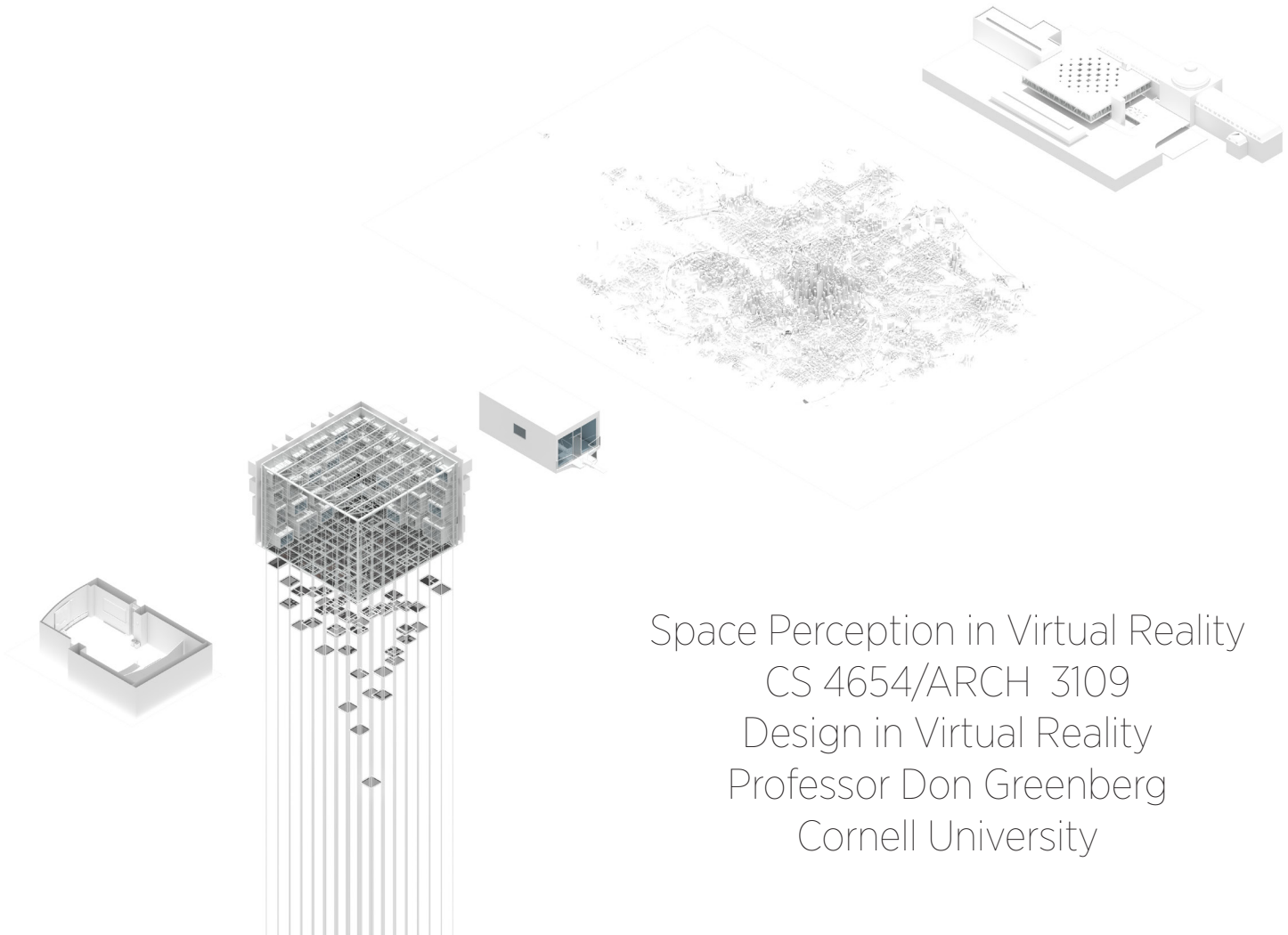


Space Perception in Virtual Reality
CS 4654/ARCH 3109
Design in Virtual Reality
Professor Don Greenberg
Cornell University

# Space Perception in Virtual Reality

This booklet outlines an experiment and demo on scale perception in virtual reality (VR). This project was developed as part of Don Greenberg's experimental architecture and computer science studio at Cornell University during the Spring 2016 semester.

