Special Topic: Web Development and Graphics

ENGR 103: Engineering Computation and Algorithmic Thinking

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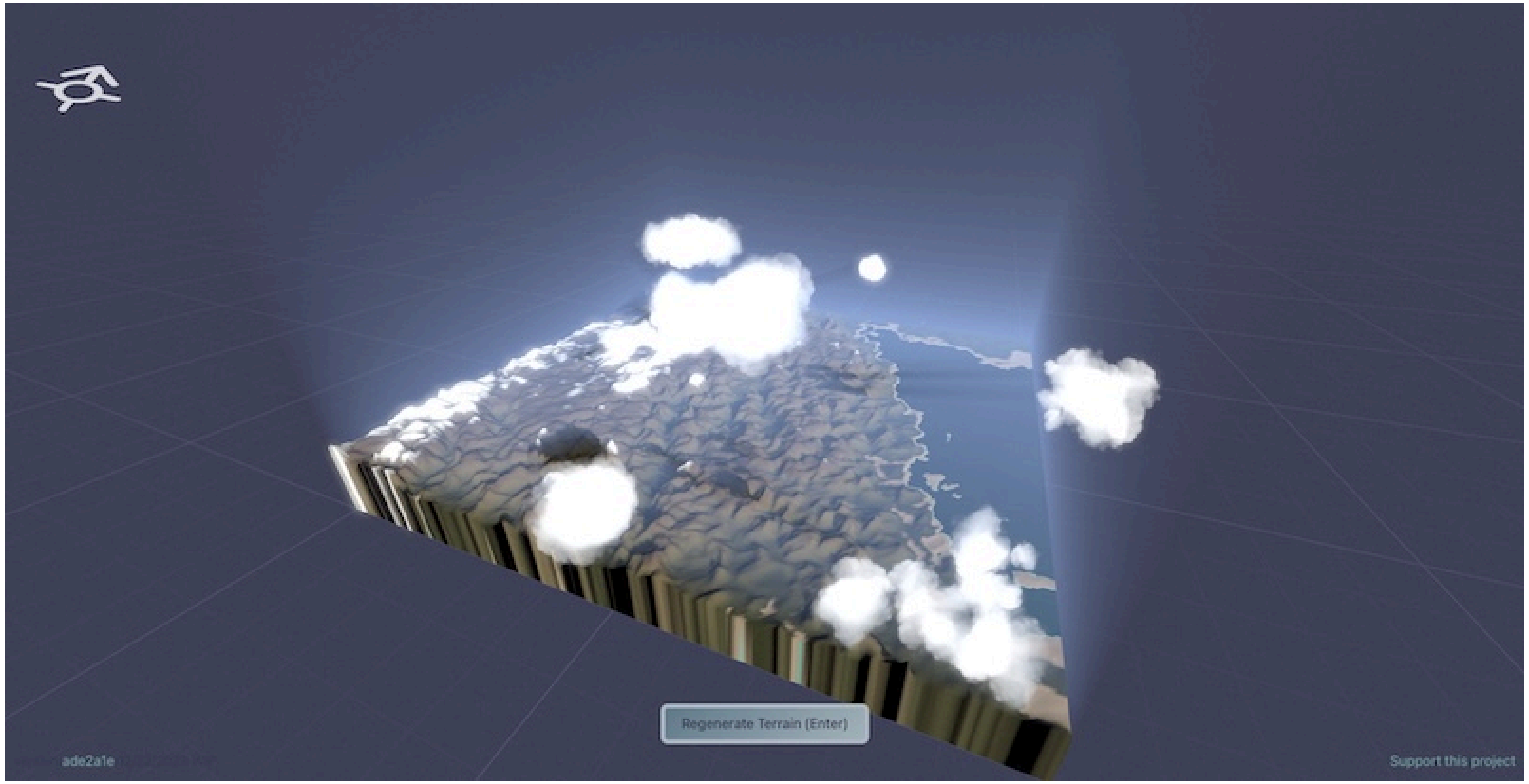
Today's Lecture

- Introduce programming languages for the browser
- Write a "Hello, World" web page
- Discuss CPUs and GPUs
- Explain a traditional "graphics" pipeline
- Graphics in the browser (Three.js and WebGL)
- Can we make a 3D rotating cube?

