Operating a Virtual Nuclear Reactor using Augmented Reality

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Background

NIST Center for Neutron Research features the National Bureau of Standards Reactor as its source of neutrons

- Research would not be possible without employees trained to operate the reactor

Reactor Operator Training

- 3 year process of learning about reactor and its systems
  - reading materials
  - learning from existing operators
  - practical applications in operation
  - reading tech manuals, safety analysis reports,
  - procedures, emergency response
- Lengthy, resource and time intensive, real consequences
- **Real control console is limited in time and use**

Project Goals

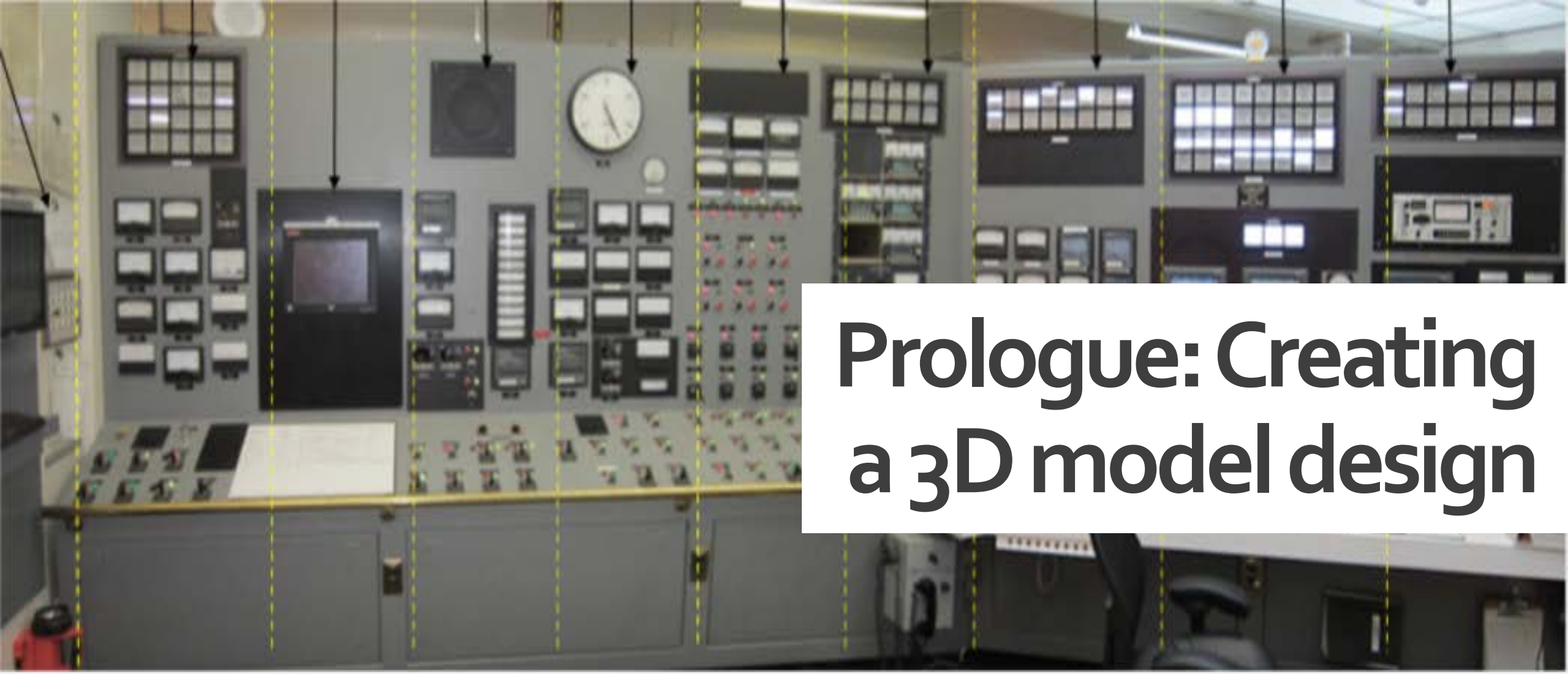
- To implement a virtual console that will allows operators to train and become familiar with the NBSR control console
- To allow operators to participate in safety training that would not be practical otherwise
  - Fire safety
  - Emergency SCRAM

Reactor Console Upgrade Design

- Upgrading the physical console is a long process due to NRC regulations and safety and implementation standards
- Virtual console can be made in a much shorter time, process is only limited by the skill and time of the programmer
- Virtual console will help future reactor operators familiarize themselves with components, diagnostics and operating and safety procedures

Benefits

- **Affordable:** less expensive to implement and maintain
- **Portable:** virtual console can be operated anywhere
- **Modular:** programmer can add features and functionality



Prologue: Creating a 3D model design

Reactor Console Upgrade Design

- Done by colleague Omar Cavazos in SURF 2017
  - Used codes and standards to design new control console (Military standard for human engineering)
  - Used SolidWorks software
  - Incorporated reactor operator feedback

Part 1: Finding the Right Tool

What is the best way to simulate a reactor console?

Microsoft HoloLens

- No wires or external components
- Passive cooling
- Fits comfortably on the head
- Runs Windows 10, easy to use

Interaction with Human:

Spatial Sound
Gaze tracking
Gesture input
Voice Input

Sensors and Capabilities

- Holographic lenses/waveguides
- 2 HD Light Engines
- 2.3 Million Light Points

- 4 Environment cameras
- 1 Inertial Measurement Unit – keeps track of the users force and angular rate
- 4 Microphones

- Projects holograms onto real physical surfaces
- No additional controls, all interaction done by voice, eyes, and hands

Unity Game Engine

- Provides an interface to create and place objects
- Provides a Scripting API in C#
- Supports creating games in 27 different platforms, used **Universal Windows Platform**

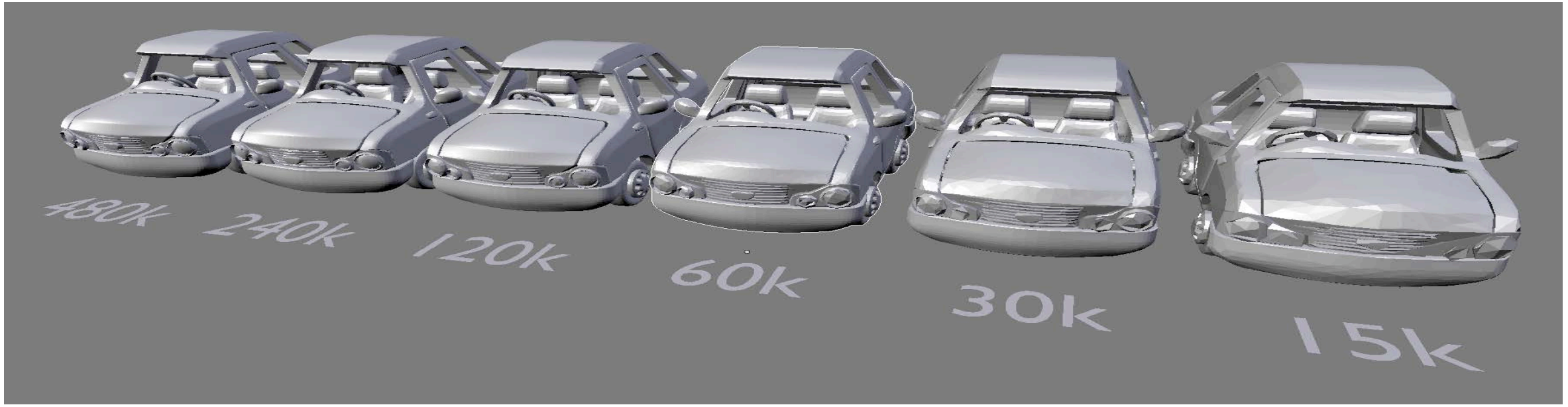
Part 2: Importing the Design to Unity

Importing to Unity

- To begin programming and creating the simulation, I needed to import Omar's SolidWorks design to Unity
  - Tried several 3D formats 3DS, FBX, OBJ etc.
  - Found that .obj worked best for Unity

