Exploring Fluid Simulation

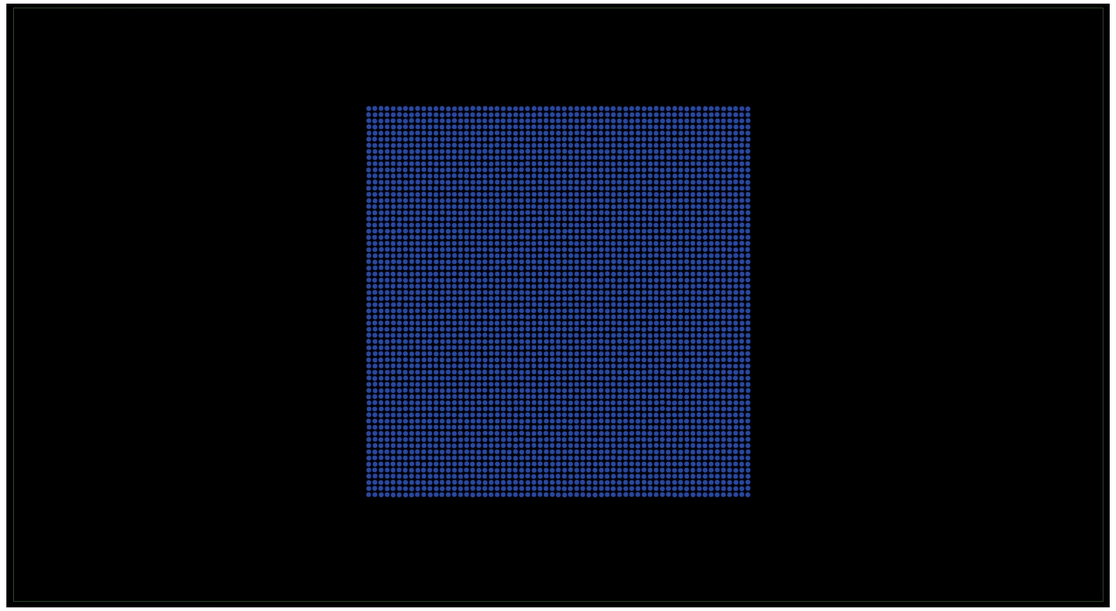
Project Design

Christopher Lee

Introduction

- Goal: develop a basic, **accessible**, 2D fluid simulator
- Apply computational techniques to simulate a fluid (liquid or gas)

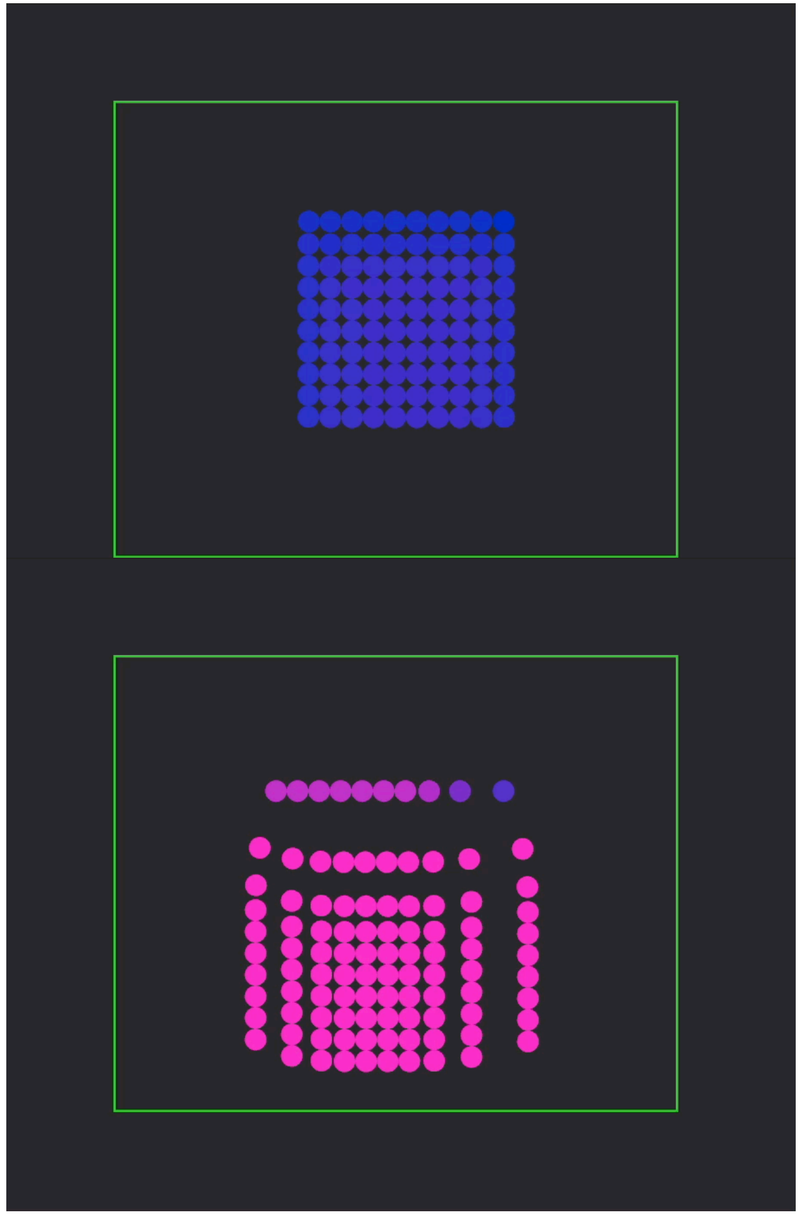
- Current Risks
  - Not a physics major
  - Learning Rust and Bevy
  - Integrating Physics, Rust, and Bevy



