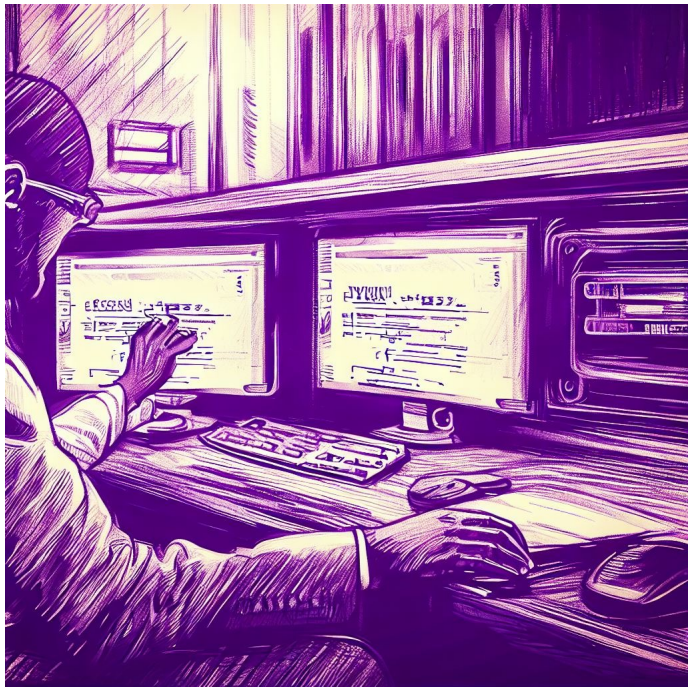

CSE 331

Intro to the Browser

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Credits: Profs. Kevin Zatloukal and James Wilcox

Class slogans

"Engineers are paid to think and understand."

— Class slogan #1

"Reasoning is not optional: either reason up front or debug and then reason."

— Class slogan #2

"Programmers overestimate the importance of efficiency and underestimate the difficulty of correctness."

— Class slogan #3

Learning a New Language

- We're going to learn JavaScript and TypeScript

- The second language can be the hardest to learn!
  - some things you took for granted no longer hold
  - must slow down think about think about every step

- We *want* to move slowly and deliberately
  - understand exactly what the type system does and does not do

    "Engineers are paid to **think** and **understand**"

  - comparison with Java will be useful

Programming for the Browser

- Will give an overview of JavaScript (JS) & TypeScript (TS)
- Both languages can be run in different environments
  - command line (like Java)
  - inside the browser
- Primarily interesting because of the browser
  - neither language would be used much otherwise
  - command line provided so you can use one language for both
- In both environments, print output with `console.log(..)`
  - prints to command line or “Developer Console” in the browser

Programming for the Browser

- JavaScript is the lingua franca of web browsers

- Previously, other languages were tried in the browser
  - Java was used but is no longer supported
  - Flash was used but is no longer supported
  - Google's "dart" language is still around (probably)

- Now, other languages used by compiling into JavaScript
  - TypeScript used this way
  - Java can be compiled to JS (but it's not great)

    you can't really get around needing to learn JS

Learning a New Language

- No rush to learn the whole language
  - we will start with a small subset of its features
  - we won't use all the language this quarter
  - have all quarter to get more familiar with JS and TS

- The second language can be the hardest to learn!
  - some things you took for granted no longer hold
  - must slow down think about think about every step

- We *want* to move slowly and deliberately
  - understand exactly what the type system does and does not do

    "Engineers are paid to **think** and **understand**"

  - comparison with Java will be useful

JavaScript

History of JavaScript

- Incredibly simple language
  - created in 10 days by Brendan Eich in 1995
  - often difficult to use because it is so simple

- Features added later to fix problem areas
  - imports (ES6)
  - classes (ES6)
  - integers (ES2020)

Relationship to Java

- Initially had no relation to Java
  - picked the name because Java was popular then
  - added Java's Math library to JS also

    e.g., `Math.sqrt` is available in JS, just like Java
  - copied *some* of Java's String functions to JS string

    e.g., `s.charCodeAt(3)` is available in JS, just like Java

- Both are in the "C family" of languages
  - much of the syntax is the same
  - more differences in data types

- We will discuss syntax (code) first and then data…

JavaScript Syntax

- Both are in the “C family” of languages

- Much of the syntax is the same
  - most expressions (`+`, `–`, `*`, `/`, `?:`, function calls, etc.)
  - control flow (`if`, `for`, `while`, `break`, `continue`, `return`)
  - comments with `//` or `/* .. */`

- Different syntax for a few things
  - declaring variables
  - declaring functions
  - equality (`===`)

Java vs JavaScript Syntax

- **The following code is legal in <u>both</u> languages:**
  - **assume "`s`" and "`j`" are already declared**

```
s = 0;
j = 0;
while (j < 10) {
  s += j;
  j++;
}

// Now s == 45
```

Differences from Java: Type Declarations

- JavaScript variables have no declared types
  - this is a problem… we will get them back in TypeScript

- Declare variables in one of these ways:

```
const x = 1;
let y = "foo";
```

  - "`const`" cannot be changed; "`let`" can be changed
  - use "`const`" whenever possible!