This studio consisted of 10 computer science students, 5 architecture students, and 1 Ergonomic student.  These students worked in small multidisciplinary teams to tackle specific challenges facing virtual reality in 2016. This represents one project centered around the theme of space perception.

# Background

## *Why virtual reality in 2016?*

Although virtual reality has been explored in the past, it is at a breaking point in 2016. Technology costs and computer speed have been driven down to make virtual reality affordable at a mass consumer scale. During 2016, several major commercial headsets are being released onto the market for the first time.

Samsung Gear
*November 2015*

Oculus Rift
*March 2016*

HTC Vive
*April 2016*

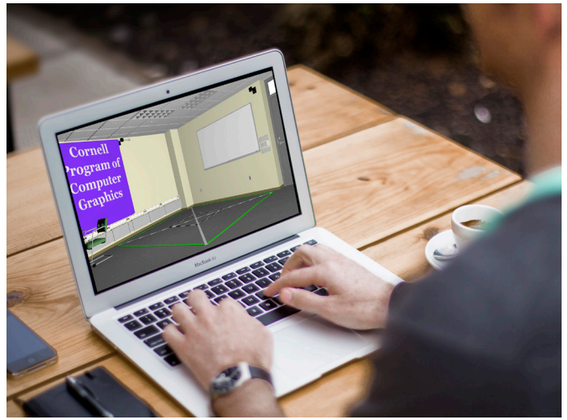
Playstation VR
*October 2016*

# Introduction

## *Space Perception in Virtual Environments*

As VR becomes more accessible, it is critical to understand the implications of space perception in VR. This is particularly applicable to architects and designers who rely on VR to showcase their designs to clients.

Currently designers rely on image renderings, animations, and interactive walkthroughs displayed on computer monitors.  Although interaction within an environment has proven beneficial, no study has directly compared interactive walkthroughs in virtual reality vs on a computer monitor.




# Hardware


Our studio class used the HTC Vive by Valve for our Virtual Reality projects. Currently the Vive is the only headset on the market that fully tracks the user and allows for both a physical and digital immersive experience. In both our experiment and demo, the ability to move within the space and control menus and objects with your hands are essential elements to the overall experience. Our environments maximize the trackable play area of the vive through our original transport tool.

# Software

MAYA

Maya was used as a modeling and UV-mapping tool. Rhodes Conference Room and Seinfeld's Apartment were modeled in Maya, and all environments were used Maya for UV-mapping.

Rhinoceros®

Rhinoceros 5.0 was used as a modeling and conversion tool. Milstein Hall, NYC, and the Space Room were modeled in Rhino, and UV-mapped in Maya.

UNREAL ENGINE

Unreal Engine 4.10 was used as the gaming engine. 3D models were brought in from Maya into Unreal. All interactions and menu UI elements were created with blueprints in Unreal.

STEAM® VR

Our projects were launched in unreal through steam VR. This allowed Unreal projects to be opened in the Vive headset.

# 1

# The Experiment

Empirical Study on
Space Perception in
Virtual Reality

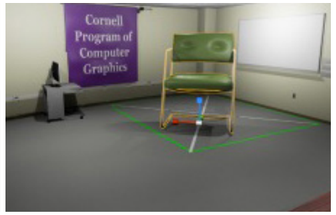
Analyzing the effects of ***contextual cues and display medium*** (HMD vs Computer Display) on ***spatial perception in virtual environments.***


# Abstract

This experiment is a two by two between-subjects factorial design. Each subject will be given 6 objects (3 pieces of furniture and 3 amorphous shapes) to study for 3 minutes each. After studying the object, the subject will be asked to scale a virtual version of the object six times. Each time will start with a random scale. The two variables are the level of contextual cues in the environment, and the medium of interaction (HMD vs Computer Monitor).

