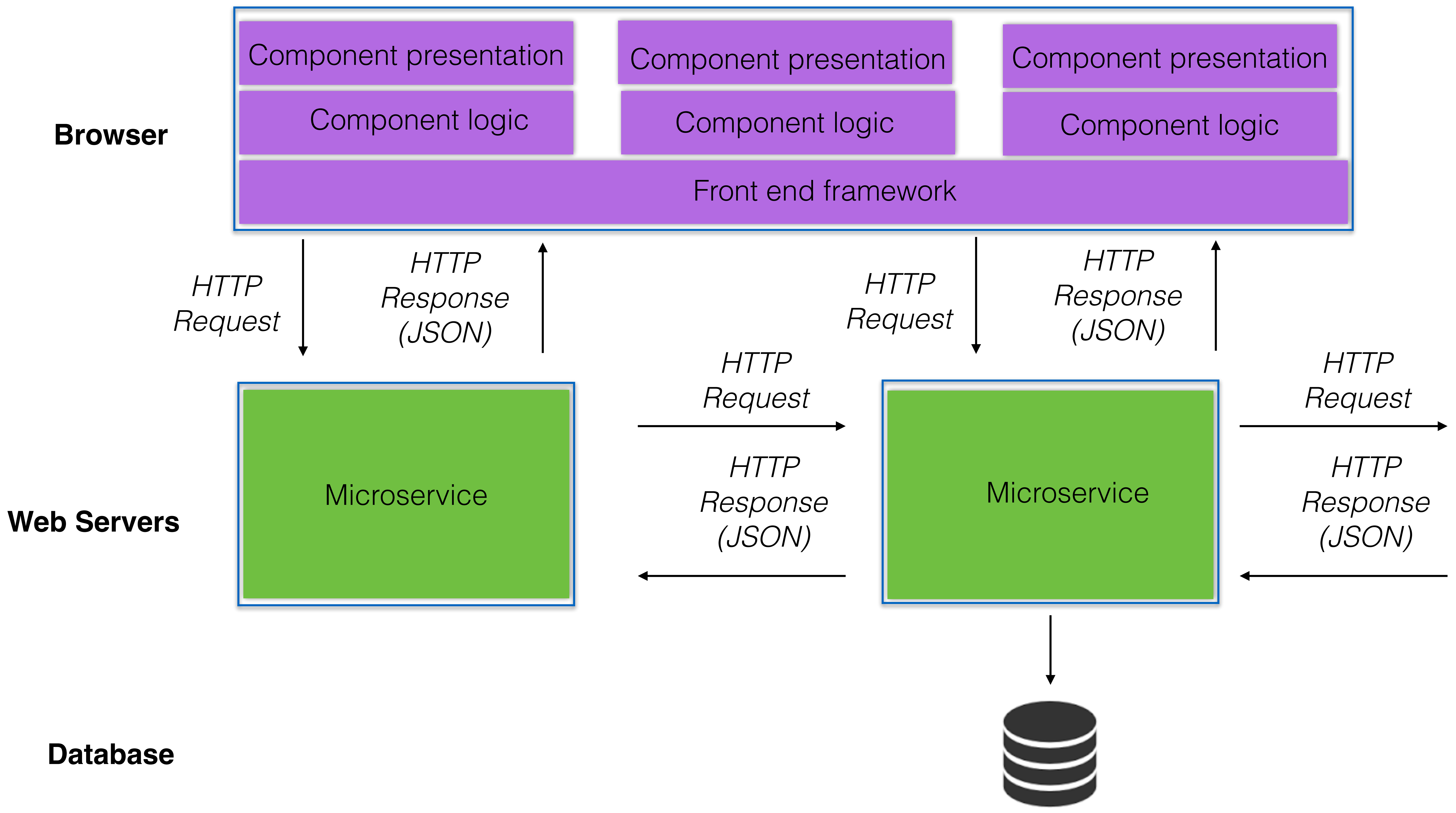
LIMITATIONS

- 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



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

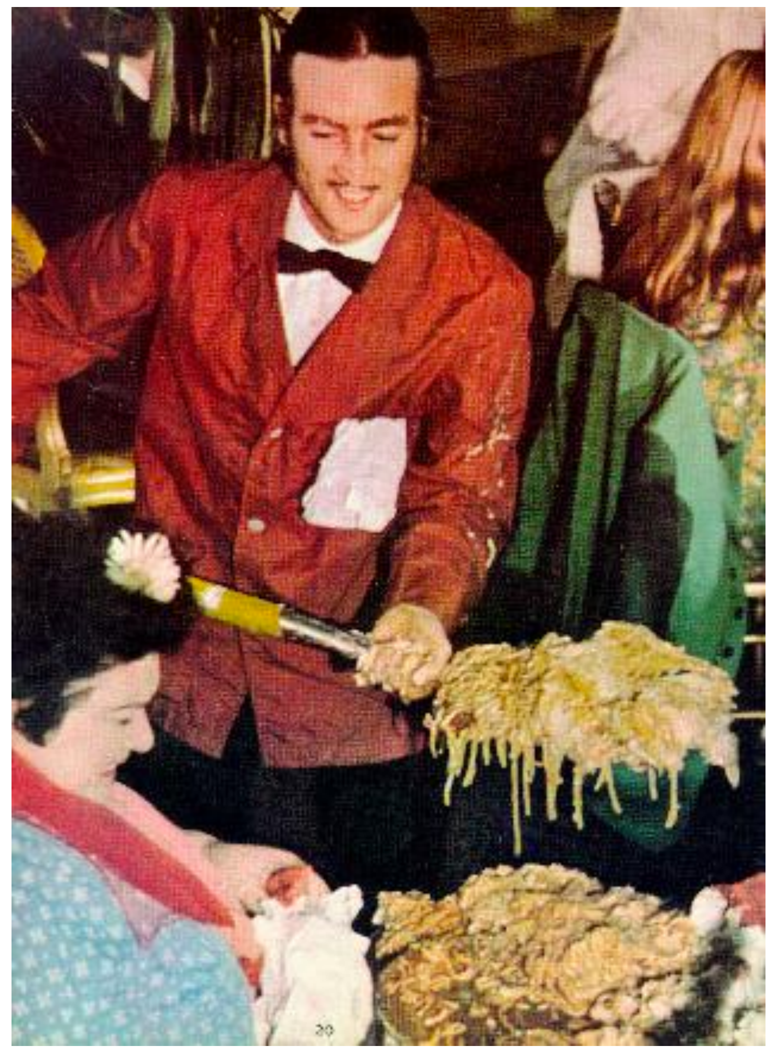
- Can also be characterized by one or more architectural decisions
  - e.g., elements in component A can send messages to elements in component B but not vice versa (i.e., layers)
- Making this decision(s) immediately has one or more consequences on architectural requirements
- Often binary
  - Either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

