Front-end building blocks: JavaScript and D3

CS424: Visualization & Visual Analytics

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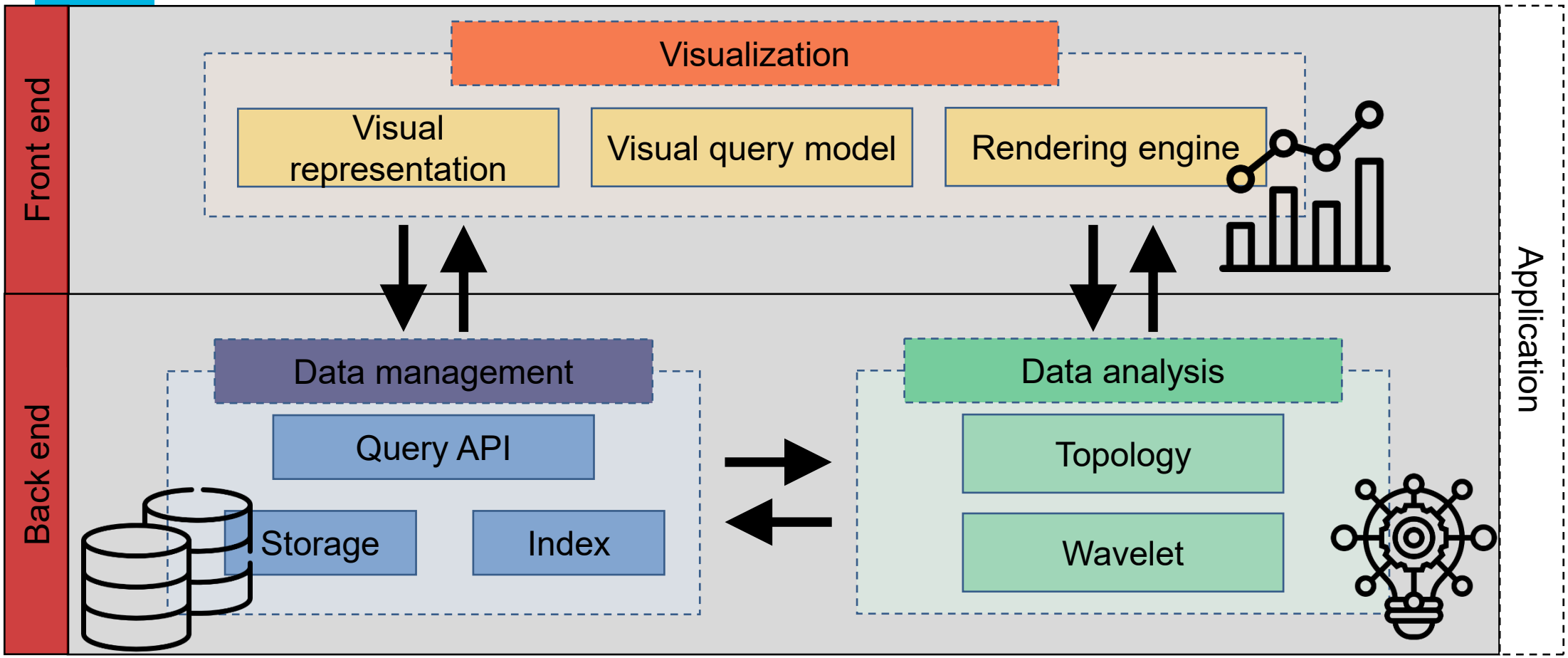
Visualization systems



Visualization systems

- Why separate front-end and back-end development?
  - Separation of concerns between presentation layer (front end) and data layer (back end).
  - Easily mapped to a client-server model.
    - Client: front end
    - Server: back end
  - Easy deployment.