# Hypotheses

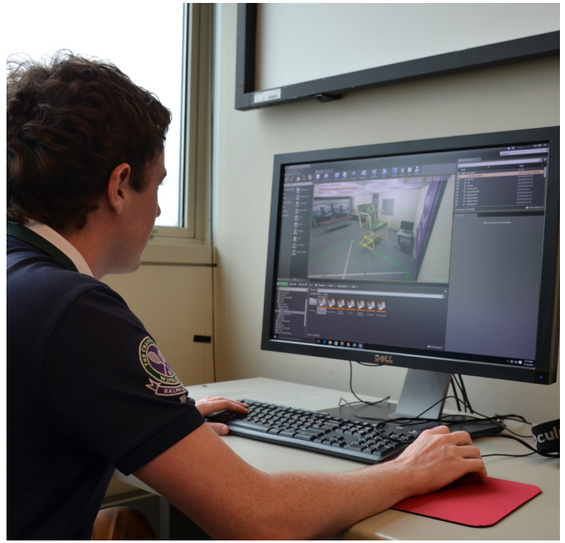
1. VR is more accurate than Computer Displays at translating scale in virtual environments
2. Presence is a mediating factor in spatial scale perception in virtual environments
3. Higher levels of contextual cues will lead to more accurate perception of scale
4. Subjects with better spatial ability will more accurately scale the objects in the virtual world




| | | *Level of Contectual Cues in Environment* | |
|---|---|---|---|
| | | *Plane Environemnt* | *Interior Environemnt* |
| *Interaction Medium* | *Head Mounted Display* | Group 1 | Group 2 |
| | *Computer Display* | Group 3 | Group 4 |

# Scaling Objects

## *Computer Monitor*

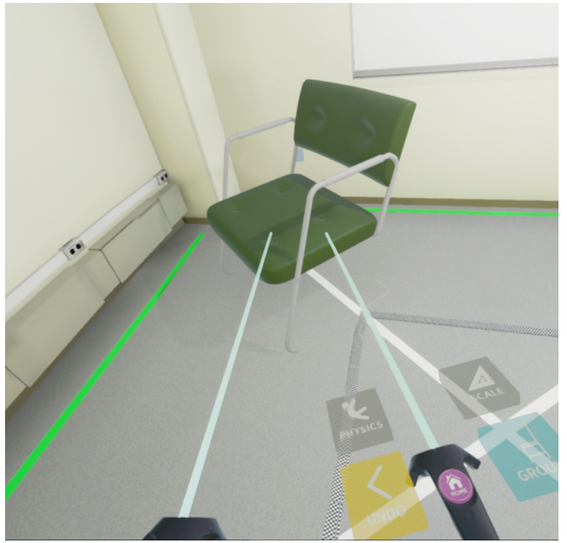


Two groups will conduct the experiment on a computer monitor. ***Computer monitors*** can often portray a false sense of scale.

The two groups using a computer monitor will scale the object with a ***gumball scaling tool.***

## *Head Mounted Display*

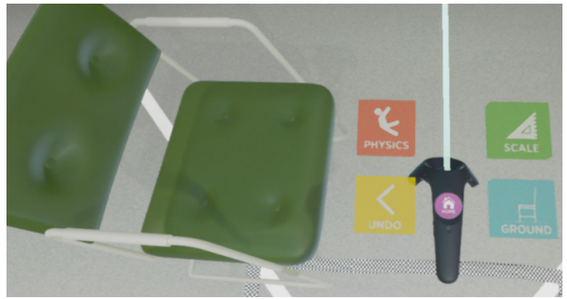
The other two groups will do the scaling experiment on the ***HTC Vive***. The Vive allows for an immersive experience.




The two groups using the HTC Vive have a ***UI menu*** that allows them to grab and dynamically scale the object.