- Also affects function argument declarations
  - more on this later…

Differences from Java: "===" operator

- **JavaScript's "==" is problematic**
  - **tries to convert objects to the same type**

    e.g., `3 == "3"` and even `0 == ""` are… true?!?

- **We will use "===" (and "!==") instead:**
  - **no type conversion will be performed**

    e.g., `3 === "3"` is false

- **Mostly same as Java**
  - **compares *values* on primitives, *references* on objects**
  - **but strings are primitive in JS (no `.equals` needed)**

    == on strings common source of bugs in Java

Basic Data Types of JavaScript

- **JavaScript includes the following runtime types**

`number`	
`bigint`	
`string`	
`boolean`	
`null`	
`undefined`	(another null)
`Object`	
`Array`	(special subtype of Object)

we won't use them until week 5/6

Numbers

`bigint`	integers
`number`	floating point (like Java `double`)

- **By default, JS uses `number` not `bigint`**
  - `0`, `1`, `2` **are numbers not integers**
  - **add an "`n`" at the end for integers (e.g., `2n`)**
- **All the usual operators: `+ - * / ++ -- +=` ...**
- **Math library largely copied from Java**
  - **e.g., `Math.sqrt` returns the square root**

Strings

- Mostly the same as Java
  - immutable
  - string concatenation with "+"

- A few improvements
  - string comparison with "===" and "<"

    no need for `s.equals(t)` ... just write `s === t`
  - use either ' . . ' or " . . " (single or double quotes)
  - new string literals that support variable substitution:

```
const name = "Fred";
console.log(`Hi, ${name}!`);  // prints "Hi, Fred!"
```

Boolean

- **All the usual operators:** `&& || !`
- **“`if`” can be used with any value**
  - **“falsey” things:** `false`, `0`, `NaN`, `""`, `null`, `undefined`
  - **“truthy” things: everything else**
- **A common source of bugs…**
  - **best to stick to boolean values**

Record Types

- JavaScript “Object” is something with “fields”
- JavaScript has special syntax for creating them

```
const p = {x: 1n, y: 2n};
console.log(p.x);  // prints 1n
```

- The term “object” is potentially confusing
  - used for many things
  - I prefer it as shorthand for “mathematical object”
- Will refer to things with fields as “records”

Record Types

- Quotes are optional around field names

```
const p = {x: 1n, y: 2n};
console.log(p.x);  // prints 1n

const q = {"x": 1n, "y": 2n};
console.log(q.x);  // also prints 1n
```

- Field names are literal strings, not expressions!

```
const x = "foo";
console.log({x: x});  // prints {"x": "foo"}
```

Checking Types at Run Time

Condition	Code
x is undefined	`x === undefined`
x is null	`x === null`
x is a number	`typeof x === "number"`
x is an integer	`typeof x === "bigint"`
x is a string	`typeof x === "string"`
x is an object or array (or null)	`typeof x === "object"`
x is an array	`Array.isArray(x)`

Hard to check if x is a specific record type at runtime.
Much easier to let the type checker do this!

We will need to check types ourselves later in the course…
when we start sending data between client and server

Functions

- **Functions are first class objects**
  - **“arrow” expressions creates functions**
  - **store these into a variable to use it later**

```
const add2 = (x, y) => x + y;
console.log(add2(1n, 2n));   // prints 3n

const add3 = (x, y, z) => {
  return x + y + z;
};
console.log(add3(1n, 2n, 3n));  // prints 6n
```

Functions

- We will declare functions like this

```
const add = (x, y) => {
  return x + y;
};

// add(2n, 3n) == 5n
```

- Functions can be passed around
  - "functional" programming language
  - but we won't do that (much) this quarter

    we will pass functions to buttons to tell them what to do when clicked

    see CSE 341 for more on that topic

Ternary Operator

- JS includes C's ternary operator ("`if`" expression):

```
console.log(x >= 0 ? x : y);  // prints x if x >= 0
                              //        y if x < 0
```