Importing to Unity

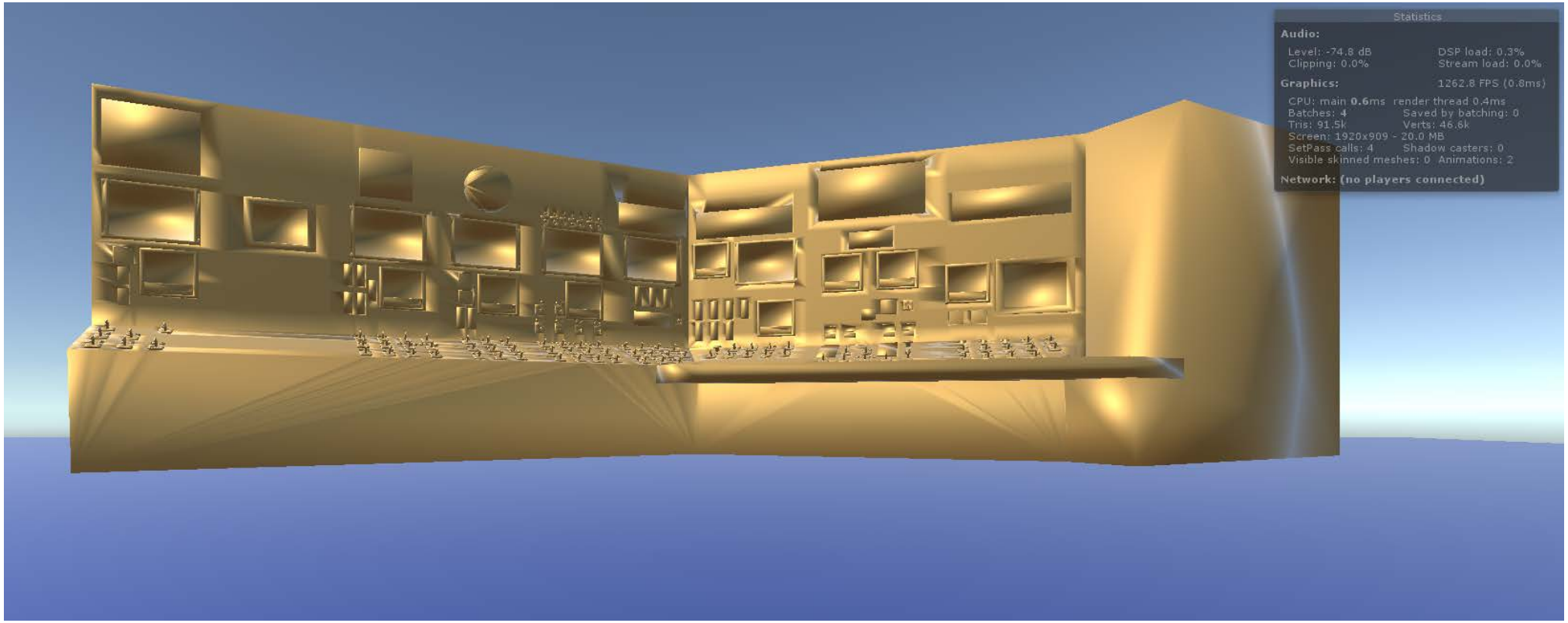
- For a hologram to operate at a stable framerate on the HoloLens, the vertex/triangle count should be lowered
  - Used Meshlab and Creo to optimize the polygon count

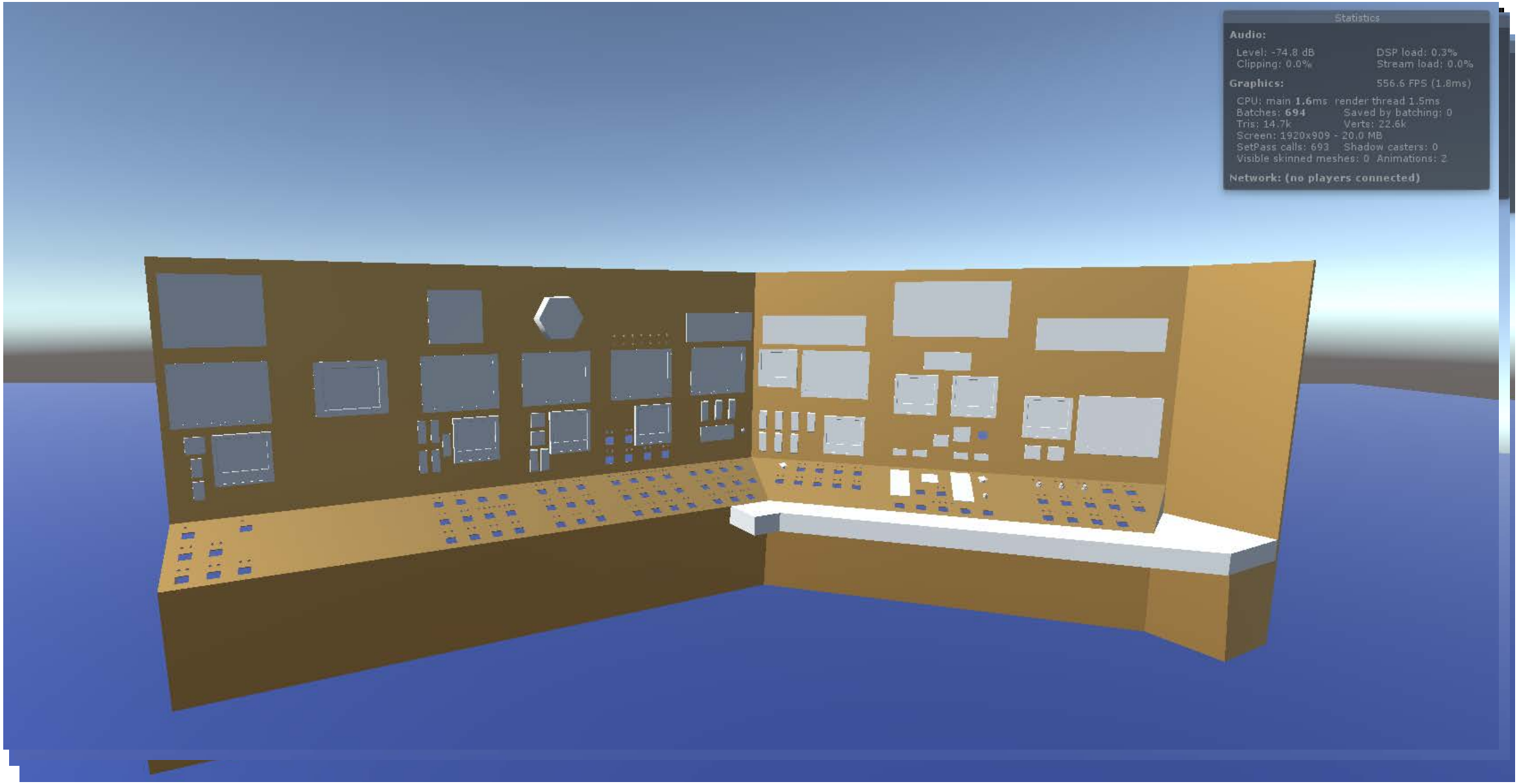


Console Iterations

- First time importing a 3D model to unity ~1,000,000 triangles

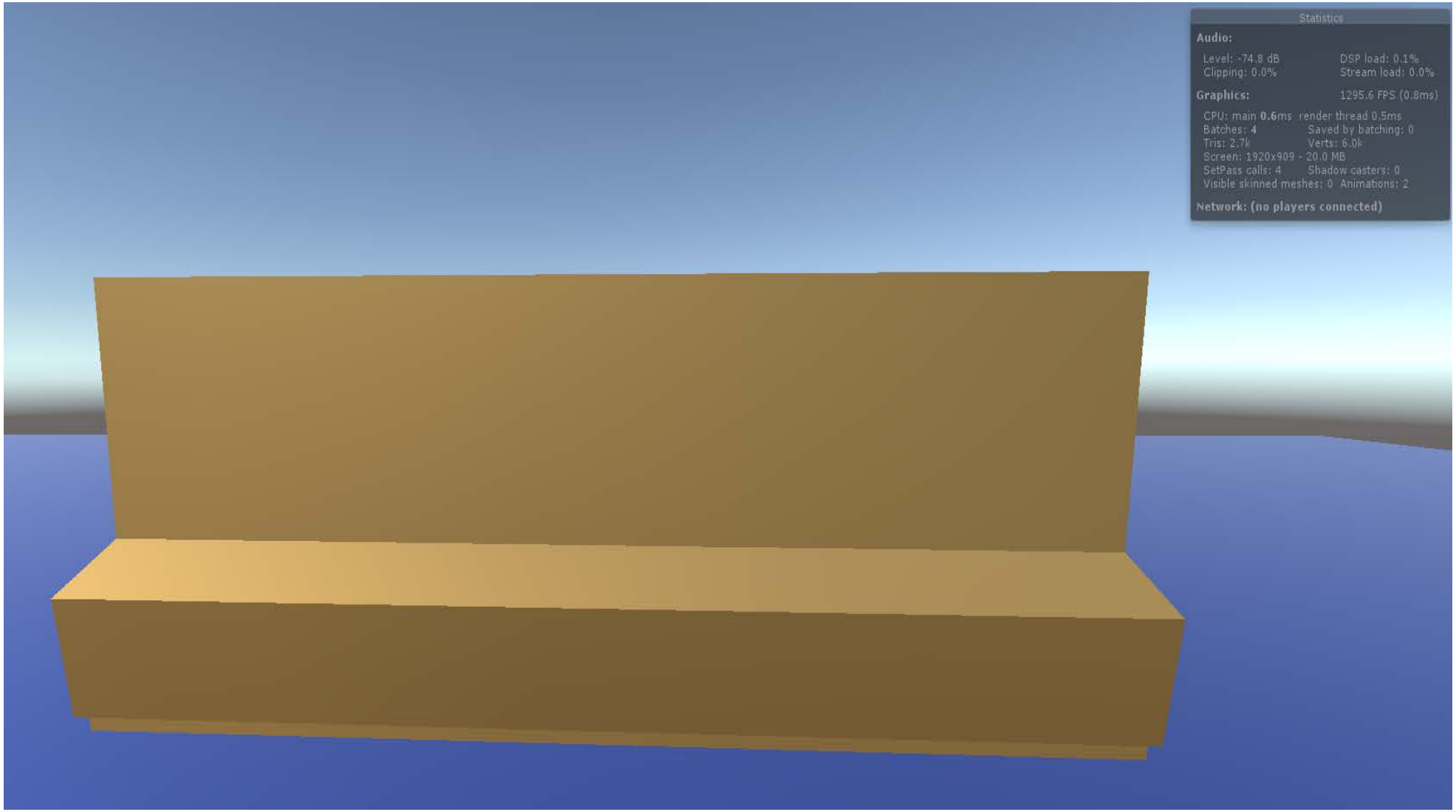
One of the first iterations with ~90,000 triangles