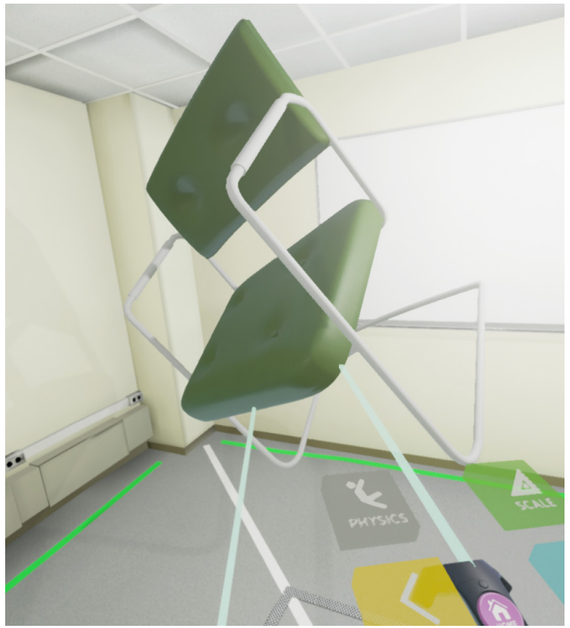
# Experiment User Interface

## *Scaling Menu*



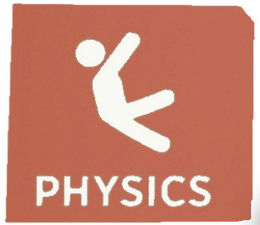

*Menu UI*


*Physics*




*Free Scale*

The physics button allows the user to use physics to throw and place objects.




The undo button allows the user to undo the last action completed.




The scale button allows the user to switch between "free scale," and "origin scale." Free scale allows the user to grab, scale, and rotate the object, while origin scale allows the user to scale from the pivot point.


The ground button places an object flat on the floor plane.

# Preliminary Findings

**Pilot Testing**

***Sense of scale is always better in VR than on a 2D display***

***2D sense of scale is dependant on context***

- Can be made arbitrarily bad without context
- Subject to anchoring bias

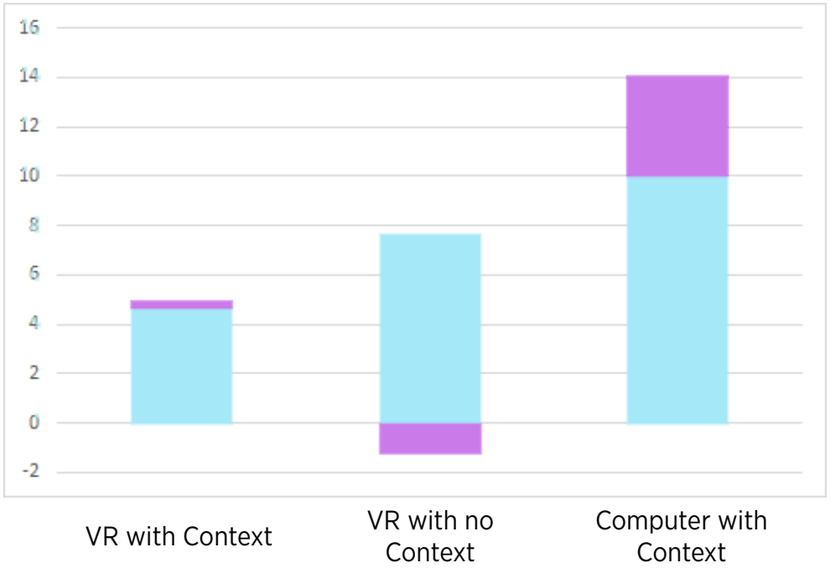
***VR sense of scale more absolute***

- Diminishes only slightly without context
- No / minimal anchoring bias

| Interaction Medium | Level of Contectual Cues in Environment: Plane Environemnt | Level of Contectual Cues in Environment: Interior Environemnt |
|---|---|---|
| Head Mounted Display | VR without context **7.6%** average error. Anchoring: <1% | VR with context **4.6%** average error. Anchoring: <1% |
| Computer Display | 2D without context **150%+** average error. Anchoring: 70% | 2D with context **10%** average error. Anchoring: 4%+ |

**anchoring = the difference between the average size participants scaled the chaired to when it started small, compared to when it started large.*

## Scaling Percentage Error



2

# The Demo

Scale VR Experience

Creating a unique virtual reality demo centered around scale, space perception, and movement through space.