- Can be replaced with an "`if`" + function call:

```
const f = (x, y) => {
  if (x >= 0) {
    return x;
  } else {
    return y;
  }
};

console.log(f(x, y));
```

TypeScript

TypeScript Adds Declared Types

- TypeScript includes declared types for variables
- Compiler checks that the types are valid
  - extremely useful!
  - produces JS just by *removing* the types
- Critical to **understand** what the type system does
  - not enough just to make the type errors go away
  - need to understand exactly what bugs the type system catches

    you do not need to worry about those

    but you are responsible for everything else

TypeScript Adds Declared Types

- Type is declared after the variable name:

```
const u: bigint = 3n;
const v: bigint = 4n;

const add = (x: bigint, y: bigint): bigint => {
  return x + y;
};

console.log(add(u, v));  // prints 7n
```

  - return type is declared after the argument list `(...)` and before `=>`

- "Where types go" is the main syntax difference vs Java
  - other key differences are functions (`=>`) and equality (`===`)

Basic Data Types of TypeScript

- **JavaScript includes the following types**

`number`	
`bigint`	
`string`	
`boolean`	
`null`	
`undefined`	
`Object`	(record types)
`Array`	(e.g., `string[]` as in Java)

- **TypeScript has these and also…**

`unknown`	(could be anything)
`any`	(turns off type checking — do not use!)

Literal Types

- Any literal value is also a type:

```
let x: "foo" = "foo";
let y: 16n = 16n;
```

- Variable can only hold that specific value!
  - can assign it again, but only with the same value

- Seems silly, but turns out to be useful…

Ways to Create New Types in TypeScript

- **Union Types** `string | bigint`
  - can be either one of these

- **Not possible in Java!**
  - TS can describe types of code that Java cannot

- **Unknown type is (essentially) a union**

```
type unknown = number | bigint | string | boolean | ...
```

Enumerations

- Use unions of literals are “enums”

```
const dist = (dir: "left"|"right", amt: bigint): bigint => {
  if (dir === "right") {
    return amt;
  } else {
    return -amt;
  }
};
```

- TypeScript ensures that callers will only pass one of those two strings (“left” or “right”)
  - impossible to do this in Java

    (must fake it with the enumeration **design pattern**)

Ways to Create New Types in TypeScript

- Can create compound types in multiple ways
  - put multiple types together into one larger type

- **Record Types** `{x: bigint, s: string}`
  - anything with *at least* fields "x" and "s"

```
const p: {x: bigint, s: string} = {x: 1n, s: 'hi'};
console.log(p.x);  // prints 1n
```

Ways to Create New Types In TypeScript

- Can create *compound* types in multiple ways
  - put multiple types together into one larger type

- Tuple Types `[bigint, string]`
  - create them like this

```
const p: [bigint, string] = [1n, 'hi'];
```

  - give names to the parts ("destructuring") to use them

```
const [x, y] = p;
console.log(x);  // prints 1n
```

  - at runtime, this is an array of length 2 (JS has no tuples)

    but do not actually use them like arrays, e.g., no array indexing

Records vs Tuples

- Records and tuples provide the same functionality
  - both allow you to put parts together into one object
  - conceptually interchangeable

- They differ in *who* names the parts and *when*
  - **record**: creator picks the names

    everyone must use the same name
  - **tuple**: user of the tuple picks the names

    each user can pick their own names

Type Aliases

- TypeScript lets you give shorthand names for types

```
type Point = {x: bigint, y: bigint};

const p: Point = {x: 1n, y: 2n};
console.log(p.x);  // prints 1n
```

- Usually nicer but not necessary
  - e.g., this does the same thing

```
const p: {x: bigint, y: bigint} = {x: 1n, y: 2n};
console.log(x);  // prints 1n
```

Structural vs Nominal Typing

- **Deeper difference between TypeScript and Java**
  - **records aren't just a quick way to describe a class**

- **TypeScript uses "structural typing"**
  - **sometimes called "duck typing"**

    "if it walks like a duck and quacks like a duck, it's a duck"

```
type T1 = {a: bigint, b: string};
type T2 = {a: bigint, b: string};

const x: T1 = {a: 1n, b: "two"};
```

  - **can pass "`x`" to a function expecting a "`T2`"!**

Structural vs Nominal Typing

- Java uses "**nominal typing**"

```
class T1 { int a; int b; }
class T2 { int a; int b; }

T1 x = new T1();
```

  - **cannot** pass "`x`" to a function expecting a "`T2`"