Example: Terrain Generation in the Browser



Terrain Synth by Kenneth Pirman. You can also check out Kenny's World Synth.

Programming Languages in the Browser

- HTML (HyperText Markup Language) - meaning and structure
- CSS (Cascading Style Sheets) - presentation/rendering
- JS (JavaScript), TS (TypeScript) - scripting
- And many libraries, frameworks, etc. (this evolves fast)

Your (web) browser (Safari, Chrome, Firefox, ...) can make sense of HTML/CSS/JS.

You can use your browser's Dev Tools to see what the browser sees.

Check learn web development on MDN to get started.

`index.html`

```html
<!DOCTYPE html>
<html lang="en">
    <head>
        <meta charset="utf-8">
        <meta name="viewport" content="width=device-width">
        <title>Hello World</title>
    </head>
    <body>
        <h1>Hello World</h1>
        <p>
            Alex was here.
        </p>
    </body>
</html>
```

CSS

Wrap the following code in a `<style>` tag in the `<head>`.

```
body {
    font-family: sans-serif;
    background-color: #f4f4f4;
}
h1 {
    color: #ea580c;
    text-align: center;
}
p {
    color: #333;
    text-align: center;
}
```

JavaScript (JS)

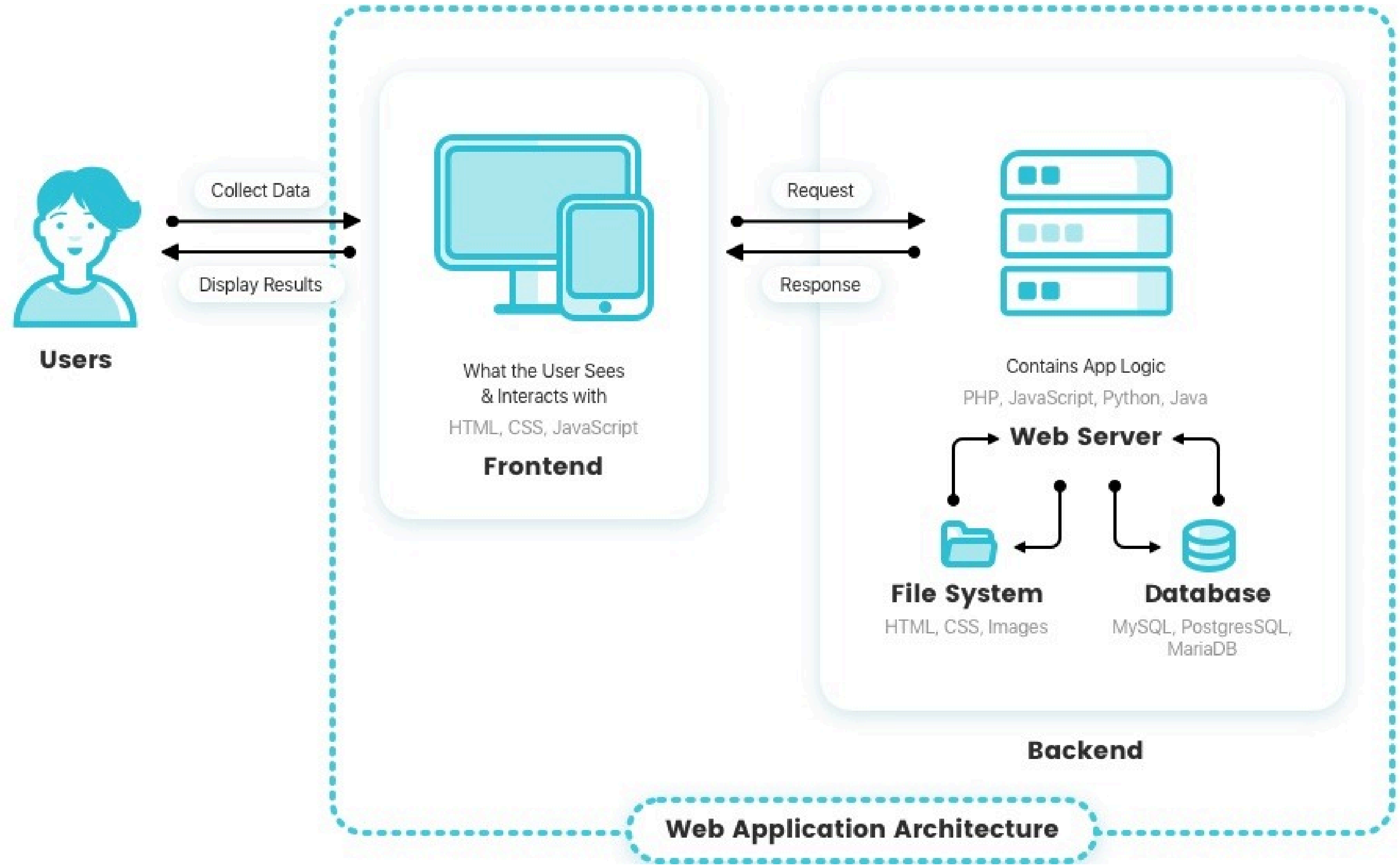
Wrap the following code in a `<script>` tag in the `<head>`.

```
let clickCount = 0;

function incrementCounter() {
    clickCount++;

    const paragraph = document.getElementById('placeholder');
    paragraph.textContent = `You clicked the button ${clickCount} time(s)`;
}
```