- 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

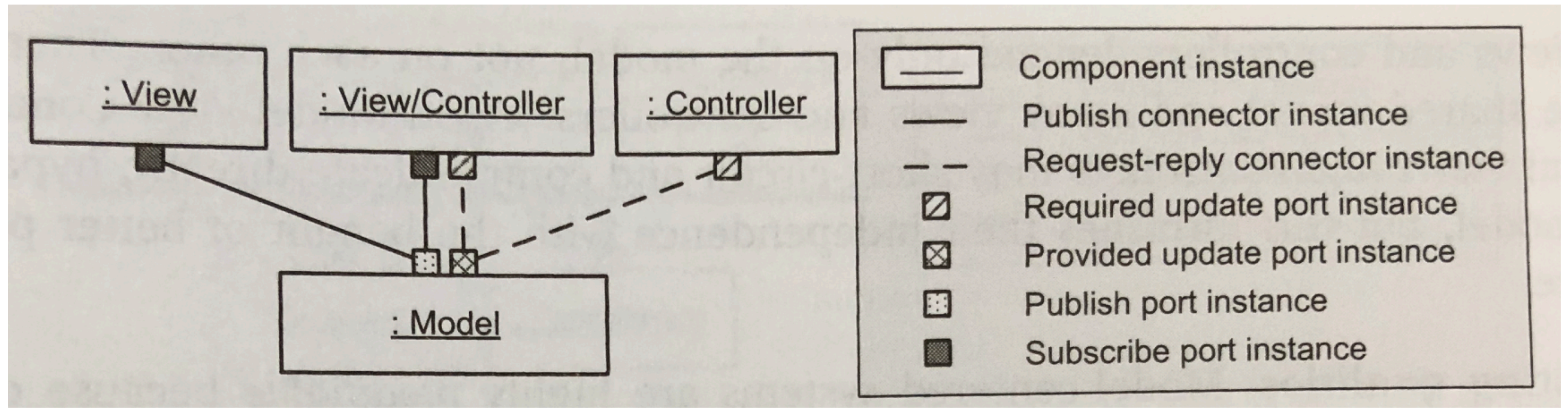

http://www.laputan.org/mud/

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

LAYERED ARCHITECTURE

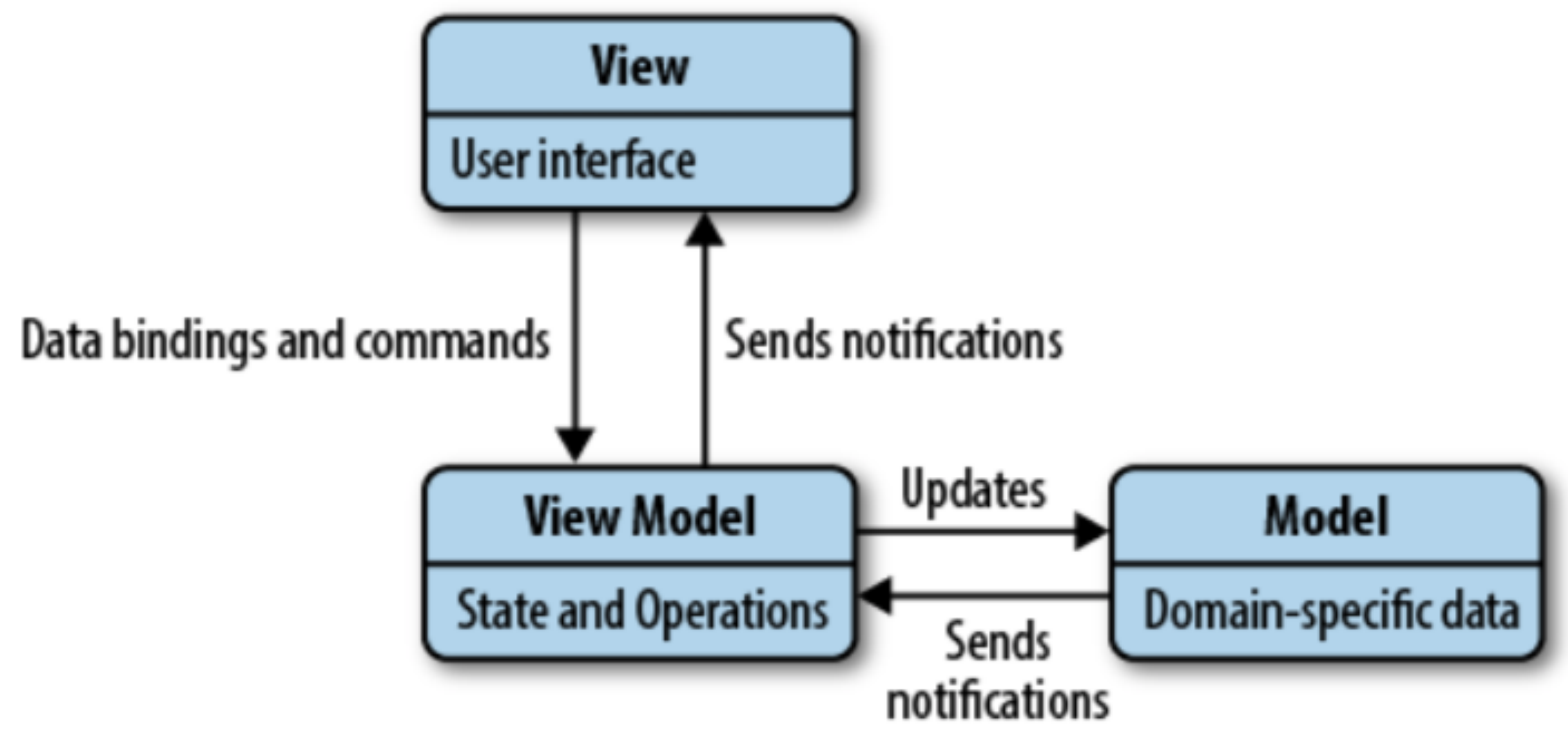
- Elements: layers
- Constraints: can only use lower layers
  - Strictly layered: can only use adjacent lower layer
- Consequences
  - Supports maintainability by making it easier to find functionality
  - Supports portability and reusability by enabling layers to be swapped out