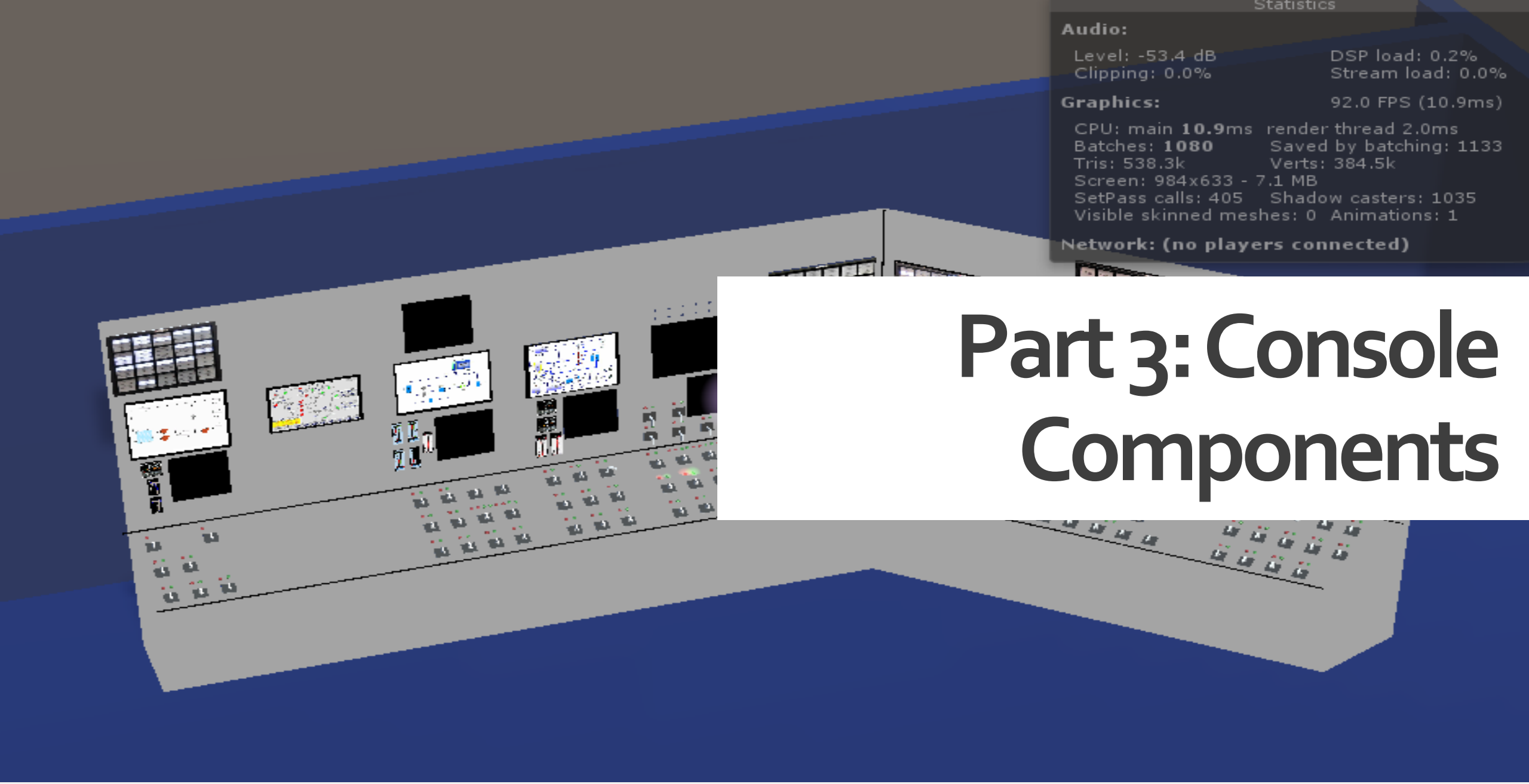



Statistics
Audio:
Level: -74.8 dB
DSP load: 0.3%
Clipping: 0.0%
Stream load: 0.0%
Graphics:
556.6 FPS (1.8ms)
CPU: main 1.6ms render thread 1.5ms
Batches: 694
Saved by batching: 0
Tris: 14.7k
Verts: 22.6k
Screen: 1920x909 - 20.0 MB
SetPass calls: 693
Shadow casters: 0
Visible skinned meshes: 0
Animations: 2
Network: (no players connected)

Final Console Mesh

- <1k Triangles
- Lower triangle and vertex count
- Sacrificed aesthetics
- Flattened console





Part 3: Console Components

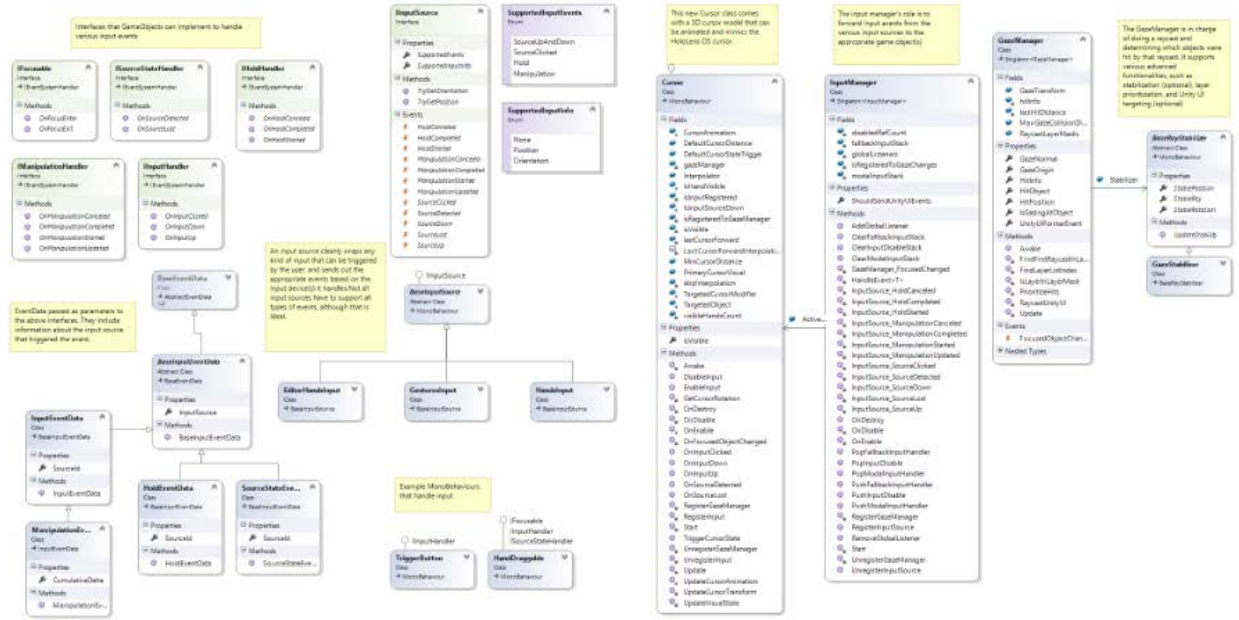
Microsoft Mixed Reality Toolkit

- "Collection of scripts and components intended to accelerate the development of applications targeting Microsoft HoloLens"
- Open Source