Footage from Sebastian Lague — Coding Adventure: Simulating Fluids

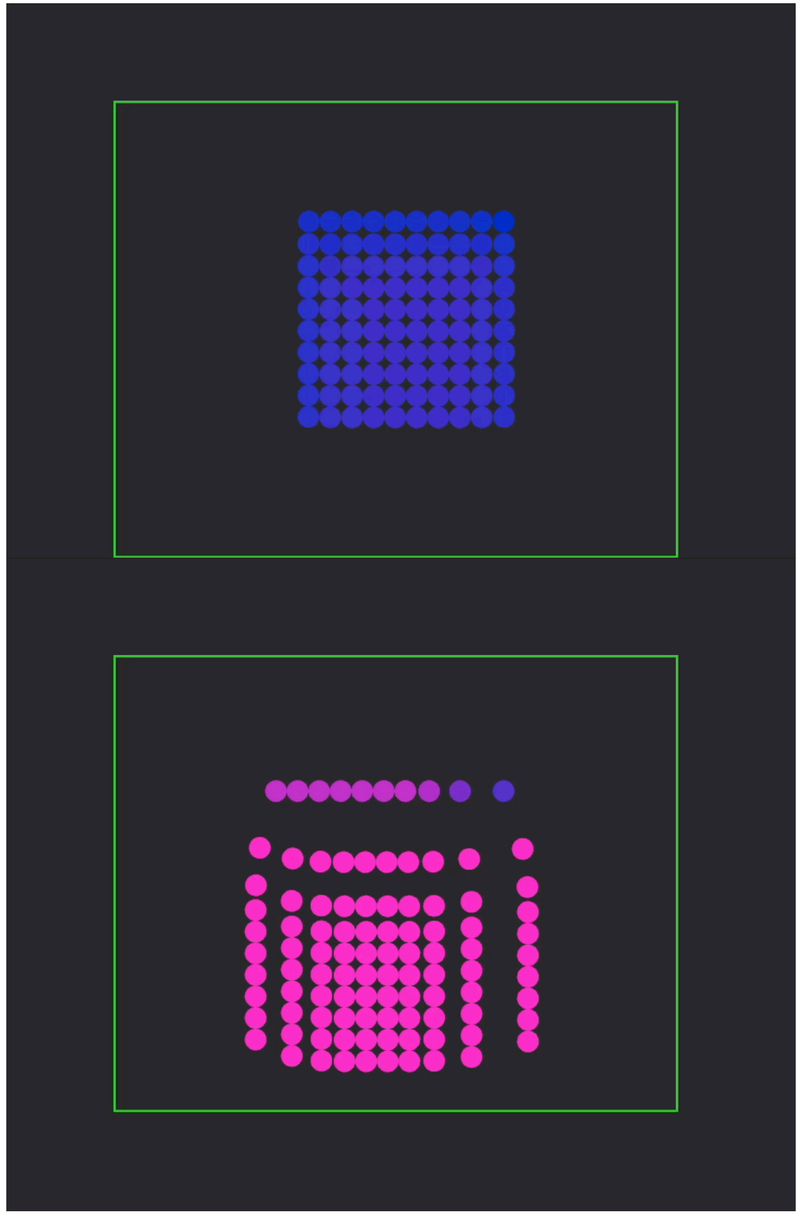
Current Status

- **Physically-inaccurate**
- 2D environment
- Particle color based on velocity
- Performant with 100 particles
- Gravity



Project Objectives

- Refine current smoothing function
  - ➡ Improve physics
- Customizable parameters
  - ➡ Toggle gravity
  - ➡ Number of particles
  - ➡ Bounding box size
- Document codebase