# Demo Levels

**Six Unique Virtual Reality Environments**

## Level 1


Rhodes Hall

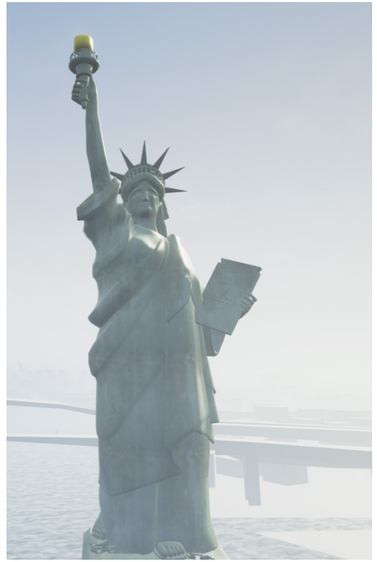
## Level 2

Chamber of Chairs

## Level 3

Gallery Room

## Level 4

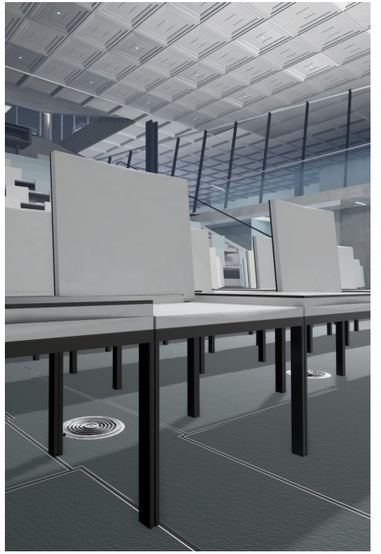


New York City

## Level 5


Seinfeld's Apartment

## Level 6



Milstein Hall

# Demo User Interface

**Controller 1- Home + Level Change**


*Image 1*

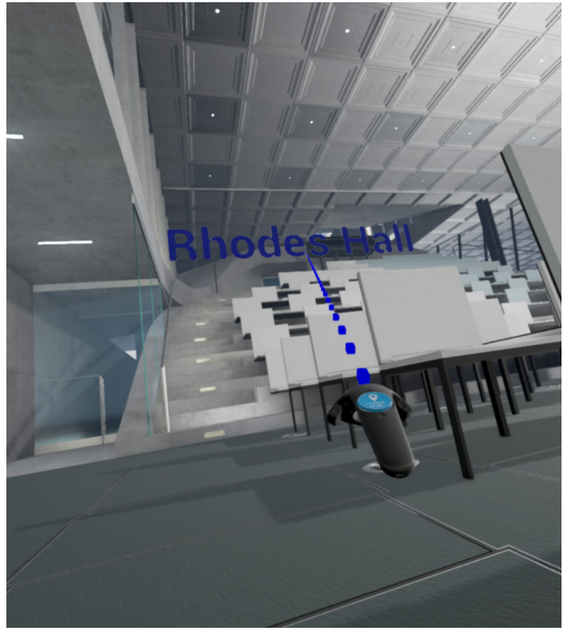



*Image 2*


### *Home Button*

Controller 1 will start with the ***home button***. When you press this button, you will return to Level 1, Rhodes Conference Room.


### *Level Change Button*

When highlighting over specific objects within the demo, the home button will transform into the ***level change button***. This button allows the user to enter a new environment within the demo. When highlighting over these special objects, text appears giving a description of the level (Image 1 + 2).