Features include support for input, spatial mapping, sound, boundary and more

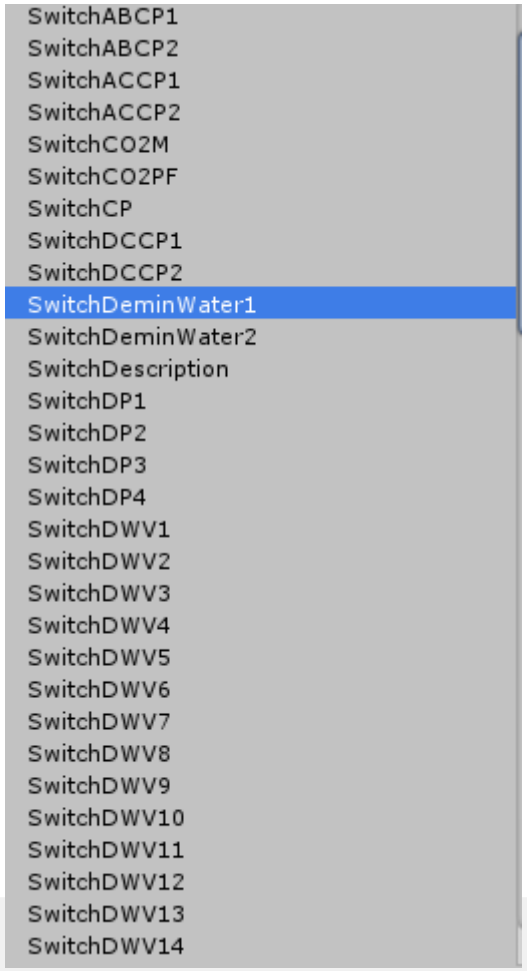
Used the Input API for programming interactions

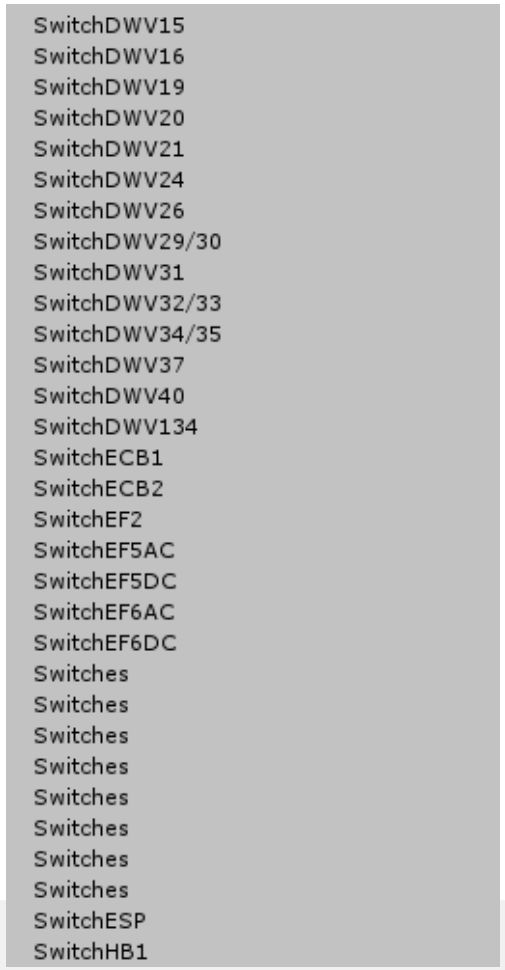
Input System Diagrams:

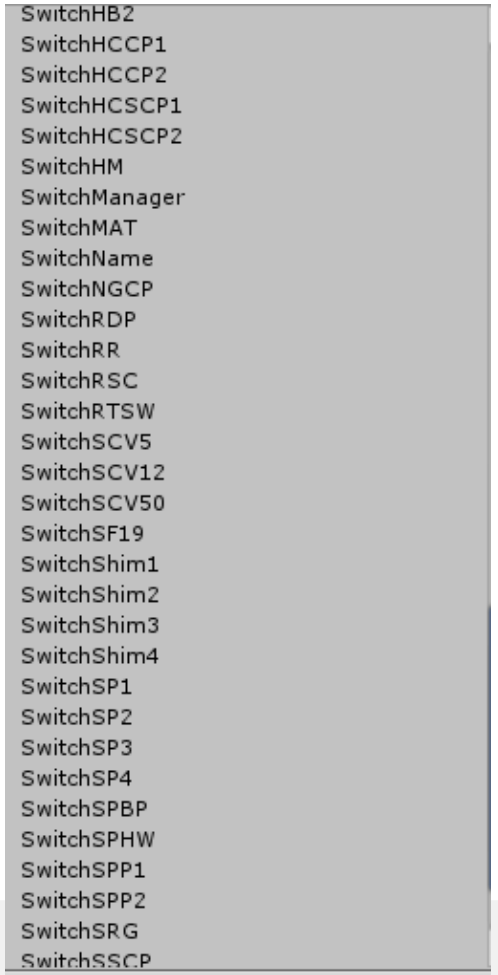


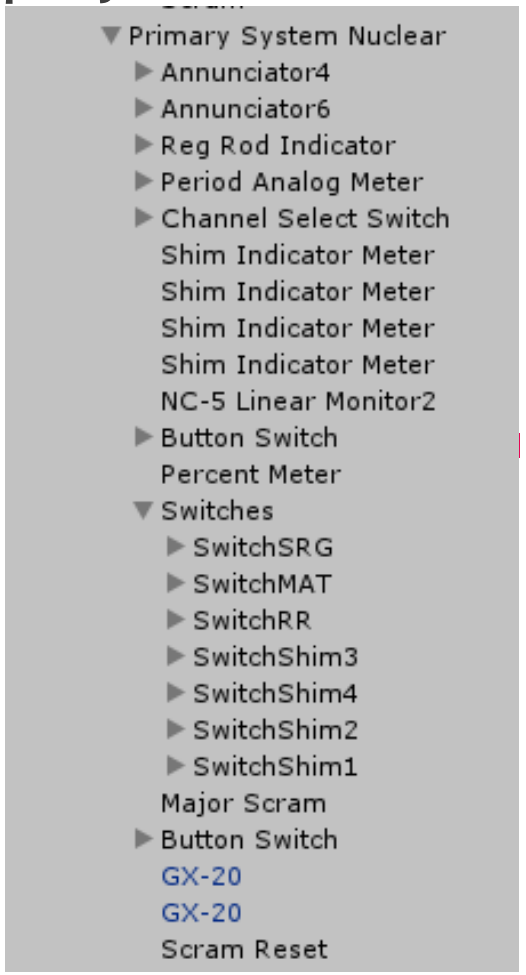
Components

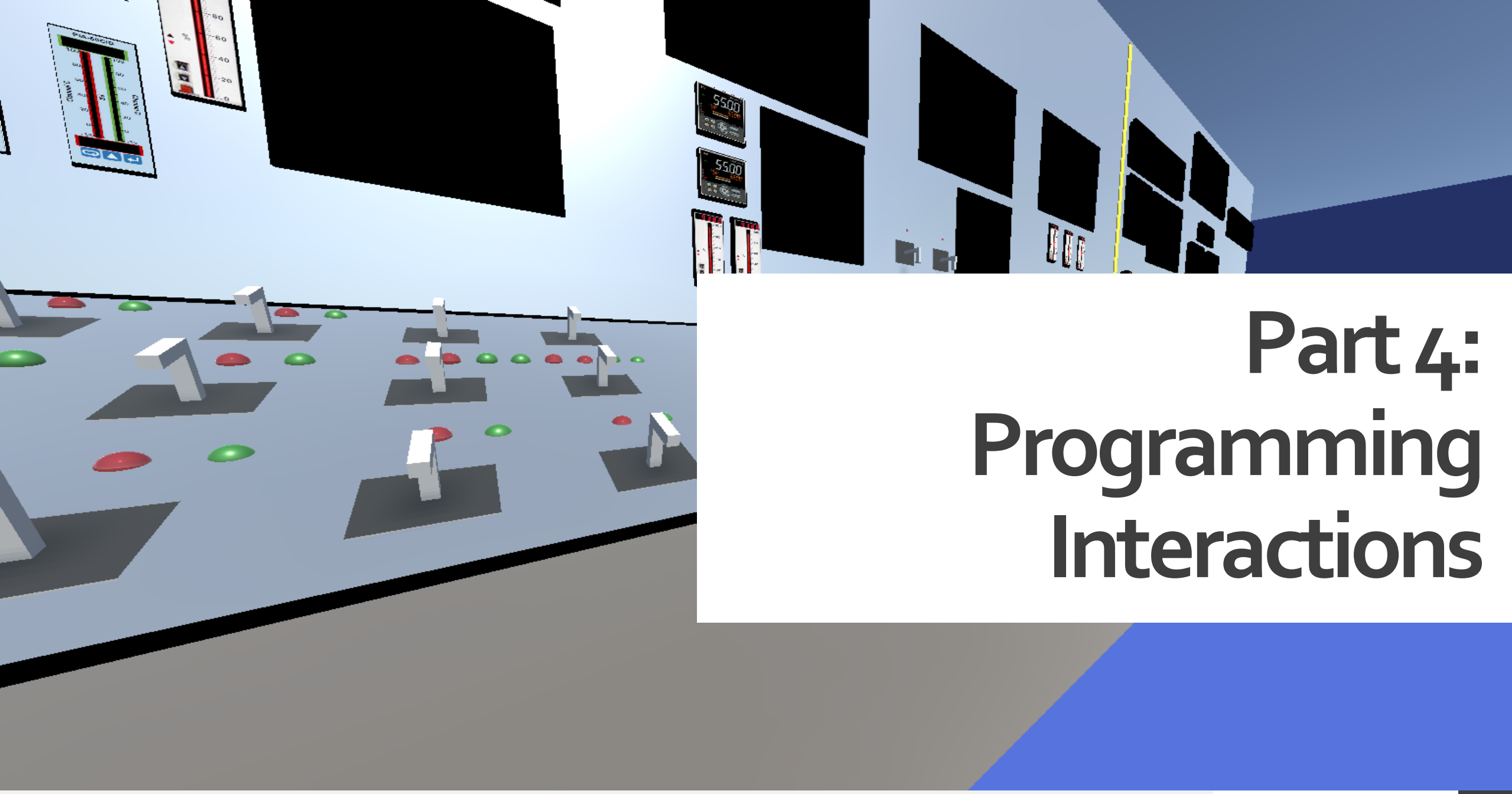
- Upgrade design incorporates approximately 84 switches, 10 recorders, 8 system screens, meters, annunciators and other digital displays
  - Each components has unique name, descriptions and function