Experimental Methods

➡ Improve accuracy w/ trial and error

- Experiment with different smoothing functions
- Alter various constants
  - Resting density
  - Gas constant
  - Dampening factor
  - Smoothing radius

$$W_{\text{poly6}}(\mathbf{r}, h) = \frac{315}{64\pi h^9} \begin{cases} (h^2 - r^2)^3 & 0 \le r \le h \\ 0 & \text{otherwise} \end{cases} \tag{20}$$

$$W_{\text{spiky}}(\mathbf{r}, h) = \frac{15}{\pi h^6} \begin{cases} (h - r)^3 & 0 \le r \le h \\ 0 & \text{otherwise,} \end{cases} \tag{21}$$

$$W_{\text{viscosity}}(\mathbf{r}, h) = \frac{15}{2\pi h^3} \begin{cases} -\frac{r^3}{2h^3} + \frac{r^2}{h^2} + \frac{h}{2r} - 1 & 0 \le r \le h \\ 0 & \text{otherwise.} \end{cases} \tag{22}$$

Equations from Particle-Based Fluid Simulation for Interactive Applications (Müller et al.)

System Architecture (Software)

- **Bevy** game engine
  - Data-driven
  - Entity Component System (ECS)
- Game loop

for all particles:

compute each particle's **density** (ρ) using smoothing function

for all particles:

compute **external forces**

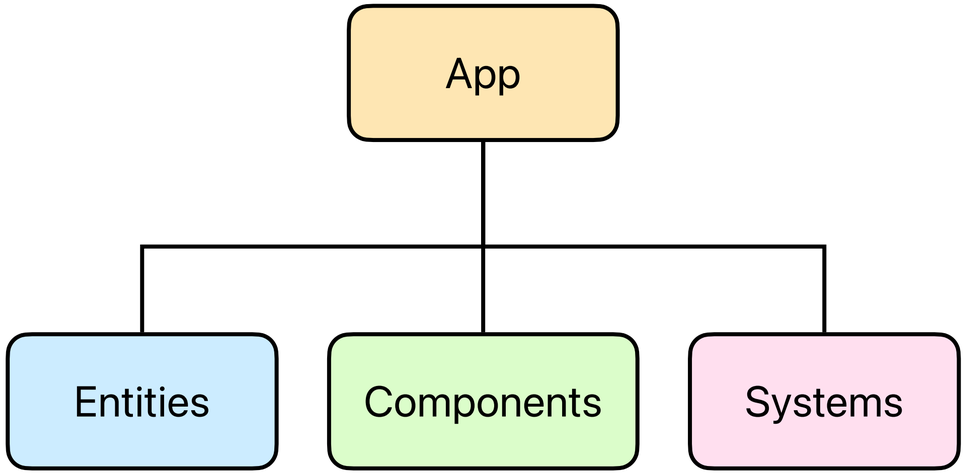
for all particles:

compute **pressure force**

for all particles:

update **velocities**

update **position**



"**Entities** are unique things that are assigned groups of **Components**, which are the processed using **Systems**."

Quoted from Bevy's Quick Start Book (https://bevyengine.org/learn/quick-start/getting-started/ecs/)

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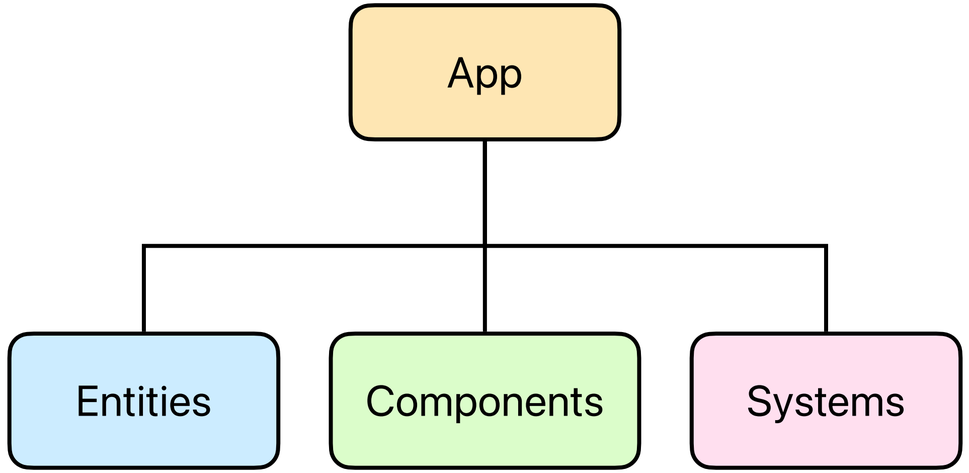