And change the HTML in the `<body>`.

```
<p id="placeholder"> Alex was here. </p>
<button onclick="incrementCounter()">Click me</button>
```

A Simplified View of the Web



Source

CPU and Clock Speed

The **Central Processing Unit (CPU)** is the chip in your computer that executes instructions to run programs. It is designed for *general-purpose computing*.

The **clock speed** measures the number of cycles your CPU executes per second, measured in GHz (gigahertz) -- billions operations per second.

The relationship between clock speed and power consumption is not linear as it depends on the voltage to the power of 2. **More power also means more heat...**

Example

- At 1 GHz CPU might use 20W at 1.0V.
- At 2 GHz, if voltage rises from 1.0V to 1.1V, power could jump to ~48W ($2 \times 1.1^2 \times 20W$), showing how both frequency and voltage hikes compound.

Parallelization

Could we scale the clock speed differently?

Instead of increasing the clock speed of **one core**, can we have **multiple** cores working **simultaneously**?

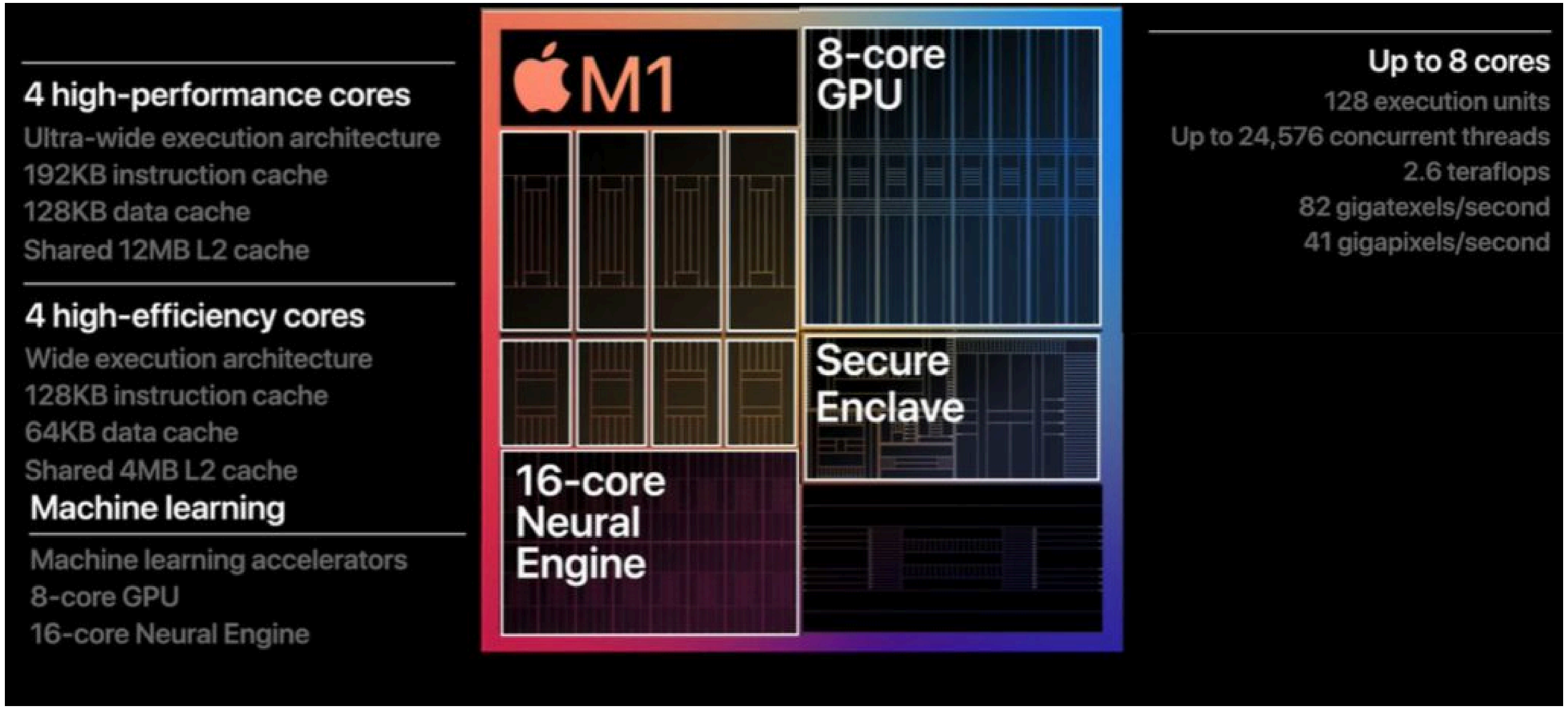
2x cores = 2x speed ≈ 2x power consumption (there is a little overhead)

Lots of tasks cannot be broken down to execute in **parallel**, they have to be done **sequentially** (in particular, if there are dependencies between operations).

Other tasks are a great fit, such as... **graphics rendering** (and also machine learning, data processing, all kinds of simulations, crypto mining, ...)