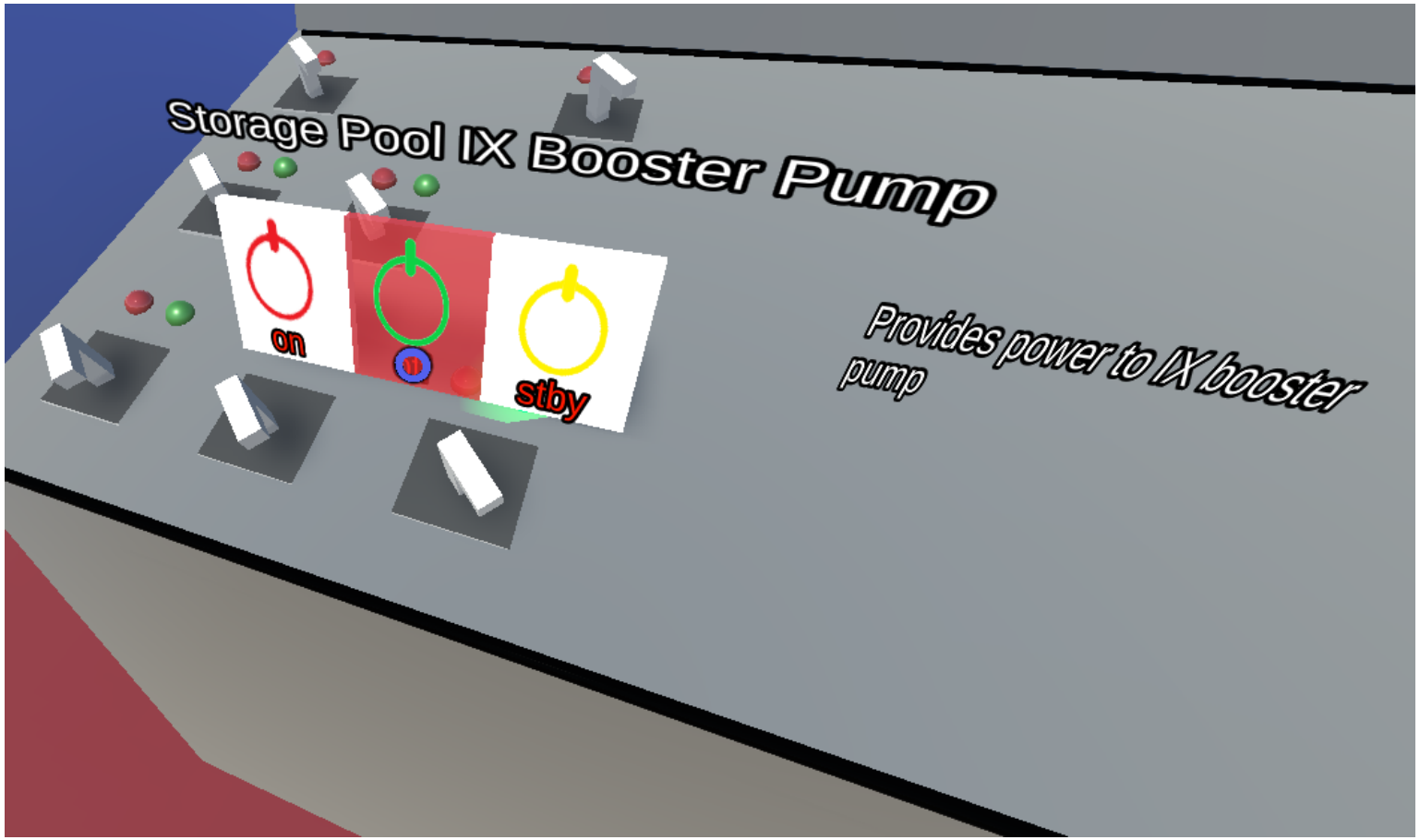
Part 4: Programming Interactions

Components

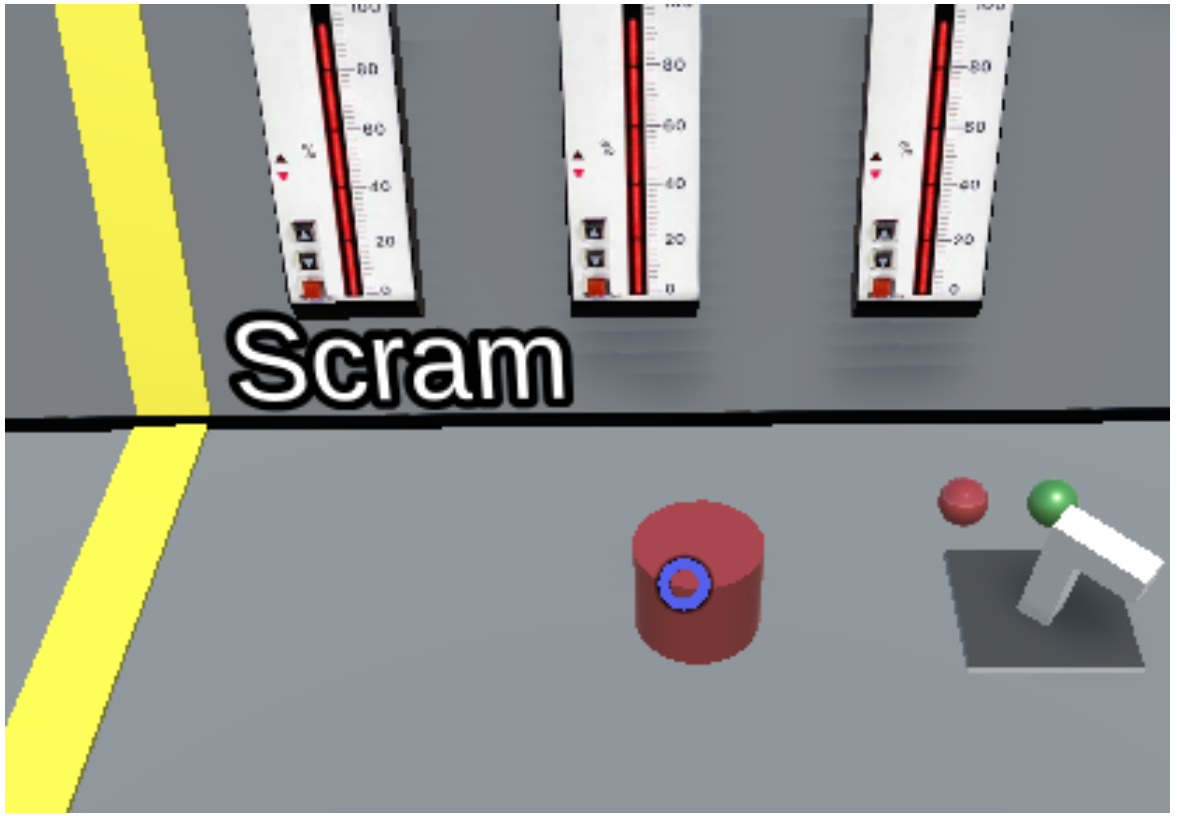
- Used Comma Separated Values (CSV files) and C# Dictionaries to produce a mapping of a switch to its corresponding actions