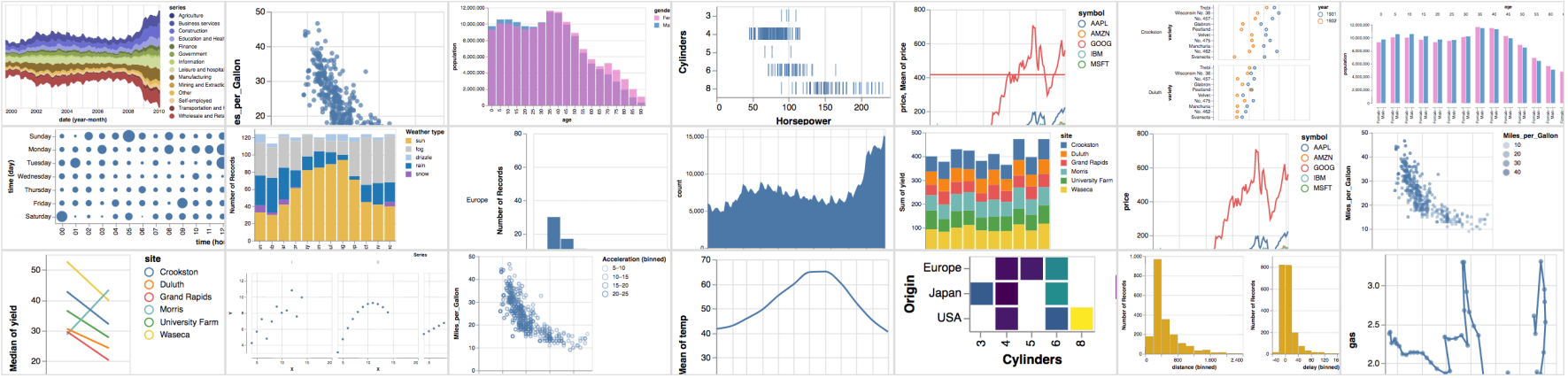
Building blocks: front-end technologies

- Web technologies
- Web environment
- JavaScript
- D3
- TypeScript
- Angular

Spectrum of visualization tools

Easy to learn — Tableau — Vega-Lite — Vega — D3 — JavaScript — Difficult to learn

More templated ⟷ More flexible



Spectrum of visualization tools

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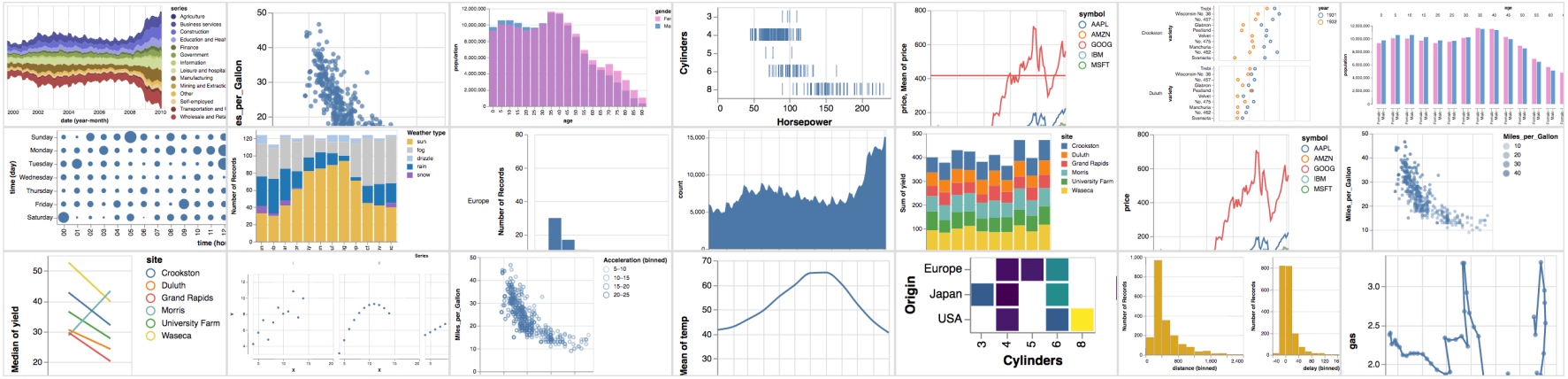
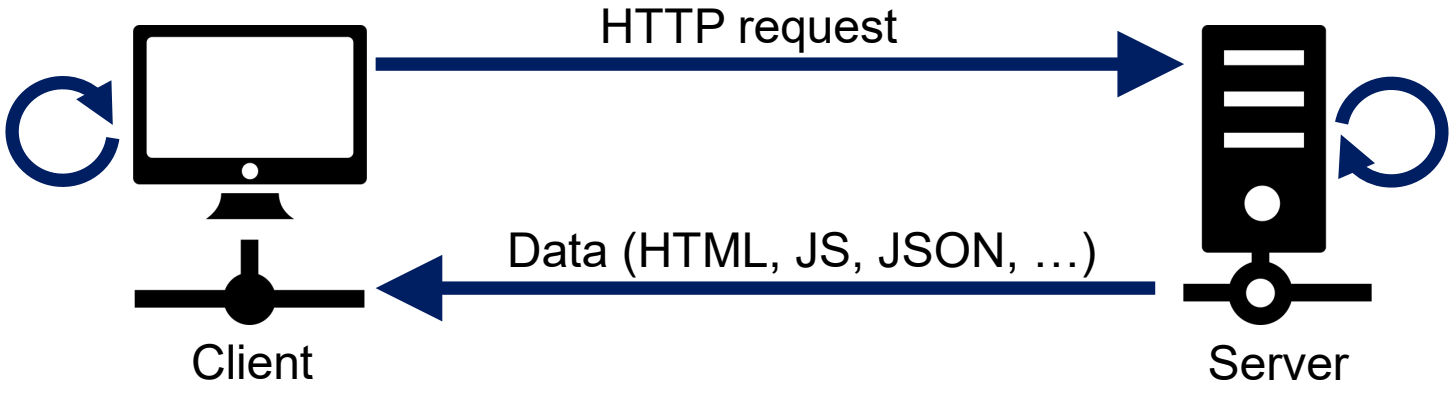