Graphics Processing Unit (GPU)

Increase the number of cores but have them run at a **lower** frequency and *optimized for data-parallel tasks*. One core can't run a whole program by itself.



How to We Get to Display Things on the Screen?

1. **Application**: "Draw a 3D scene" → CPU prepares data
2. **Graphics Engine**: Organizes scene into renderable chunks
3. **Graphics API**: Issues draw commands (e.g., "render triangles")
4. **Driver**: Translates API commands to GPU instructions → GPU executes pipeline (vertex → fragment → framebuffer)
5. **Operating System**: Manages resources and queues framebuffer for display
6. **Compositor**: Blends GPU output with UI → final image
7. **Display Interface**: GPU sends pixels to screen hardware

Read more about the graphics pipeline, or transforming a 3D scene into a 2D representation on your screen.

Example

1. **Game (CPU)**: Calculates player position, sends mesh data.
2. **Unity (CPU)**: Culls unseen objects, prepares shaders.
3. **DirectX 11 (CPU)**: Builds a command list.
4. **NVIDIA Driver (CPU/GPU)**: Converts commands to Ampere instructions → GPU renders 8M pixels in parallel.
5. **Windows (CPU/GPU)**: WDDM flips the framebuffer, DWM composites with taskbar.
6. **DisplayPort (GPU)**: Sends 4K@60Hz pixel stream to monitor.
7. **Screen**: Displays the frame in ~16ms.