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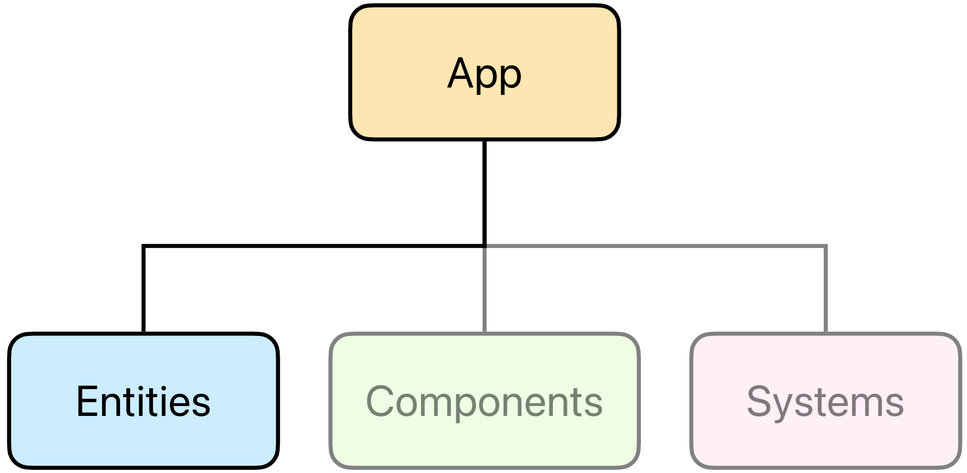

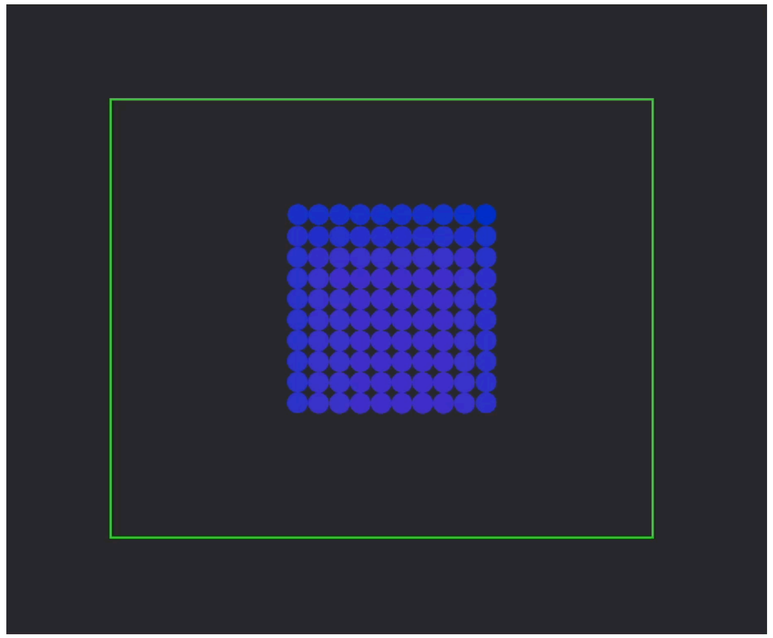

Entities in fluid simulation:

- Particle

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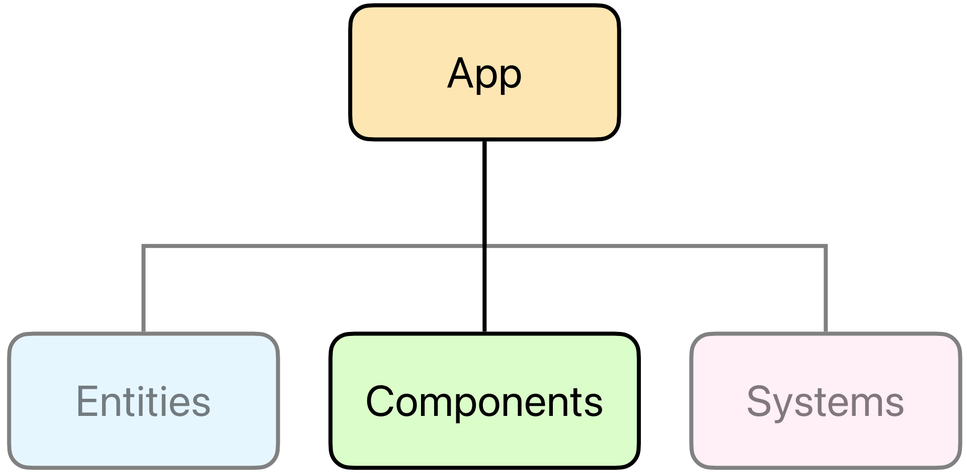