Client and server

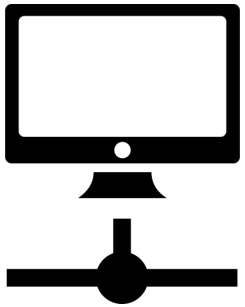
Client-side:
- Rendering
- Interaction
- Light-weight aggregation
- Filtering



Server-side:
- Database query
- Feature extraction
- Data mining

Client and server

Application



HTTP request

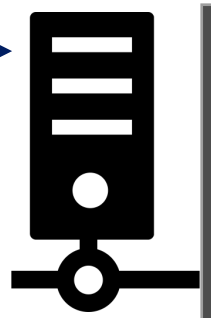
Data

HTML, JS, CSS files

Geometry files

Tiles

Features



HTTP Server

Serve HTML, JS, CSS files

Serve geometries

Compute tiles

Extract features

Simple server

```
user@DESKTOP MINGW64 ~/example
$ python -m http.server
Serving HTTP on 0.0.0.0 port 8000 (http://0.0.0.0:8000/) ...
```

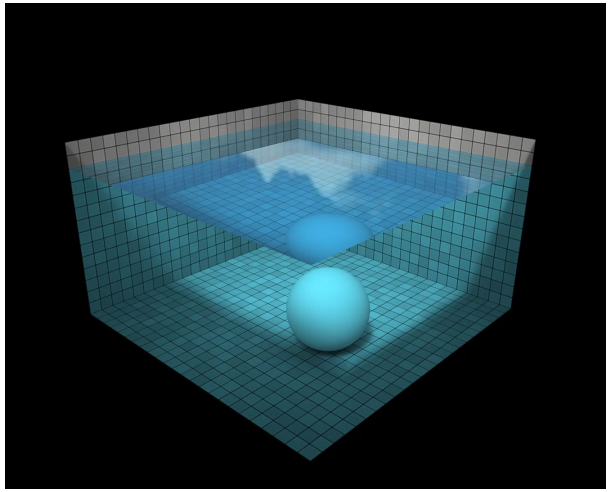
Detailed steps: https://mzl.la/3bSLff0

JavaScript: a client-side programming language

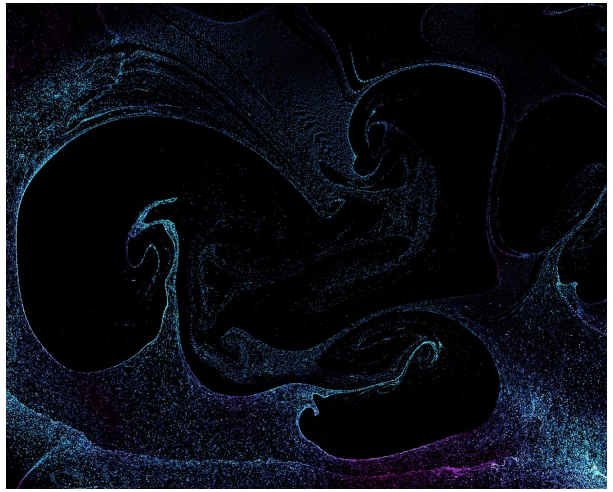
- Interpreted object-oriented language.
- Loosely typed language.
  - Does not require a variable type to be specified.
- Add, delete, and modify nodes from the document tree.
- Integration with other frameworks and toolkits:
  - Qt
  - Swift