- Libraries do not interoperate unless it was pre-planned
  - create "adapters" to work around this

    example of a design pattern used to work around language limitations

Type Inference

- If you leave off the type, TS will try to guess it
  - often, but not always, it guesses correctly

- This will work fine

```
const p = {x: 1n, y: 2n};
console.log(p.x);  // prints 1n
```

  - compiler should correctly guess `{x: bigint, y: bigint}`
  - can see in VSCode by hovering over "`p`"

Type Inference

- If you leave off the type, TS will try to guess it
  - often, but not always, it guesses correctly

- In 331, type declarations are required on
  - function arguments and return values
  - variables declared outside of any function ("top-level")

    these could be exported, so types should be explicit

- We do not require declarations on local variables
  - but it is fine to include them
  - if TS guesses wrong, you will need to include it

Imports

- JS / TS code can now be split into multiple files
  - JS didn't initially have that feature before ES6
- By default, declarations are hidden outside the file
- Add the keyword "export" to make it visible

```
export const MAX_NUMBER = 15;  // in src/foo.ts
```

- Use the "import" statement to bring into another file

```
import { MAX_NUMBER } from './foo';  // in src/bar.ts
```

  - '`./foo`' is relative path from this file to `foo.ts`
  - extension (`.ts`) is not included

Imports

```
export const MAX_NUMBER = 15;          // in src/foo.ts

import { MAX_NUMBER } from './foo';    // in src/bar.ts
```

- For code you write, you will only need this syntax
- JS / TS includes other ways of importing things
  - full explanation is very complicated
  - don't worry about it...
- Starter code will include some that look different, e.g.:

```
import React, { Component } from 'react';

import './foo.png';  // include a file along with the code
```

Linters

Linters

- Linters are like type checkers
  - try to find potential bugs in the program
  - as well as poor style / design issues

- In 331, we have our own linter ("comfy-tslint")
  - tries to check that our coding conventions are followed
  - e.g., types are declared except local vars in functions

- They can be overzealous
  - can flag issues that aren't really problems
  - (happens with type checkers also, but less frequently)

JS Linting

- Linter will complain about unused variables

```
const f = (a: bigint, b: bigint): bigint => {
  return b;
};
```

  - linter will complain that `a` is unused

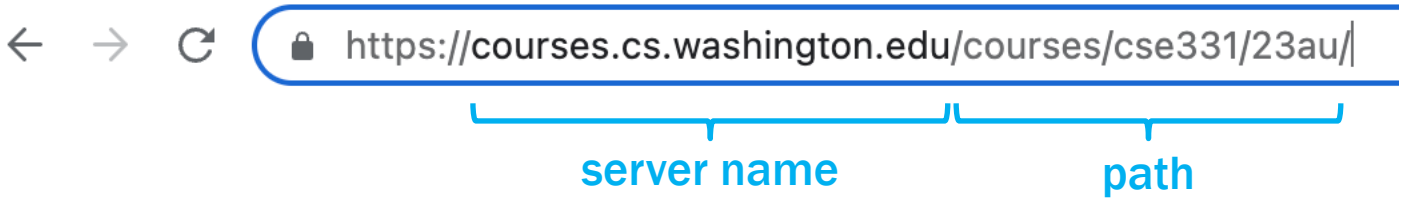
    this looks suspicious, doesn't it?

- This ignores variables whose names start with "_"
  - the underscore indicates you know it is unused
  - change the variable name to get rid of the error