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

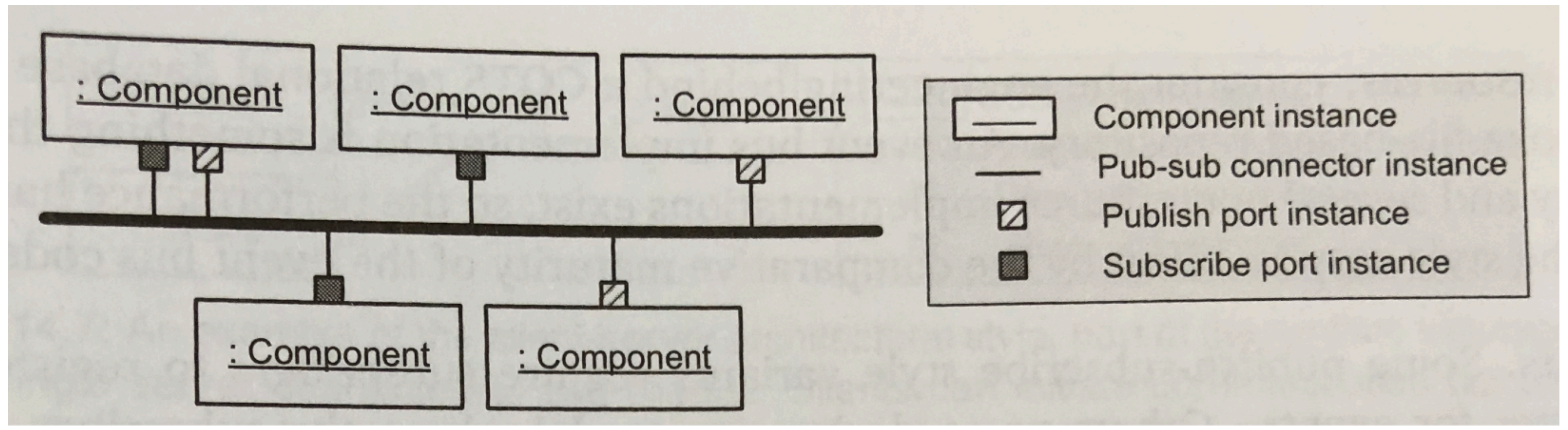
- Elements: model, view (optional), controller (optional), view-controller (optional)
- Constraints
  - Components interact with a central model rather than each other
  - Changes originates outside of model, propagate to model, trigger notifications to elements depending on model
- Synonyms: repository, 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

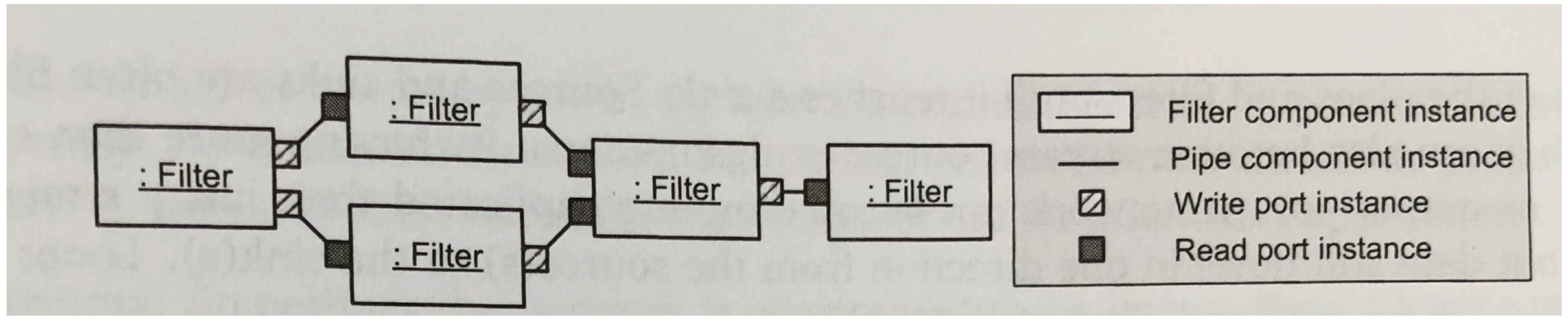


- Elements: component, event bus
    - Components broadcast events to listeners on event bus
- Constraints
    - Components do not know why an event is published
    - Subscribing components do not know **who** published event, depending on event type rather than specific publisher
- Synonyms: event-based, 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: ARCHITECTURAL STYLE OF A FRAMEWORK

- In groups of 2 or 3, describe the architectural style of a framework (NOT React).
- You should clearly describe (1) the key elements which exist, (2) the constraints on these elements, and (3) the consequences of these constraints.
- Illustrate the architectural style by describing how you'd build a simple TODO application using the architectural style. In particular, you should describe the architecture of the TODO application using a component and connector diagram and then use text to describe how it follows and respects the architectural style.
- Deliverables:
    - Name of a framework and a clear description of its architectural style
    - Component and connector diagram illustrating how to architect a TODO application, following the architectural style of the framework
    - Text explaining how the TODO application follows the architectural style.

DESIGN ACTIVITY: STEP 2: DISCUSSION

- Combine groups, forming groups of 4-6
- Compare and contrast designs based on each architectural style
- (no deliverable)