JavaScript: a client-side programming language

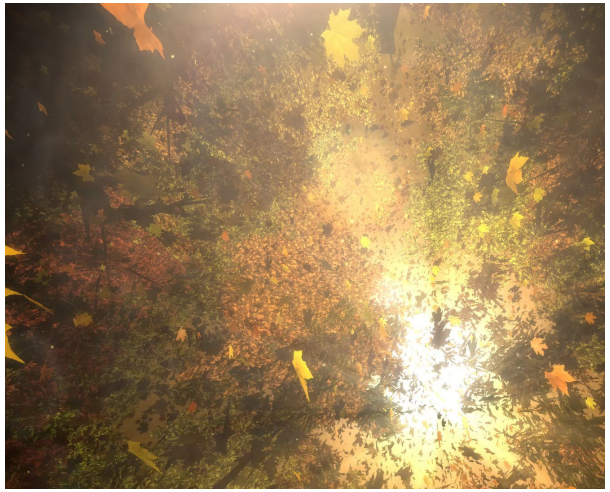
- Is JavaScript slow?
  - JavaScript engines in browsers are getting much faster.
  - Not an issue for graphics, since we transfer the data to the GPU with WebGL.



http://madebyevan.com/webgl-water/



https://haxiomic.github.io/projects/webgl-fluid-and-particles/



http://oos.moxiecode.com/js_webgl/autumn/

JavaScript basics

- Two scopes:
  - Local
  - Global
- Variable created inside a function with ‘var’ keyword: local to function.
  - Created and destroyed every time function is called.
  - BUT: variables declared without ‘var’ keyword are always global.
- Variable created outside a function: global

JavaScript basics

- Inserting JavaScript code in a web page:
  - Inside an HTML tag script.
  - In an external file.
  - As an HTML attribute value.

```
<script type="text/javascript">
    alert("Here is an example.");
</script>
```

```
<script type="text/javascript" src="file.js"></ script>
```

Statements, comments, and variables

- Statements: separated by new line or semicolon.
- Comment:
  - Single line: // here is a comment
  - Multi line: /* here is a comment */
- Loops and iteration:
  - for, for…in, for…of, do…while, while.
- Variables:
  - Assignment operator (=) to assign values.

Variable scope

```
var message = 'Hi';

function modify1(){
    var message = 'Hello';
}

function modify2(){
    message = 'Ola';
}

modify1();
console.log(message);

modify2();
console.log(message);
```

Hi

Ola

Functions

- Different ways to define functions:
  - Named
  - Anonymous
- Function expressions cannot be used before they appear in the code.

Function declaration

Function expression

```
function namedFunction1() {
    console.log('Named function 1');
}

var myNamedFunction = function namedFunction2() {
    console.log('Named function 2');
}

var myAnonFunction = function() {
    console.log('Anonymous function');
}
```

Anonymous function

Functions

- Function declarations load before any code is executed, while function expressions load only when the interpreter reaches that line.
- Function expressions: closures, arguments to other functions

```
alert(foo());
function foo() { return 5; }
```

Function declaration: error in this case, as foo wasn't loaded yet.

```
alert(foo());
var foo = function() { return 5; }
```

Function expression: alerts 5. Declarations are loaded before any code can run.

Functions

- Functions are first-class objects:
  - Supports passing functions to other functions.
  - Returning them as values from other functions.
  - Assigning them to variables or data structures.
- Closure:
  - Function that maintains the local variables of a function, after the function has returned.

Closure example

```
function sayHi(name){
    var whatToSay = 'Hi '+name;

   return function(){
        console.log(whatToSay);
    }
}

var say = sayHi('Bob');
say();
```

A closure: a function inside a function

No matter where it is executed, closure function will always remember variables from sayHi.

Data types: numbers and strings

- Numbers: a primitive data type (32-bit float).
- String: sequence of characters.
- Booleans.

```
var aux1 = 3.0;
var aux2 = 3;
var aux3 = '3';

console.log(aux1+aux2+aux3);
console.log(aux3+aux2+aux1);
```

"63"

"333"

Objects

- In JavaScript, objects are a collection of properties with a name and a value.

```
var myObject = new Object();
console.log(myObject);

myObject.name = "My Object";
console.log(myObject);
```

Object { }

Object { name: "My Object" }

Arrays

- List-like objects.

```
var cities = ['NYC', 'Chicago'];

console.log(cities[0]);
console.log(cities[cities.length-1]);

cities.forEach(function(item, index)) {
    console.log(item, index);
}
```

NYC

Chicago

NYC 0
Chicago 1

Arrays

- List-like objects.

```
cities.push('LA'); // in place
console.log(cities);

cities.pop(); // in place
console.log(cities);

var pos = cities.indexOf('Chicago');
console.log(pos);

cities.splice(pos, 1);
console.log(cities);
```

["NYC", "Chicago", "LA"]

["NYC", "Chicago"]

1

["NYC"]