In Practice

Drivers are proprietary and very low-level, they change depending on your hardware.

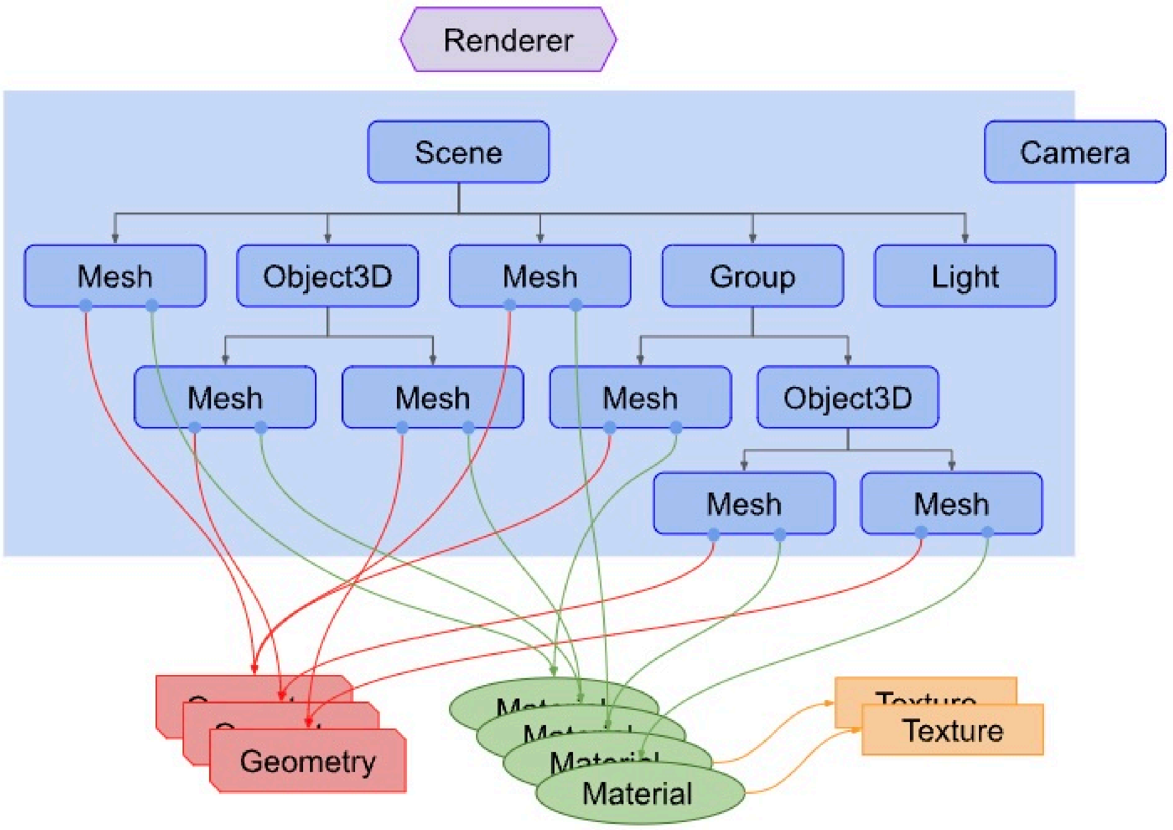
Graphics API are a little better but are still low-level, and *might* change based on your operating system (e.g., DirectX is only for Microsoft, Metal for MacOS).

A graphics engine is often a full-featured, self-contained platform. It does a lot of things in addition to "just" rendering.

What if we want something a little more lightweight, a little more accessible? Something we could use on the web.

Three.js

A web library that wraps WebGL (the API), offering a higher-level abstraction.