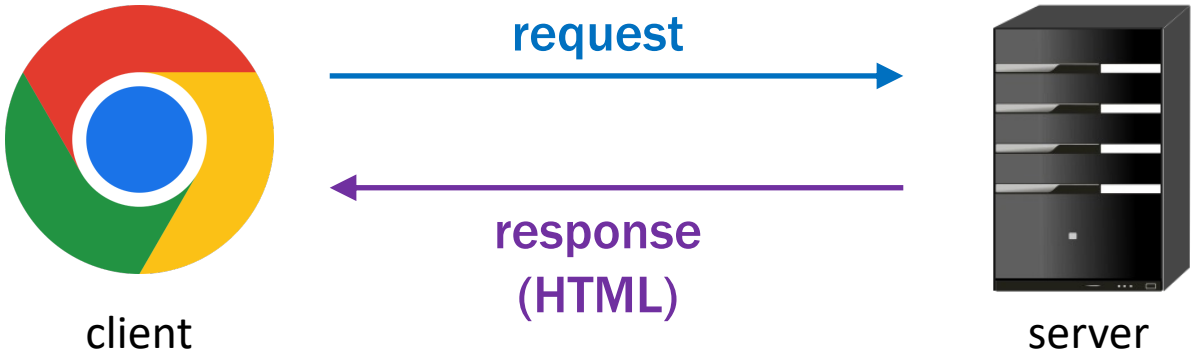
Browsers

Browser Operation

- Browser reads the URL to find what HTML to load



- Contacts the given server and asks for the given path



Browser Operation

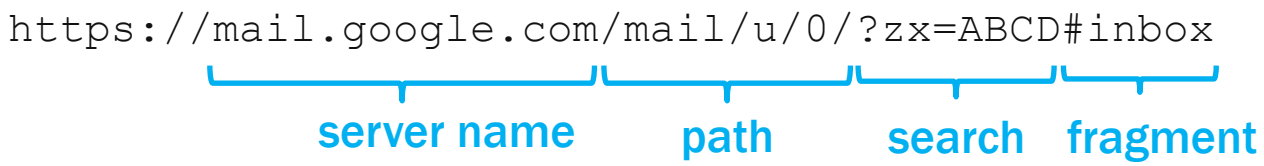
- **Page can include JavaScript to execute**
  - **each reload of the page re-executes the code**
- **Simple demo...**
  - `ex1.html` **invokes** `ex1.js`

Running Code in the Browser

- Our code runs each time the page loads
- We can produce output with `console.log`
  - we will do fancier output shortly
- What about input?
  - easiest way to start is to pass input in the URL

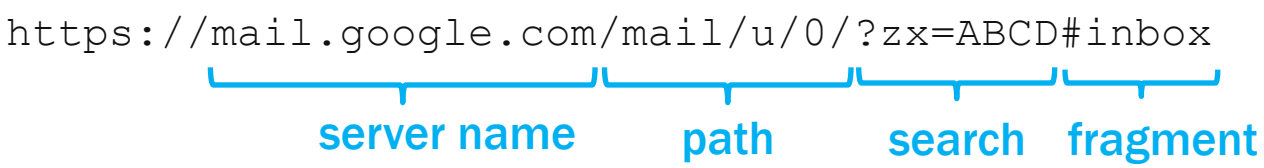
URL Parts

- URLs have more parts than just server and path:



- Path identifies the file to load from the server
- Search string is the **input** passed to that file when run
- (Fragment will not be important for us.)

URL Parts



- **Get access to the URLs parts in** `window.location`

```
window.location.hostname   "mail.google.com"
window.location.pathname   "/mail/u/0"
window.location.search     "?zx=ABCD"
window.location.hash       "#inbox"
```

Query Parameters

- Search string can pass multiple values at once
  - we call these "query parameters"

- Each parameter is of the form "`name=value`"
  - no spaces around the "="

- Multiple values are placed together with "`&`"s in between

```
?a=3&b=foo&c=Kevin%20Z
```

  - encodes three query parameters: a is "3", b is "foo", c is "Kevin Z"
  - note that all values are strings
  - note that special characters (like spaces) are encoded

    the `encodeURIComponent` function does this for us

Query Parameters

```
?a=3&b=foo&c=Kevin%20Z
```

- **Not necessary to write code to parse query params**
  - **take advantage of the built-in `URLSearchParams` class**
    (important in general to take advantage of provided libraries)

- **Read query parameters from the URL like this:**

```
const params = new URLSearchParams(window.location.search);
console.log(params.get("a"));  // prints "3" or null
```