When the HoloLens user fixes their gaze onto a switch - its name, description and a menu of all of its options appear

Already serves as an educational tool



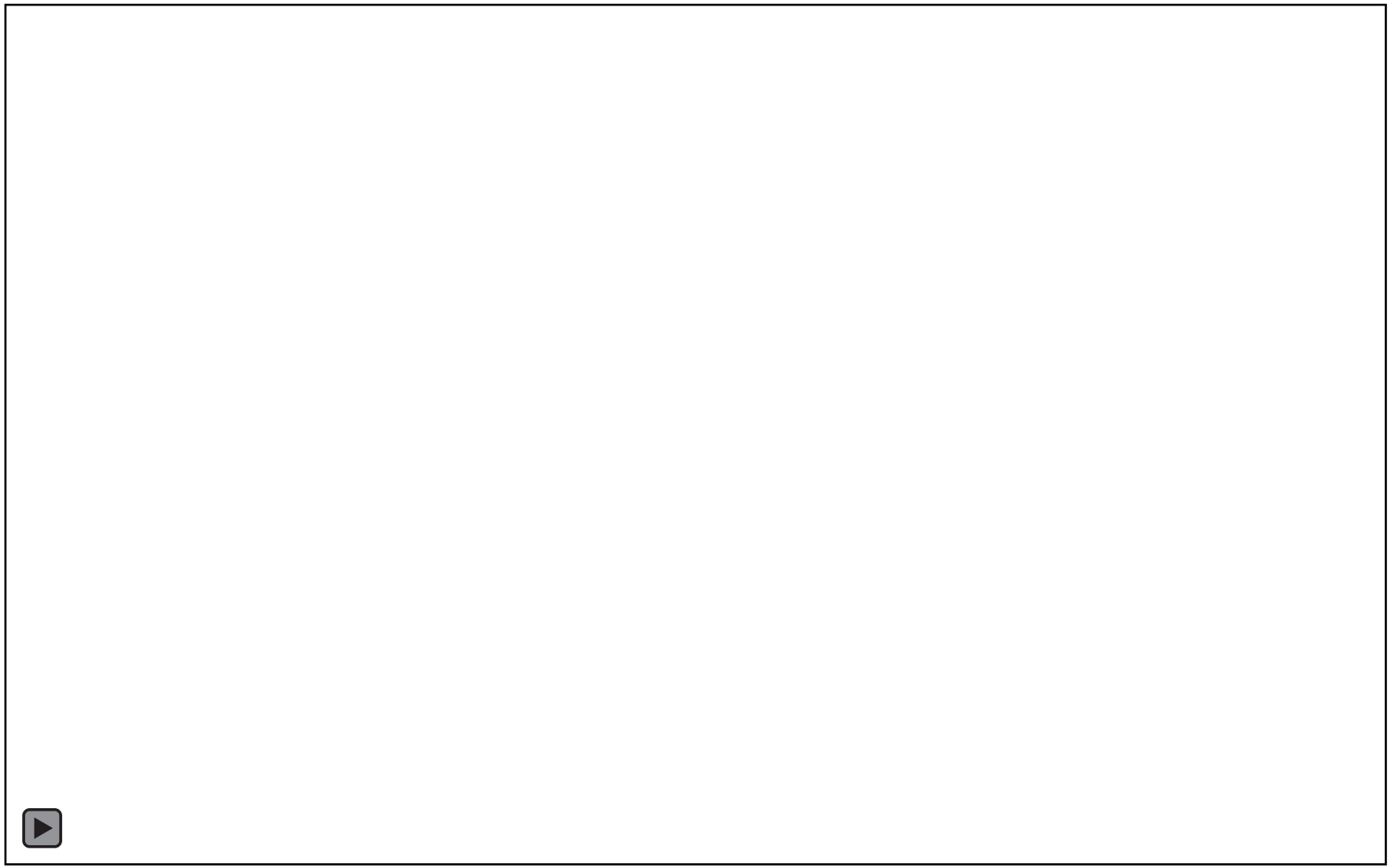
Same action for single action buttons like Annunciators and SCRAM



Switch Movement

Switch also has a state that controls its movement

Switch position and indicator light depends on its position

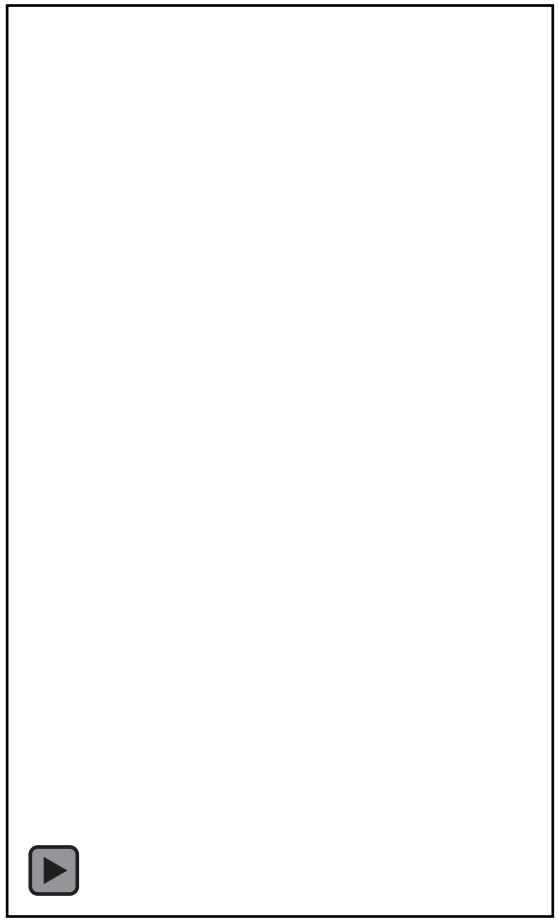


Updating Simulation Values

- A reactor console has many components that keep track of various data and information crucial to the safe operation of the reactor
- Designed and implemented an architecture that allowed the continuous updating of values

Storage Pool system screen updating every second in accordance with realistic values

Updating Simulation Values

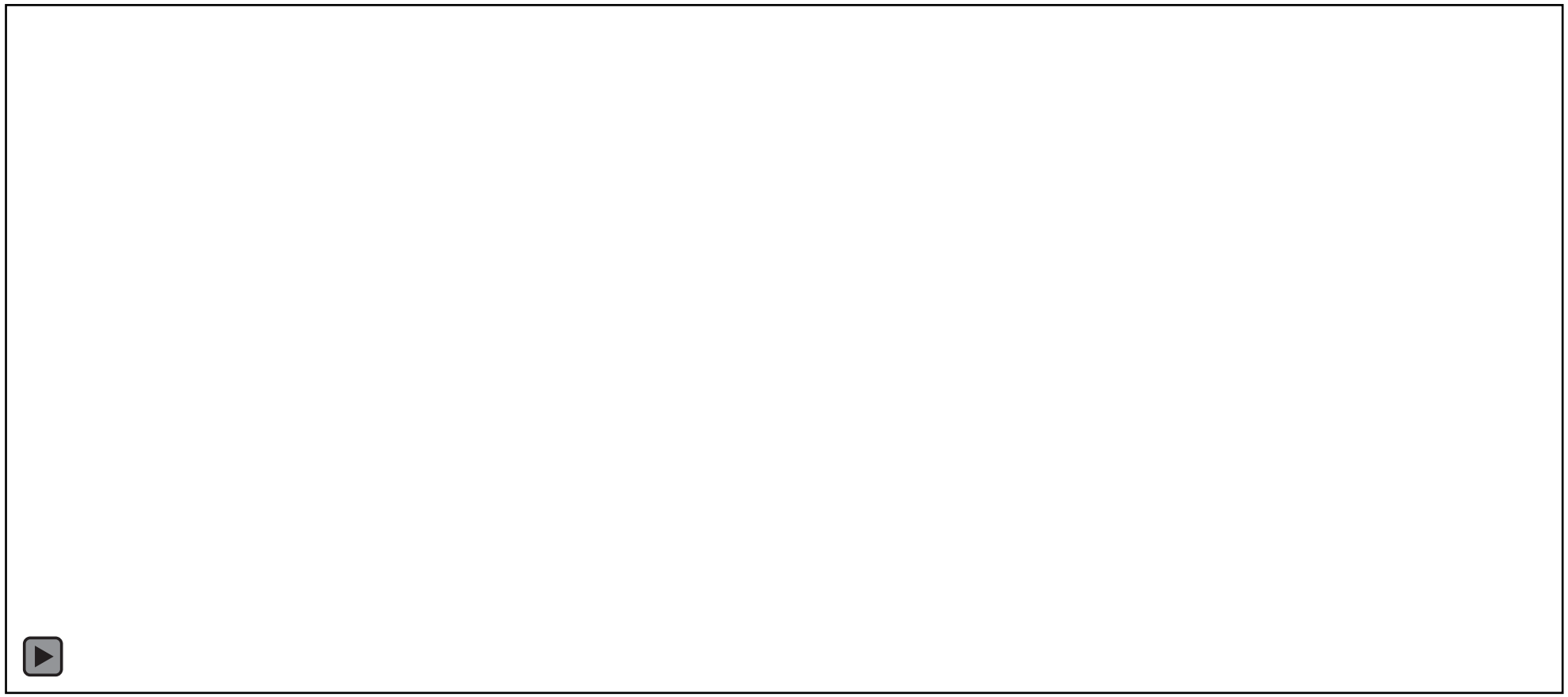


Similar to Switches, updating database values on the UI component of the Console involves loading CSV file at runtime and using a dictionary to map the name to a GameObject