Example: map

```
var a = [1, 2, 3];

for(var i=0; i<a.length; i++){
    a[i] = a[i] * 2;
}

for(var i=0; i<a.length; i++){
    console.log(a[i]);
}
```

```
var a = [1, 2, 3];

function map(f, a){
    for(var i=0; i<a.length; i++){
        a[i] = f(a[i]);
    }
}

map(function(x){return x * 2;}, a);
map(alert, a);
```

Example: reduce

```javascript
var nums = [1, 2, 3, 4];

function sum(a){
    var sum = 0;
    for(var i=0; i<a.length; i++)
        sum += a[i];
    return sum;
}

function mult(a){
    var mult=1;
    for(var i=0; i<a.length; i++)
        mult *= a[i];
    return mult;
}

console.log(sum(nums));
console.log(mult(nums));
```

```javascript
var nums = [1, 2, 3, 4];

function reduce(f, a, init){
    var s = init;
    for(var i=0; i<a.length; i++)
        s = f(s, a[i]);
    return s;
}

function add(a, b){
    return a+b;
}
function mult(a, b){
    return a*b;
}

console.log(reduce(add, nums, 0));
console.log(reduce(mult, nums, 1));
```

Manipulating documents

- So far: HTML, CSS, JavaScript.
- But how can we use JavaScript to modify nodes from DOM?
- Answer: **document object**.
- When an HTML document is loaded by a browser, it becomes a **document object**, containing the root node of the HTML document.

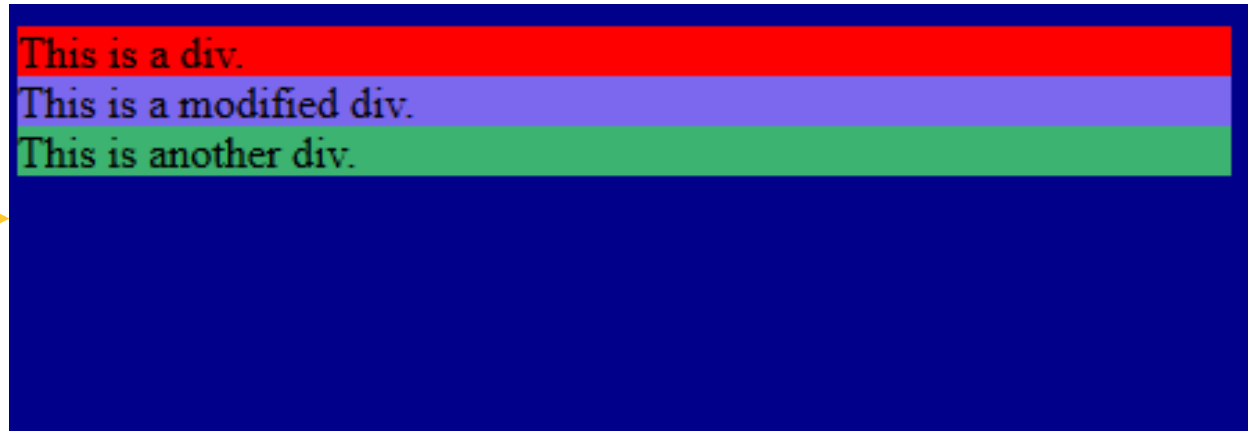
Document object

```
» document
← ▼ HTMLDocument https://www.google.com/
    URL: "https://www.google.com/"
  ▶ __wizdispatcher: Object { La: trigger(c) ↱≡ , Fa: {…}, Aa: false, … }
  ▶ __wizmanager: Object { w0: false, JN: (1) […], Ha: 10, … }
  ▶ activeElement: <body id="gsr" class="hp vasq big" jsmodel="TvHxbe" jsaction="VM8bg:.CLIENT;hWT9Jb:.CL…:.CLIENT;kWlxhc:.CLIENT"> ⊡
    alinkColor: ""
  ▶ all: HTMLAllCollection { 0: html ⊡ , 1: head ⊡ , 2: meta ⊡ , … }
  ▶ anchors: HTMLCollection { length: 0 }
  ▶ applets: HTMLCollection { length: 0 }
    baseURI: "https://www.google.com/"
    bgColor: ""
  ▶ body: <body id="gsr" class="hp vasq big" jsmodel="TvHxbe" jsaction="VM8bg:.CLIENT;hWT9Jb:.CL…:.CLIENT;kWlxhc:.CLIENT"> ⊡
    characterSet: "UTF-8"
    charset: "UTF-8"
    childElementCount: 1
```