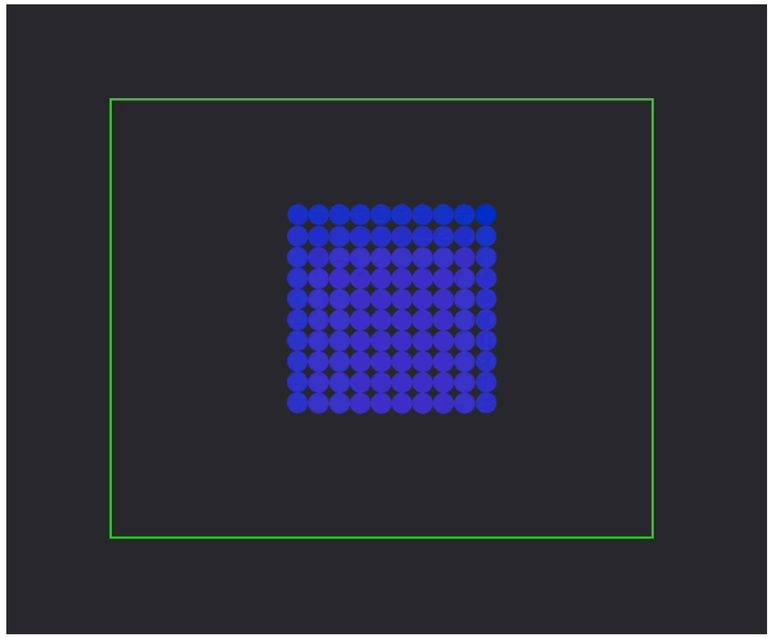

Particle

Components in fluid simulation:

- Velocity
- Density
- Viscosity

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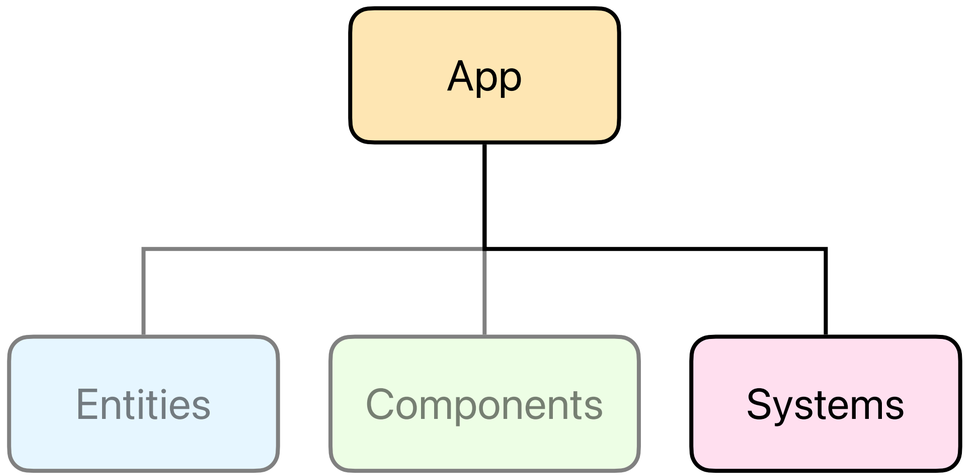


Particle

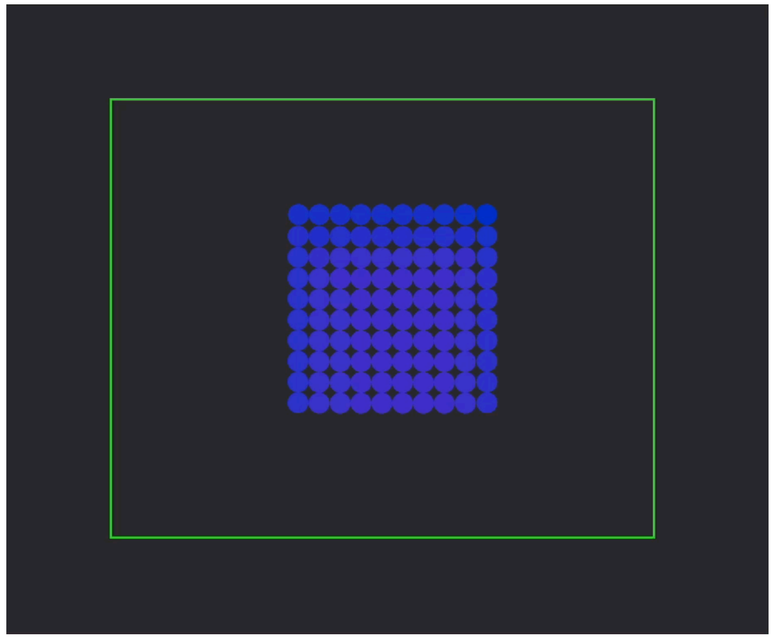
Velocity

Density

Viscosity

Systems in fluid simulation:

- Setup (camera, boundary, particles)
- Movement (particles)
- Debug (FPS, time control)



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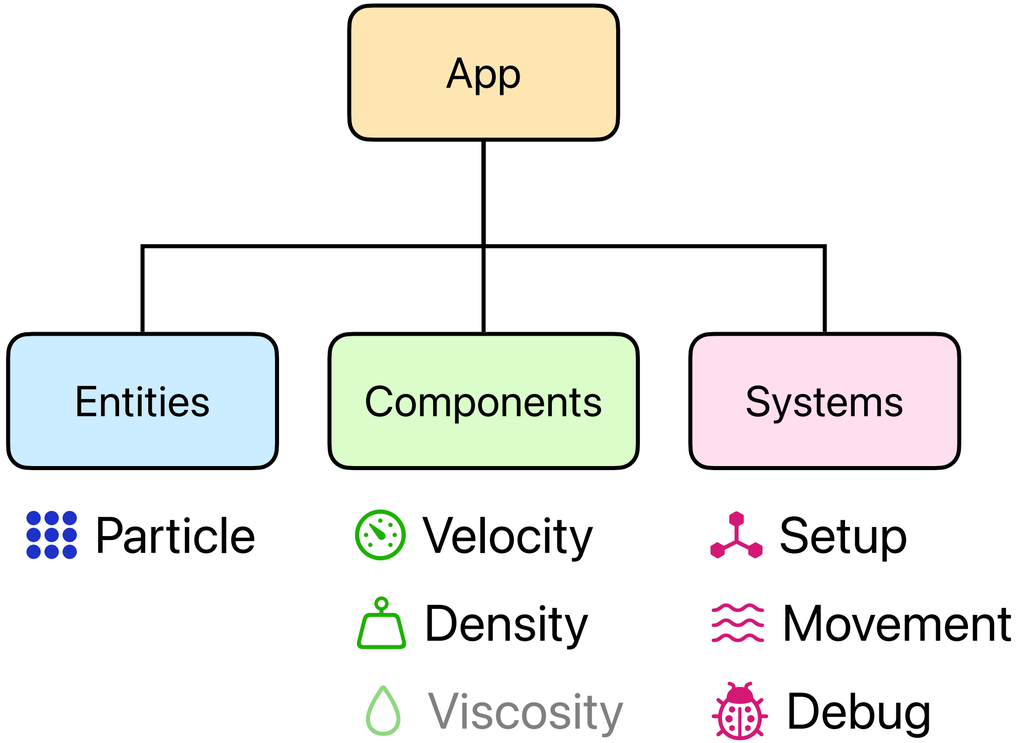

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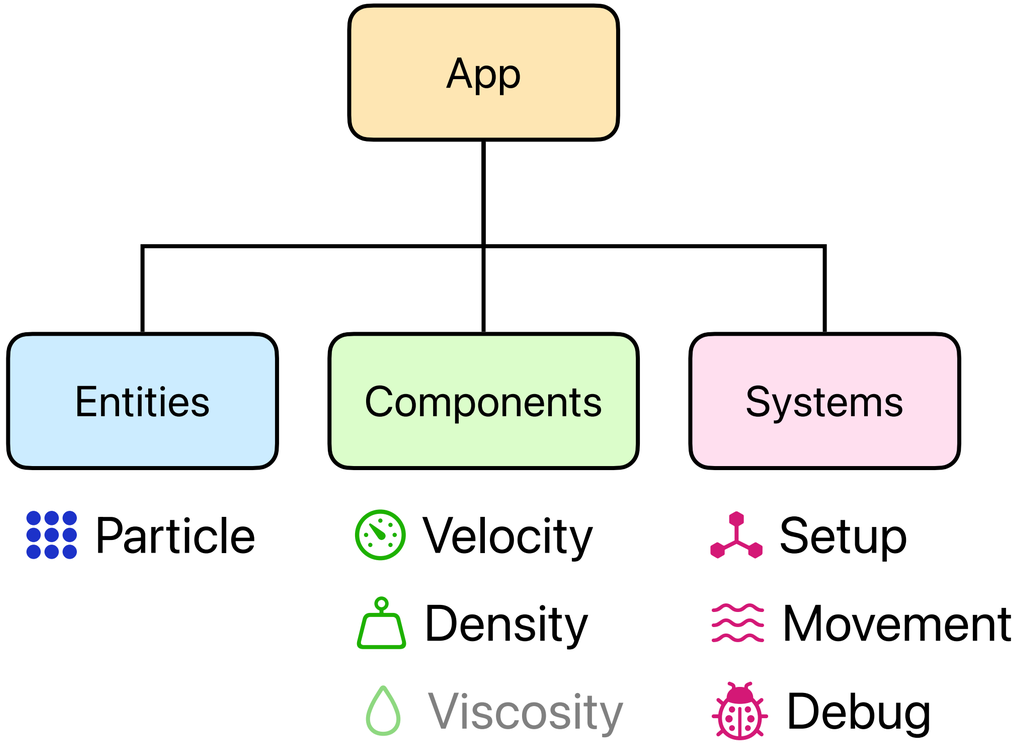