Storage Pool IX Booster Pump	on/off/stby	Provides power to IX booster pump	SwitchSPBP	HIC-33	0		
EXP Demin Water Pump #1	on/off/stby	Provides power to the experimental demin water pump #1	SwitchDeminWater1	HIC-35	0		
EXP Demin Water Pump #2	on/off/stby	Provides power to the experimental demin water pump #2	SwitchDeminWater2	HIC-34	0		
Helium Compressor Sec Cooling Pump #1	on/off/stby	Provides power to the Helium Compressor Sec Cooling Pump #1	SwitchHCCP1	HIC-81	0	Thermal Column	
Helium Compressor Sec Cooling Pump #2	on/off/stby	Provides power to the Helium Compressor Sec Cooling Pump #2	SwitchHCCP2	HIC-82	0		
He Make Up	open/closed/auto	Does something related to Helium	SwitchHM		0		
CO2 Makeup	open/closed/auto	Does something related to CO2	SwitchCO2M		0		
D2O Exp Cooling Iso Valve DWV-26	open/closed	Opens or closes the Valve	SwitchDWV26	HIC-29	0		
D2O Exp Return Iso Valve DWV-24	open/closed	Opens or closes the Valve	SwitchDWV24	HIC-31	0		
Helium Blower #1 & Discharge Valve HEV-6	on/off/stby	Blows Helium?	SwitchHB1	HIC-79	0		
Helium Blower #2 & Discharge Valve HEV-7	on/off/stby	Blows Helium?	SwitchHB2	HIC-78	0		
D2O Exp Cool Booster Pump #1	on/off/stby	Activates the D2O booster pump	SwitchECB1	HIC-74	0		
D2O Exp Cool Booster Pump #2	on/off/stby	Activates the D2O booster pump	SwitchECB2	HIC-73	0		
Thermal Column Pump #1	on/off/stby	Activates the Thermal Column Pump	SwitchTCP1	HIC-61	0		
Thermal Column Pump #2	on/off/stby	Activates the Thermal Column Pump	SwitchTCP2	HIC-62	0		
CO2 Purge Fan	on/off	Activates the CO2 purge fan	SwitchCO2PF		0	Aux System	
Emer Tank Make-up Valve DWV-40	open/closed	Controls the emergency tank make up valve	SwitchDWV40	13-4	0		
Pre-Filter Isolation Valve DWV-16	open/closed	Controls the Pre-Filter Isolation valve	SwitchDWV16	12-2.	0		
Reactor Pump Up Isolation Valve DWV-134	open/closed	Controls the reactor pump up isolation valve	SwitchDWV134	HIC-24	0		
#1 Storage Tank Pump Outlet Valve DWV-14	open/closed	Controls the Storage Tank Pump Outlet	SwitchDWV14	HIC-23	0		
#2 Stoage Tank Pump Outlet Valve DWV-15	open/closed	Controls the Storage Tank Pump Outlet	SwitchDWV15	HIC-20	0		
HE-2 Sec Inlet SCV-12	open/closed	Controls whatever	SwitchSCV12	HIC-19	0		
D2O Stor Tank Pump #1	on/off/stby	Controls the D2O storage tank pump	SwitchSTP1	HIC-71	0		
D2O Stor Tank Pump #2	on/off/stby	Controls the D2O storage tank pump	SwitchSTP2	HIC-72	0		
Dilution Exhaust Fan EF-2	on/off/stby	Controls the dilution exhaust fan	SwitchEF2	EF-2	0	Ventilation System	
Decontamination Recirculation Fan SF-19	on/off/stby	Controls the decontamination recirculation fan	SwitchSF19		0		
AC Power Emer Exh Fan EF-5	on/off/stby	Controls the AC power emergency exhaust fan	SwitchEF5AC		0		
AC Power Emer Exh Fan EF-6	on/off/stby	Controls the AC power emergency exhaust fan	SwitchEF6AC		0		
DC Power Emer Exh Fan EF-5	on/off/stby	Controls the DC power emergency exhaust fan	SwitchEF5DC		0		
DC Power Emer Exh Fan EF-6	on/off/stby	Controls the DC power emergency exhaust fan	SwitchEF6DC		0		
Fuel Transfer Overflow Valve DWV-37	open/closed	Controls the fuel transfer overflow valve	SwitchDWV37	HIC-18	0		
Exp D2O Emer Cooling Valves DWV-29 & 30	open/closed	Controls the emergency cooling valves 29 & 30	SwitchDWV29/30	HIC-13	0		
Emer Cooling to Plenums DWV-34 & 35	open/closed	Controls the emergency cooling to plenums valves	SwitchDWV34/35	HIC-15	0		

Trending data values

- The upgraded control console uses 10 Digital Recorders to display pertinent trending and graph data
- To simulate this, used Chart and Graph Software for Unity



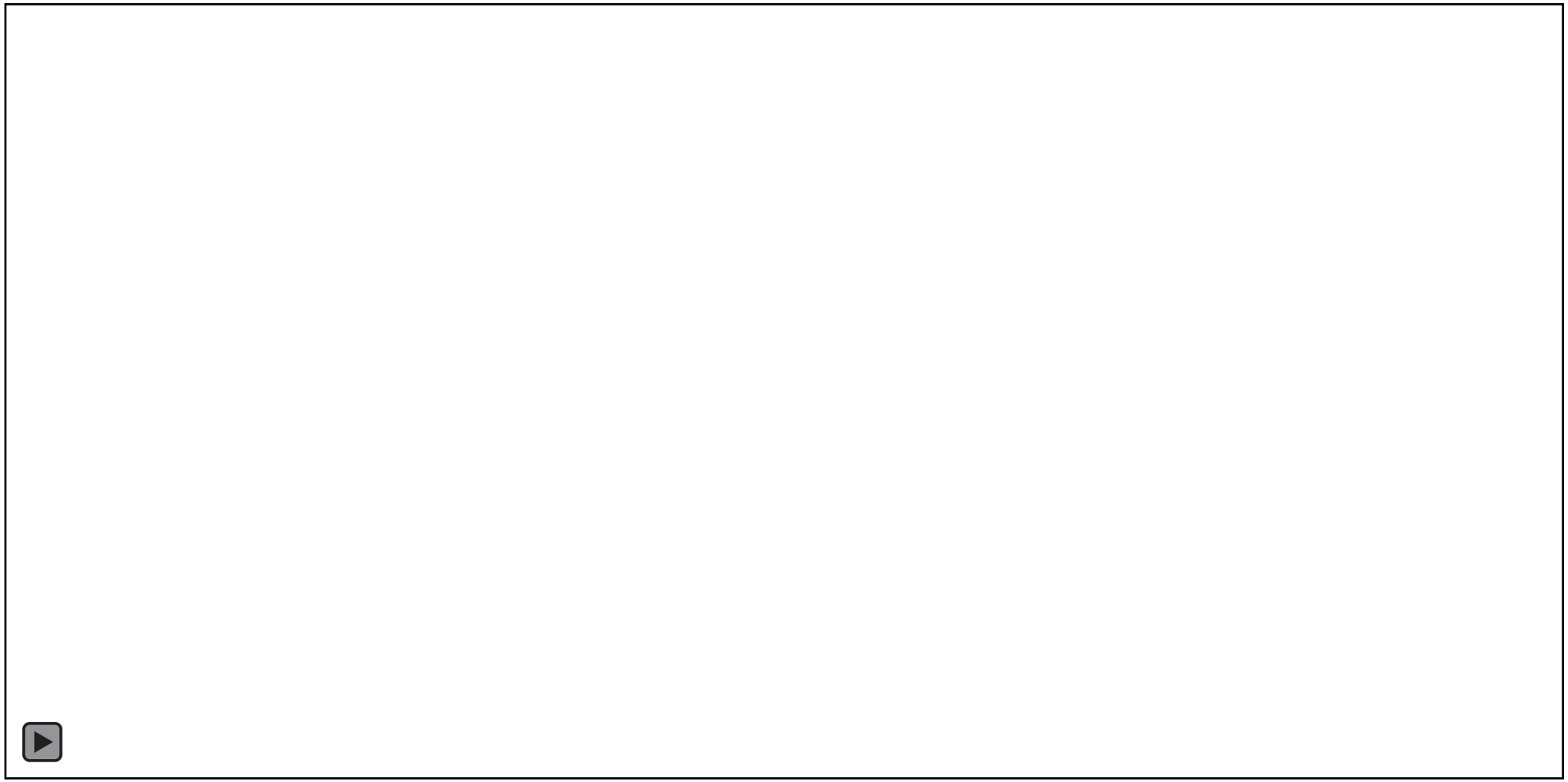
Perturbation Manager

- To simulate the complex interactions between the user and the console we had to come up with a mapping matrix between cause and effect
- For example, changing a switch that controlled flow would change the flow indication which affects other values such as temperature/pressure of the system