- **Another demo...**
  - `ex2.ts` **takes name and age as inputs**

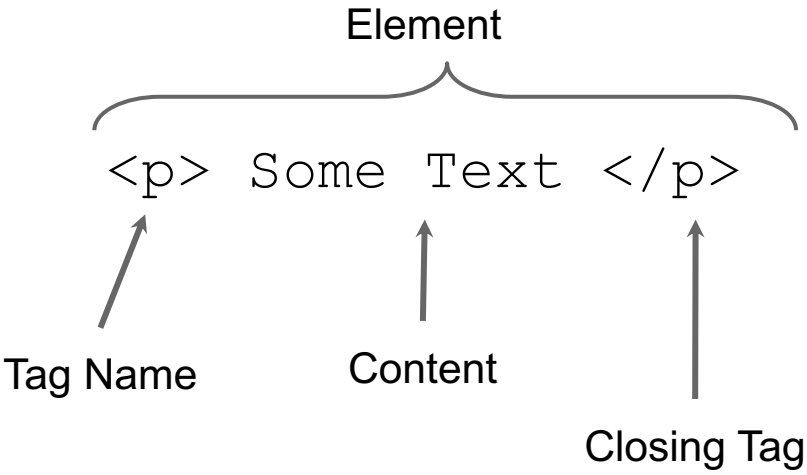
HTML

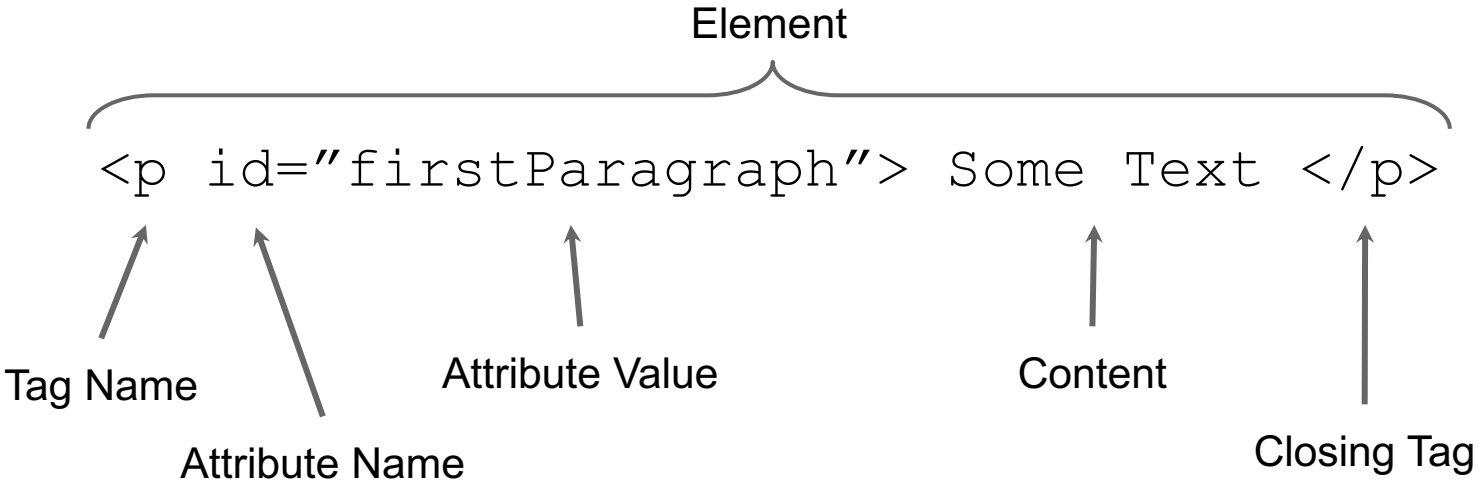
HTML

- HTML = Hyper Text Markup Language
  - text format for describing a document / UI
  - text describes what you want *drawn* in the browser

- HTML text consists primarily of “tags” and text

HTML Tags

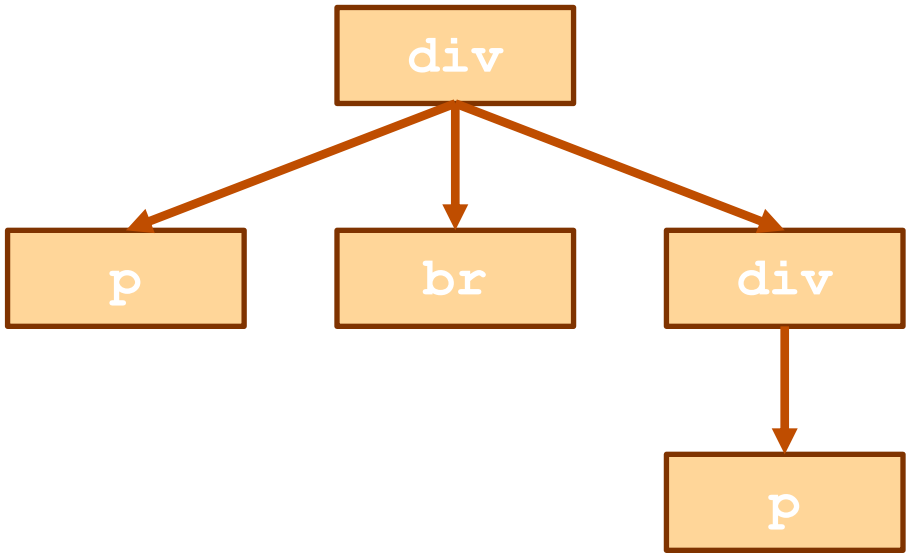

Element
 Some Text
Tag Name
Content
Closing Tag


Element
 Some Text
Tag Name
Attribute Name
Attribute Value
Content
Closing Tag

Elements Form a Tree

- **Elements can have children (text or elements)**
  - **text is always a leaf in the tree**

```
<div>
    <p id=”firstParagraph”> Some Text </p>
    <br>
    <div>
        <p>Hello</p>
    </div>
</div>
```