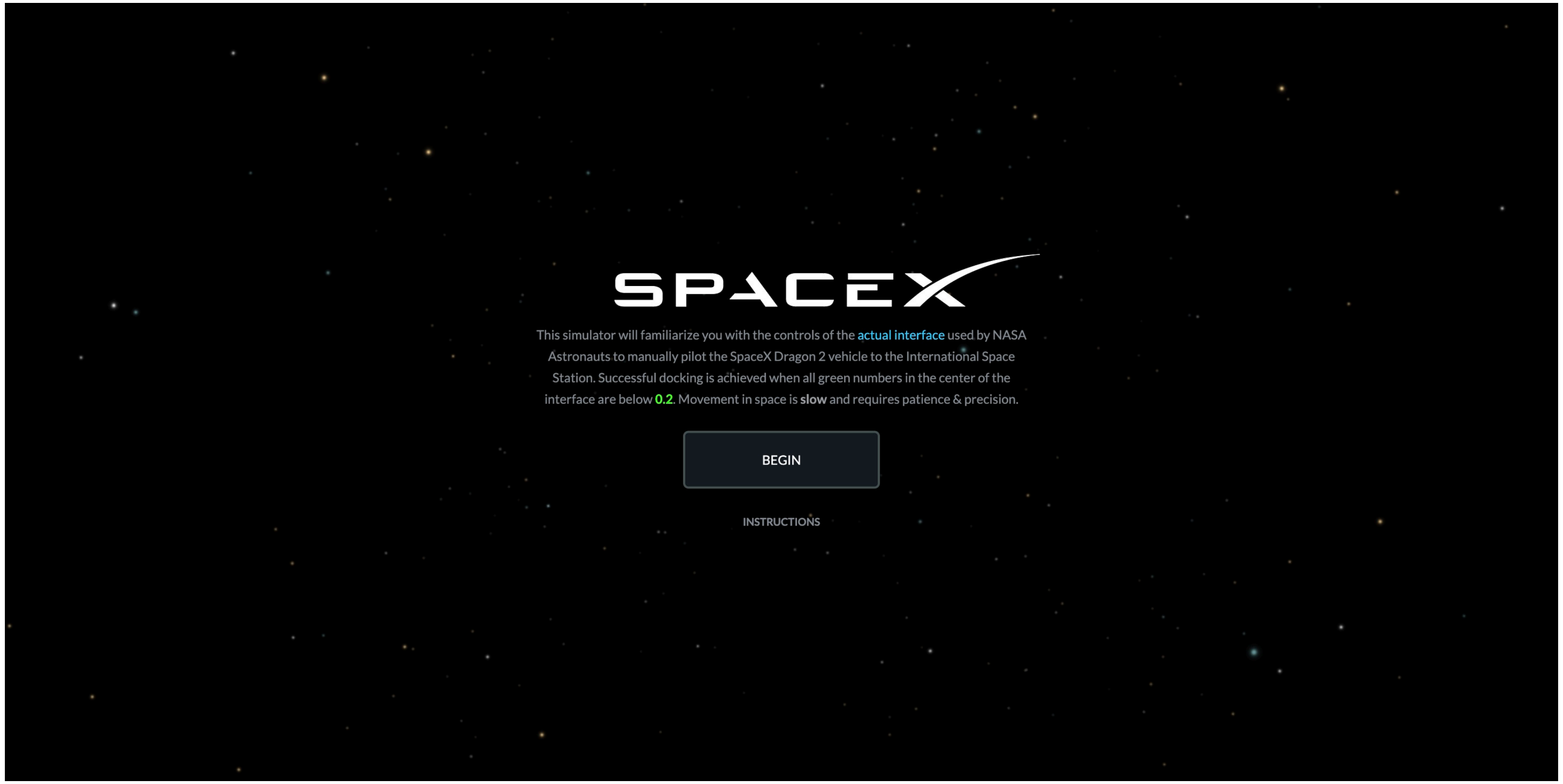


What Would We Need to Display a 3D Rotating Cube in our Browser?

- A new `<canvas>` element in our HTML for WebGL to draw graphics and animations
- Importing the Three.js library in our HTML page with JavaScript (JS)
- Write a JS Script:
    - Create a Scene and a Camera
    - Add a Cube to the Scene
    - Animate the Cube
    - ...