DOM elements using selectors

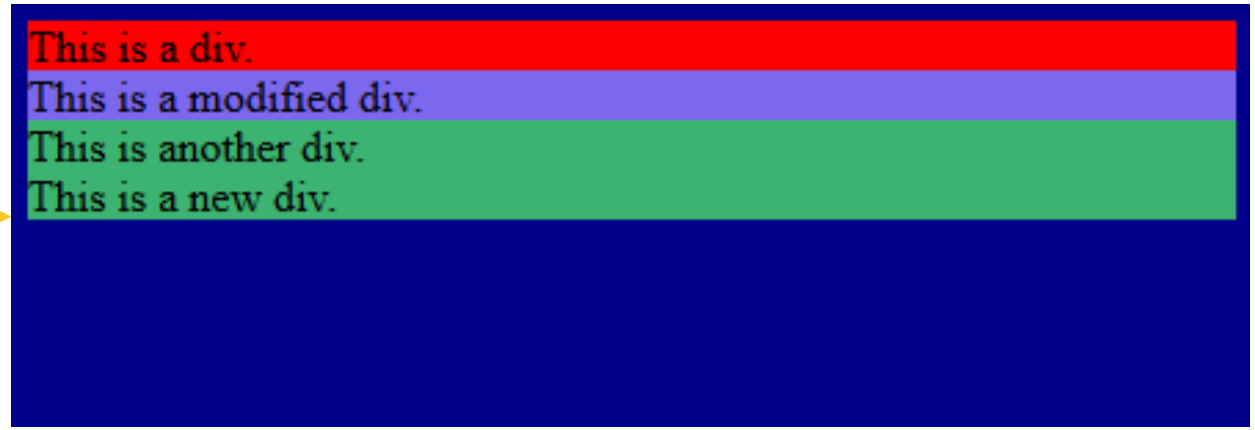
```
var allDivs = document.querySelector('div');
var myDiv = document.querySelector('#mydiv');
var mySecondDiv = document.querySelector('#myseconddiv');
var myClass = document.querySelector('.myclass');
```

```
mySecondDiv.textContent = 'This is a modified div.';
```



DOM elements using selectors

```
var newDiv = document.createElement('div');
newDiv.textContent = 'This is a new div.';
newDiv.className = 'myclass';
document.querySelector('body').appendChild(newDiv);
```



Event handlers

- Events are actions like being clicked, pressed keys, getting focus, etc.
- Different ways to specify handlers for a particular event:

```
<button onclick="handleClick()">
```

```
document.querySelector("button").onclick = function(event) {}
```

Debugging JavaScript

Inspector | Console | Debugger | Style Editor | Performance | Memory | Network | Storage | Accessibility | Application

Sources | Outline

- Main Thread
  - localhost:8000
    - example.html
  - resource://gre

example.html

```
1  <html lang="en">
2  <style>
3      body { background-color: darkblue;}
4      #glcanvas { width: 100px; height: 100px;}
5  </style>
6  <script type="text/javascript">
7      function main() {
8          var canvas = document.querySelector('#glcanvas');
9          var gl = canvas.getContext('webgl');
10         gl.clearColor(0.3, 0.1, 0.7, 1.0);
11         gl.clear(gl.COLOR_BUFFER_BIT);
12     };
13     window.onload = main;
14 </script>
15 <body>
16     <canvas id="glcanvas"></canvas>
```

(1, 1)

Paused on breakpoint

Watch expressions

Breakpoints

Pause on exceptions

example.html

document.querySelector('#glcanvas… 8:21

Call stack

main example.html:8

EventHandlerNonNull

<anonymous> example.html:13

Finally drawing something

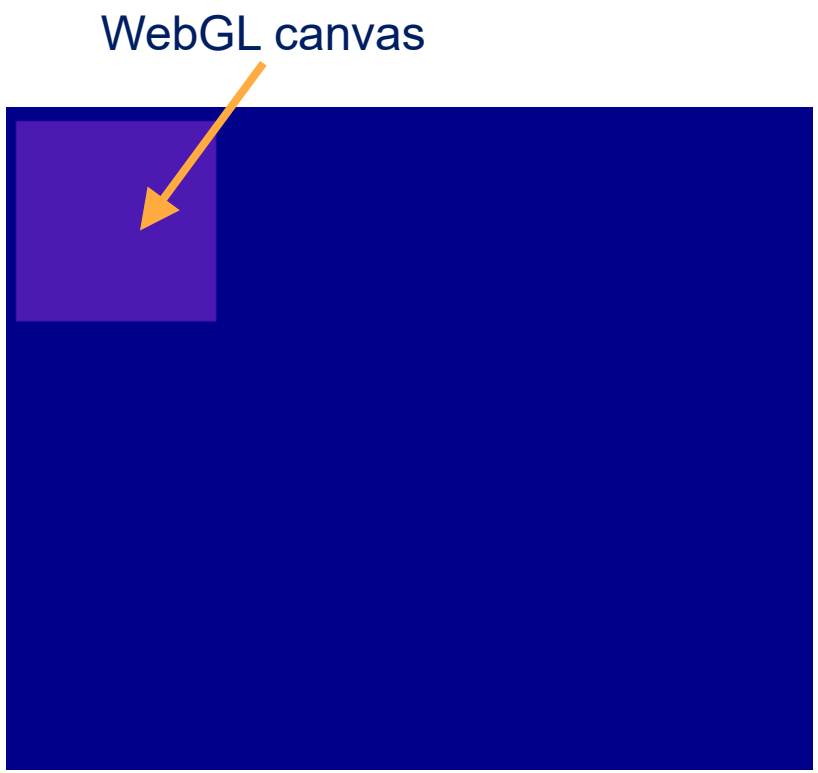
- Several ways to draw graphics on the web:
  - SVG
    - XML-based format for vector images.
    - Simple option for small data.
    - Easy event and CSS integration.
  - Canvas
    - HTML element.
    - No object-level interaction.
  - WebGL
    - Complex 3D geometries.
    - Uses rendering pipeline.
    - Hardware acceleration.