# Demo User Interface

**Controller 2- Transport Trajectory**

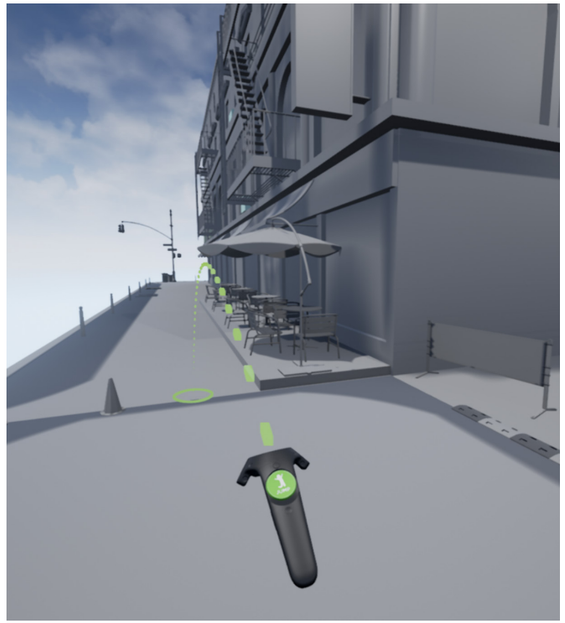


*Image 1*

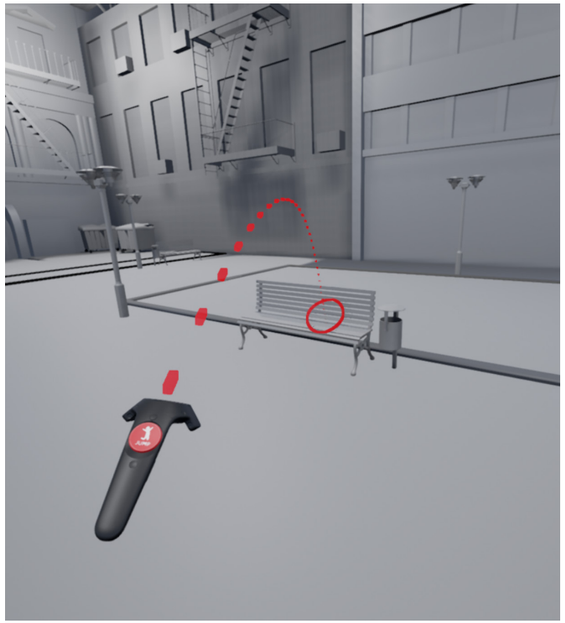


*Image 2*


*Jump (Transport/Trajectory) Button*

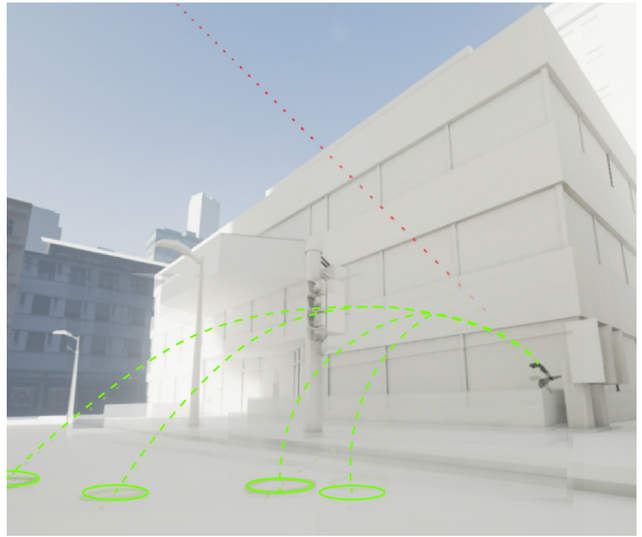
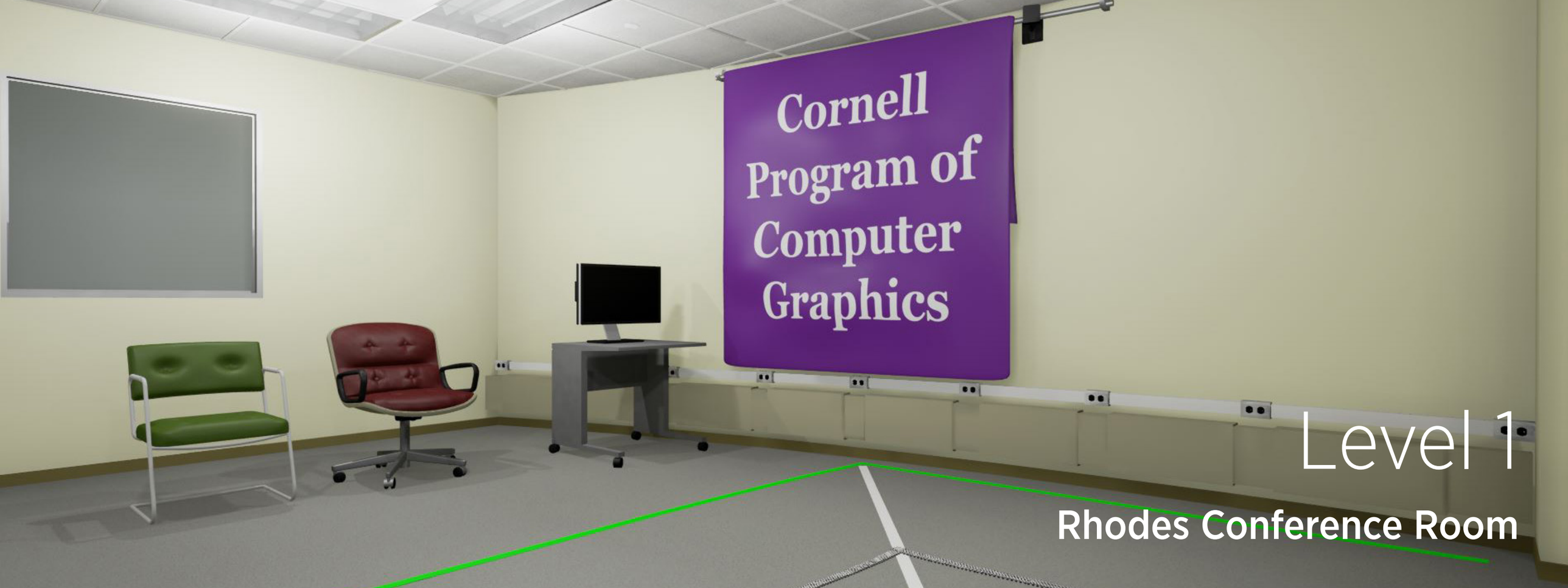


*Image 3*

To move around environments that are outside the vive tracking area, we developed