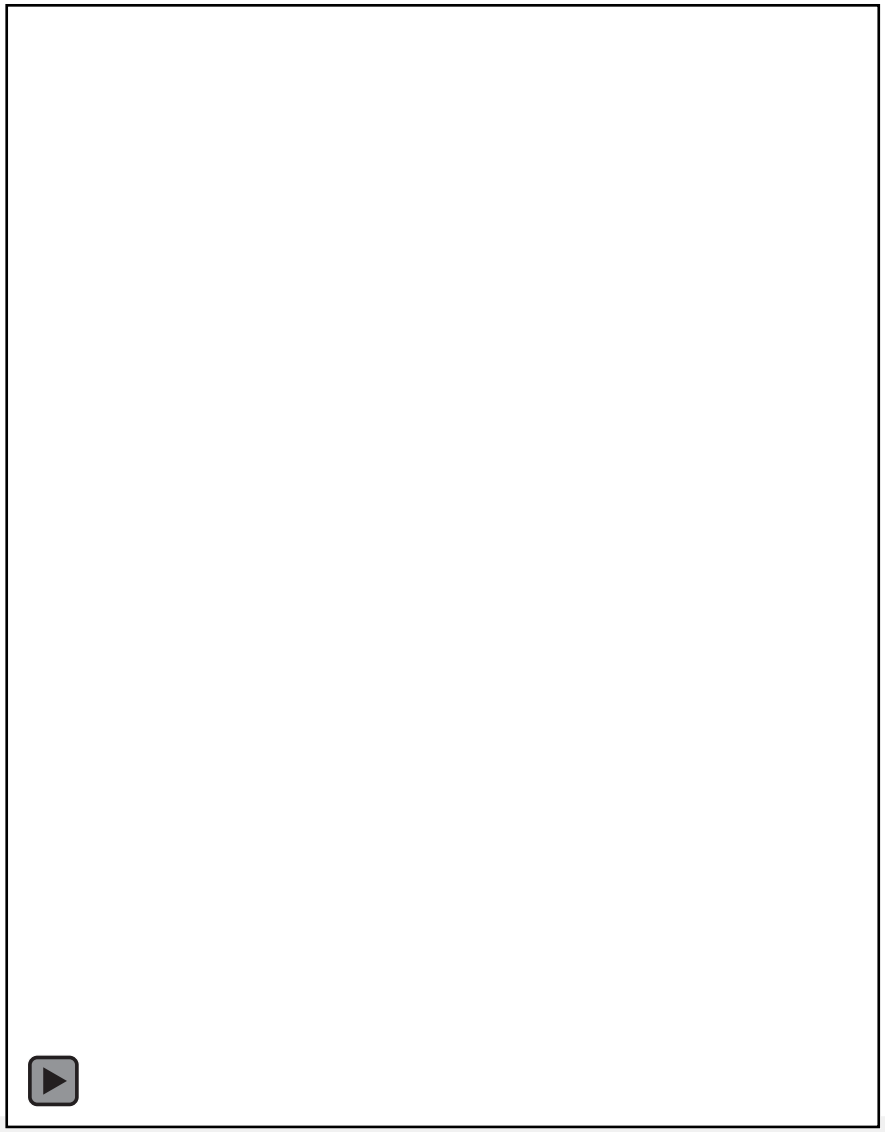
Surroundings

Programmed a model to move around the room

- Have plans to add interaction capabilities
  - Help prompt the user
  - Issuing commands to operate equipment outside of the control room



Menu Screen, Version .1

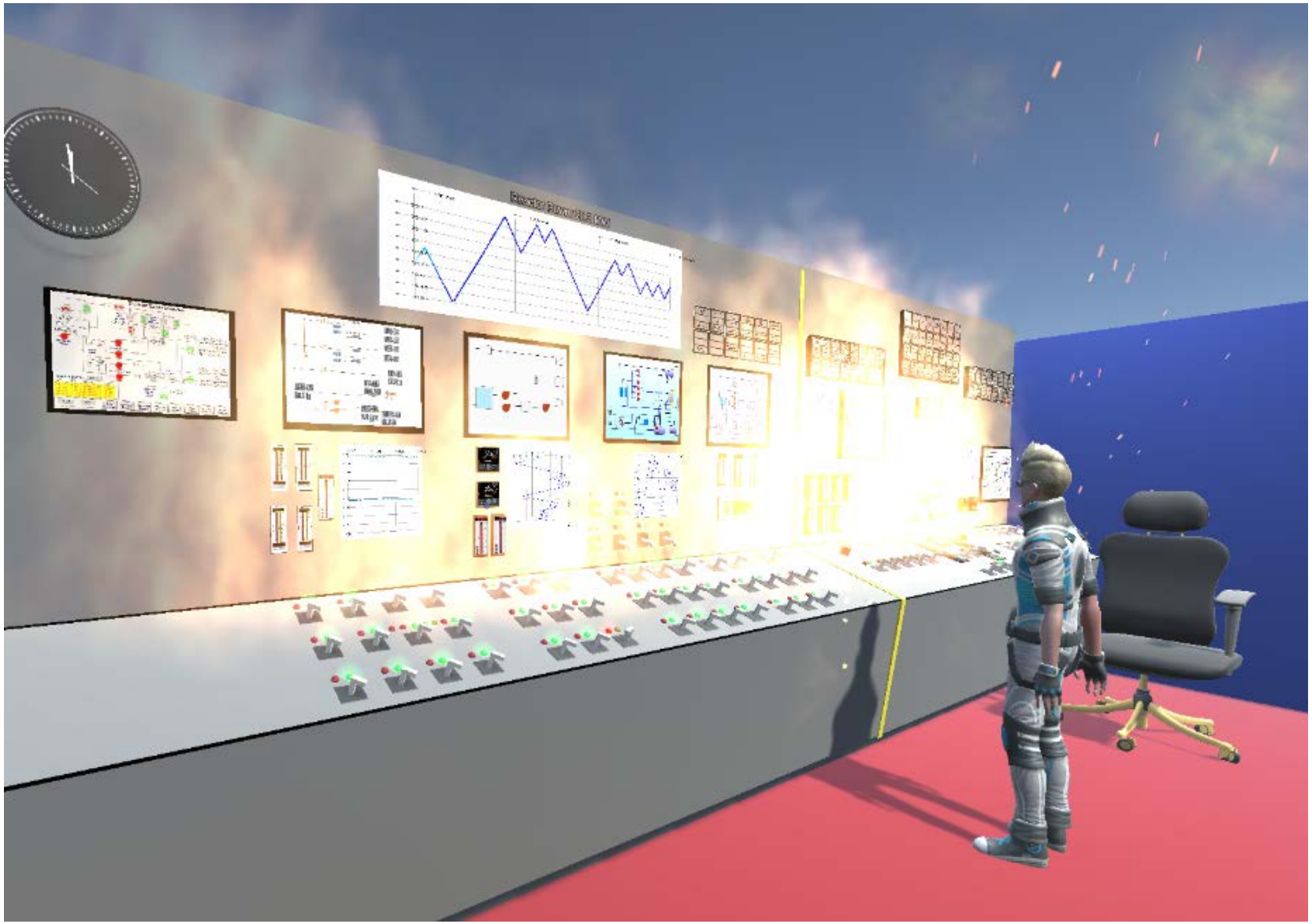


Start Button leads to a menu that allows you to select the scenario/scene

Options menu will be for setting text size, switch menu options, anything we can think of

Scenarios

- Operator can choose from multiple scenarios
  - Fire on Console
  - Startup procedure
  - Scram Procedure
- Possibilities are endless as long as you can program them



Current Final Version

Future Work

- Improving visuals
  - Make switches, lights, meters and components look more realistic
  - Install new system screens as soon as they are created and update tags
- Operator interaction
- Scenario creation: SCRAM, emergency loss of coolant
- **Performance optimization**
- Adding more dynamic interactions to the console

Acknowledgements

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Questions?


NSF
CHRNS
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