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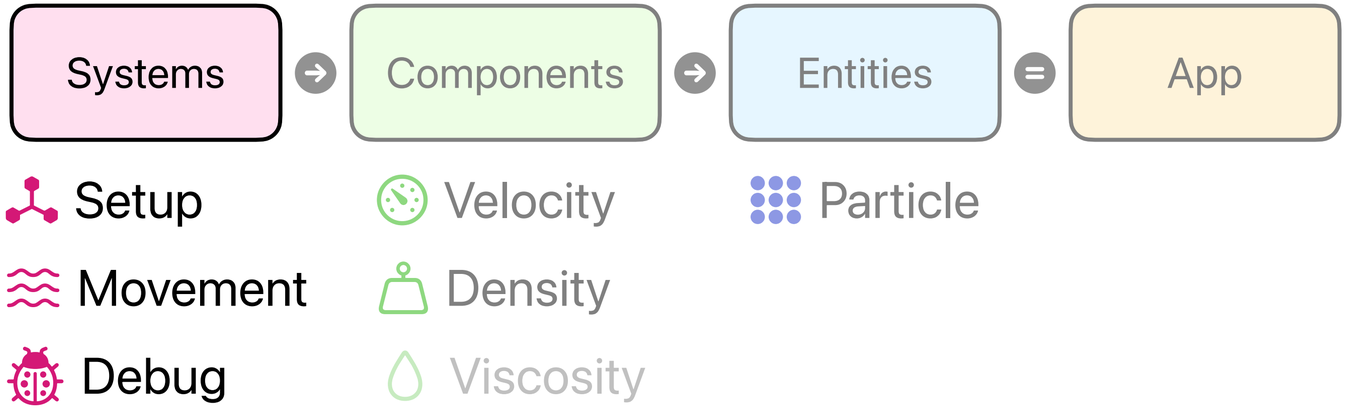
Software Design

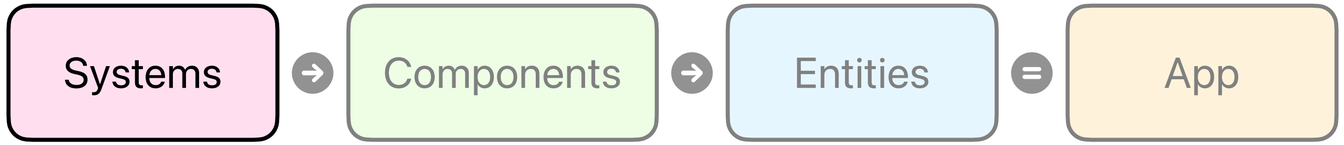


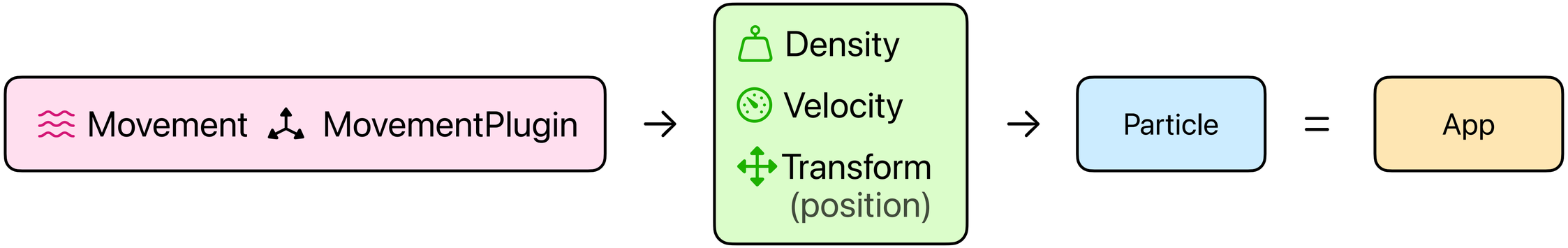
Software Design

Systems → Components → Entities = App

Setup	DefaultPlugins	→	Loads and initializes default plugins for Bevy
	BoundaryPlugin	→	Creates the boundary box based on **BOUNDS** constant
	CameraPlugin	→	Creates the camera to render the 2D environment
	ParticlesPlugin	→	Spawns **N** particles in a grid or randomly
Movement	MovementPlugin	→	Updates the densities for each particle
			Computes the external forces applied to each particle
			Computes the pressure forces exerted on each particle
			Updates the velocities and positions for each particle
Debug	DebugPlugin	→	Displays the current FPS and logs component info
	TimePlugin	→	Observes keyboard inputs for (un)pausing, speeding up, and slowing down time