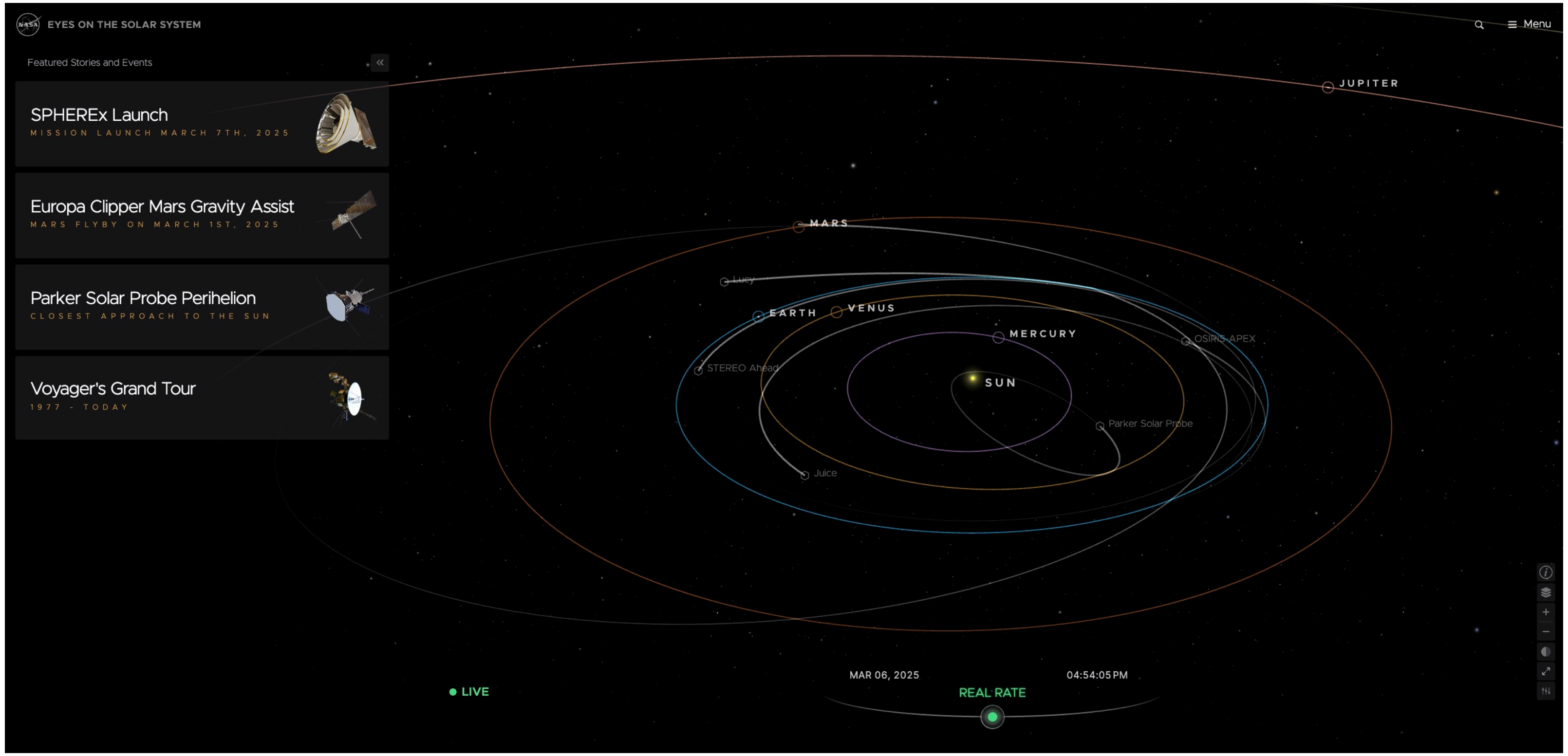
All the code from this lecture is available on GitHub.

Example: Docking with the ISS



ISS Docking Simulator by SpaceX

Example: Exploring the Solar System in Real-Time



Eyes on the Solar System by NASA

Example: Learn About Digital Banking Solutions

Coast World by Coastal Community Bank