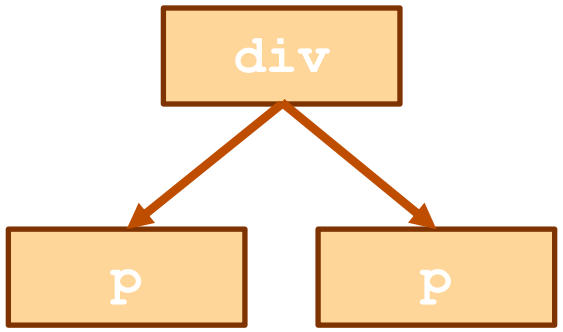


More on HTML

- **HTML is a text format that describes a tree**
  - **nodes are elements or text**

```
<div>
  <p>Some text</p>
  <p>More text</p>
</div>
```

HTML text



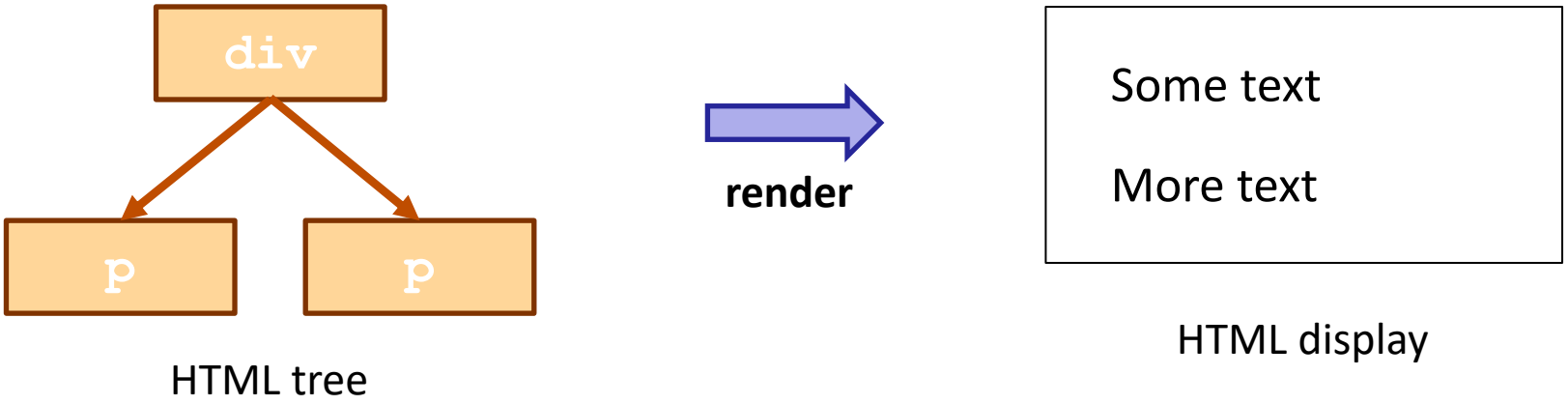
HTML tree

  - **HTML text is parsed into a tree ("DOM")**
  - **JS can access the tree in the variable "`document`"**

    our code lives in the world on the right side

More on HTML

- **Browser window displays an HTML document**
  - **tree is turned into drawing in the page**



HTML tree

HTML display

  - **browser displays (renders) the HTML in the window**

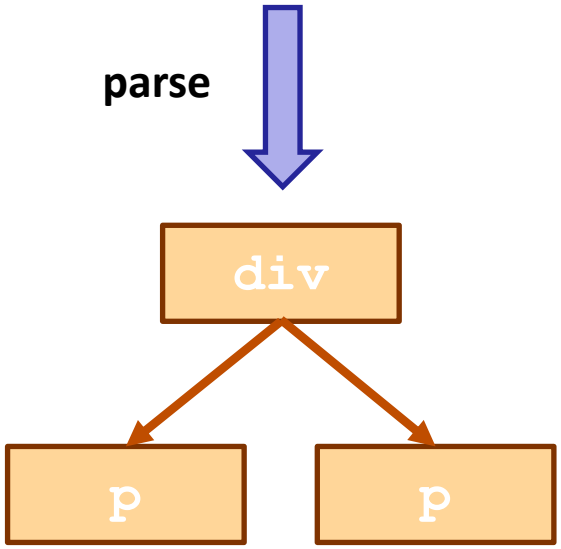
    browsers *parse* and *render* very quickly