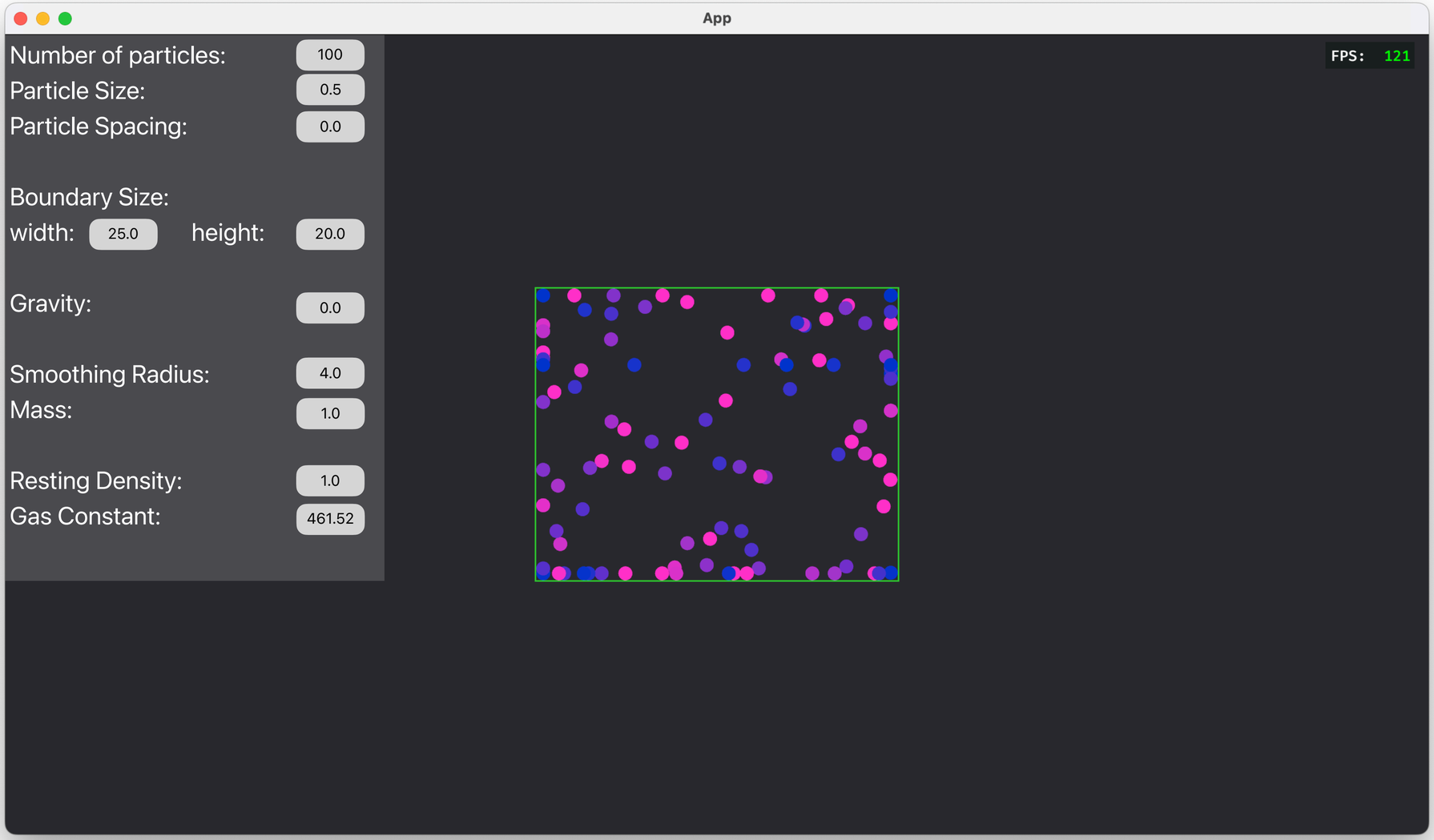
Software Design





Systems Interface

⚠️ Work-in-progress mockup



Detailed Hardware Design

- Modern computer
- Operating system supported by Bevy (MacOS, Linux, Windows)

Equity Statement

29%

of the science and engineering workforce are women

Per an article in the Yale Scientific by Ishani Singh

Equity Statement

Given the history of a male-dominated engineering industry in both the workforce and educational settings...

- Make fluid simulation **accessible** to **everyone**
- Well-documented code
- Easy-to-understand and follow software architecture
- Teach a basic understanding of how fluids move
- Outline key equations and implementation in code

Thank You