WebGL: a bird's-eye view

- API for rendering graphics within a web browser without plug-ins.
- Hardware accelerated.
- Shader based (no fixed-function API).
  - Fixed function pipeline: set of calls for matrix transformation, lighting.
  - Programmable pipeline: shaders for vertex and fragment processing.
- WebGL 2.0 based on OpenGL ES 3.0.

WebGL: a bird's-eye view

```html
<html lang="en">
<style>
    body { background-color: darkblue;}
    #glcanvas { width: 100px; height: 100px;}
</style>
<script type="text/javascript">
    function main() {
        var canvas = document.querySelector('#glcanvas');
        var gl = canvas.getContext('webgl2');
        gl.clearColor(0.3, 0.1, 0.7, 1.0);
        gl.clear(gl.COLOR_BUFFER_BIT);
    };
    window.onload = main;
</script>
<body>
    <canvas id="glcanvas"></canvas>
</body>
</html>
```



D3.js: a bird's-eye view

- Library for manipulating documents based on data.
- Facilitates DOM manipulation to visualize data.
- D3 is not:
  - a visualization library (but you can visualize data using it).
  - a map library (but you can visualize maps using it).
  - restricted to DOM manipulation (there are several others auxiliary functions).

D3.js: first steps

Creating a paragraph

```
var body = d3.select("body");
var p = body.append("p");
p.text("New paragraph!");
```

Creating a paragraph with D3.js

```
d3.select("body")
  .append("p")
  .text("New paragraph!");
```

D3.js: selecting elements

D3 object

Selection: d3.select() and d3.select() accept a CSS selector and return elements

```
d3.select("body")
  .append("p")
  .text("New paragraph!");
```

Text between tags

Append: insert elements in the DOM at the current selection

D3.js: setting attributes

Set attributes, accept anonymous functions

```
circles
  .attr('cx', d => d.cx)
  .attr('cy', d => d.cy)
  .attr('r' , d => d.r)
  .style('fill', 'SeaGreen');
```

Set CSS styles

D3.js: binding data

- Given a selection in D3, one can bind data to it using `.data()`
- This will create a mapping between *each* element in the selection and *each* data element.
  - Default is sequential, i.e, element `i` is mapped to data at index `i`.
- Once bound, one can use data to define attributes:

```
circles
  .attr('r', function(d,i) {
     return d * 100;
  });
```

D3.js: virtual selections

- D3 data operator returns three virtual selections: `enter`, `update`, and `exit`.
- Enter selection: placeholder for missing elements.
- Update selection: update existing elements, bound to data.
- Exit selection: remove remaining elements.

D3.js: virtual selections

```
var data = [5,10,15,20,15]

var ps = d3.select('body')
  .selectAll('p')
  .data(data);
  .enter()
```