  - **JS has *limited* access to display information**

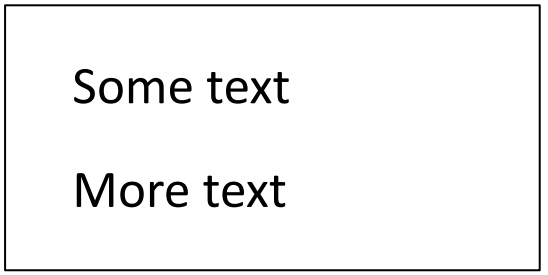
Browser Operation

HTML text

```
<div>
  <p>Some text</p>
  <p>More text</p>
</div>
```



HTML tree



HTML display

Our code runs in the middle part.

We can make changes to the tree.

The browser will then re-render.

Web App UI (From Section)

- Browser will render any HTML included in server response
- Our servers will send a page that just executes our code
  - page is mostly *empty*
- How do we display HTML from our code?
  - need to make HTML
  - need to tell the browser to render it

Web App UI (From Section)

- **Initial page has a placeholder in the HTML:**

```
<div id="main"></div>
```

(empty DIV in `index.html`)

- **Put HTML into it from code like this:**

```
const elem: HTMLElement | null = document.getElementById("main");
if (elem !== null) {
  const root: Root = createRoot(elem);
  root.render(… /* some HTML */);
}
```

  - `createRoot` **is a function provided by the React library**
    (more details on this later on…)
  - **how do we create the HTML?**

HTML Literals

- Extension of JS / TS allows HTML expressions
  - file extension must be `.jsx` (or `.tsx` for TS)

```
const x = <p>Hi there!</p>;
```

- TypeScript will make sure the HTML is valid
  - will complain if it has unknown tags or attributes
  - will complain if attribute values have the wrong type
  - these checks are very useful!

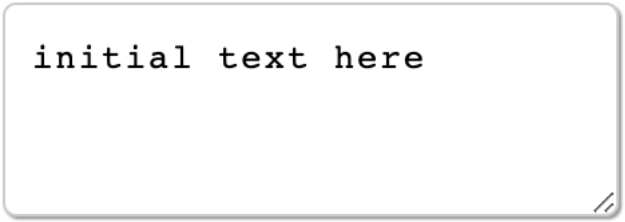
HTML Literals

- **Supports substitution like `` `. . .` `` string literals,**
  - **but uses `{ . . }` not `${ . . }`**

```
const name = "Fred";
return <p>Hi {name}</p>;
```

- **Can also substitute the value of an attribute:**

```
const rows = 3;
return (
  <textarea rows={rows} cols="25">
    initial text here
  </textarea>);
```



Styling

- The “style” attribute controls appearance details
  - margins, padding, width, fonts, etc.
  - see an HTML reference for details (when necessary)

- Attribute value can include many properties
  - each is “name: value”
  - separate multiple using “;”

```
<p>Hi,
  <span style="color: red; margin-left: 15px">Bob</span>!
</p>
```

Hi, Bob!

  - we will generally not worry much about looks in this class…

Calculating the Style

- How do we calculate part of the style in code?
  - you might think this would work

```
const n = 15;
…
<p>Hi,
  <span style={`color: red; margin-left: ${n}px`}>Bob</span>
</p>
```

  - but it does not type check!
  - the type of the "`style`" attribute is not **`string`**

Style Attribute in JSX

- **The type of the style attribute is a record!**
  - **more accurate type checking this way (string would have none!)**

```
const r = {color: "red", marginLeft: `${n}px`};
return <p> Hi, <span style={r}>Bob</span>!</p>;
```

- **Field names differ slightly from HTML**
  - **JS doesn't allow "-" in a field name**
  - **JS uses `camelCapNames` instead of `camel-caps-names`**

- **Looks weird, but record can be written in-line:**

```
return (<p> Hi,
    <span style={{color: "red"}}>Bob</span>!</p>);
```

JSX Gotchas

- **Must wrap multi-line HTML literals with `( . . )`**

```
return (<p>This is some HTML that
          spans multiple lines</p>);
```

- **Must have a single root tag (i.e., must be a tree)**
  - **e.g., cannot do this**

```
return <p>one</p><p>two</p>;
```

  - **instead, wrap in a `<div>` or just `<> . . </>` (“fragment”)**

- **Replacements for attributes matching keywords**
  - **use “`className=`” instead of “`class=`”**
  - **use “`htmlFor=`” instead of “`for=`”**