Add placeholder elements for each data element without DOM element correspondent

D3.js: virtual selections

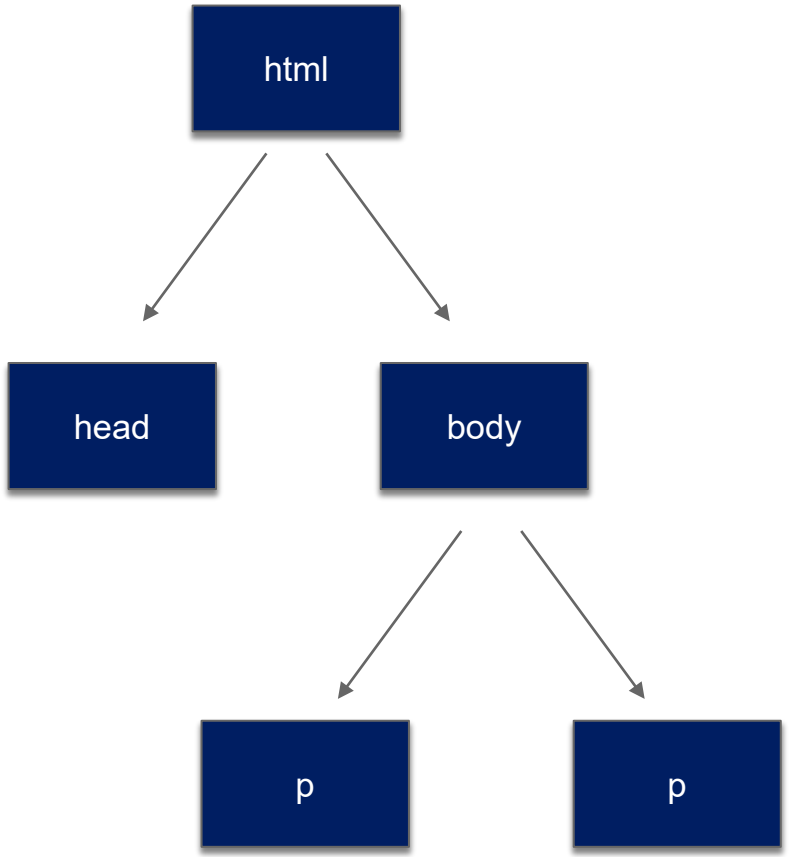
```
var data = [5,10,15,20,15]

var ps = d3.select('body')
  .selectAll('p')
  .data(data);

ps.text('New paragraph');
```

If no previous <p> element inside <body> then this is an **empty** selection

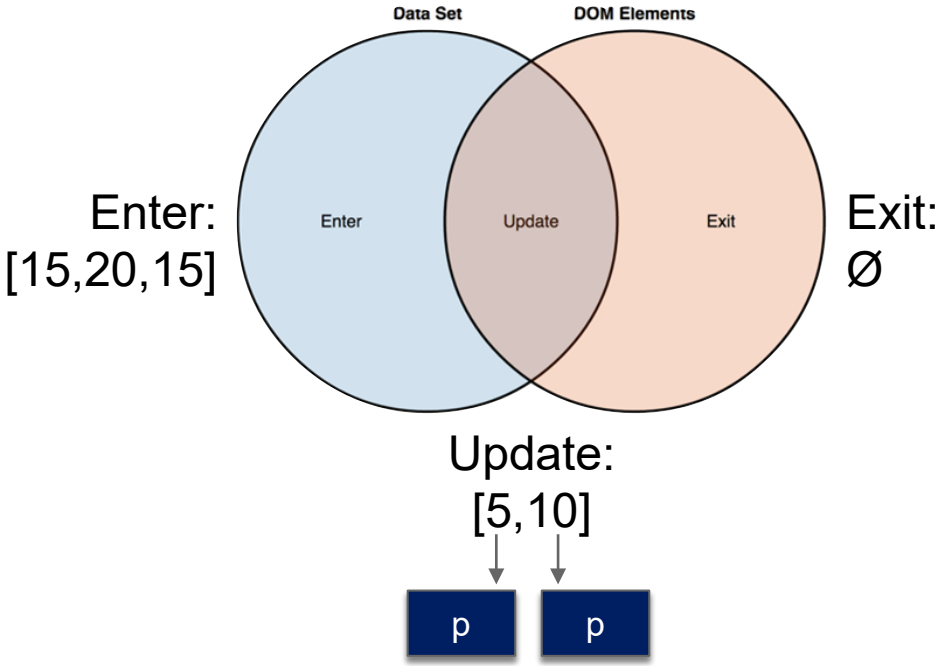
```
var data = [5,10,15,20,15]

var ps = d3.select('body')
  .selectAll('p')
  .data(data);

ps.enter()
  .append('p')
  .text('New paragraph');
```

Creating placeholder elements

D3.js: virtual selections




```
var data = [5,10,15,20,15]
var ps = d3.select('body')
  .selectAll('p')
  .data(data);
```



D3.js: virtual selections

```
var data = [5,10,15,20,15]
var ps = d3.select('body').selectAll('p').data(data);

// enter
ps.enter().append('p')
.text( function(d){ return d; } );

// exit
ps.exit().remove();

// update
ps.text( function(d){ return d; } );
```

Data access