a transport tool on controller 2. This tool projects a green trajectory where you can teleport (Image 1). When you are placing the trajectory on an area you can't transport to, the line and button turn red (Image 2). You can change the distance of the trajectory by scrolling on the thumb pad (Image 3).



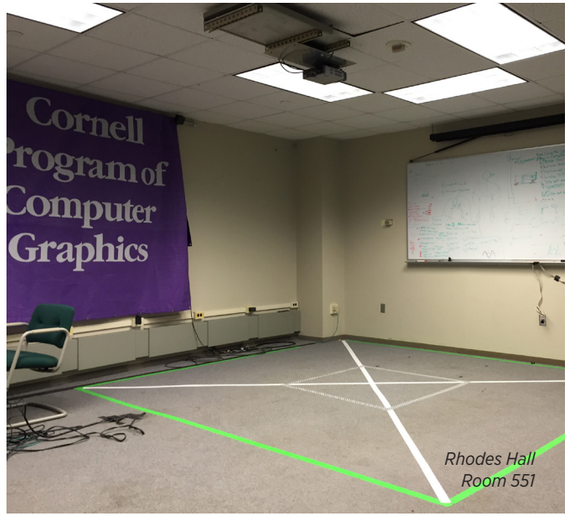

# Level 1

## Rhodes Conference Room

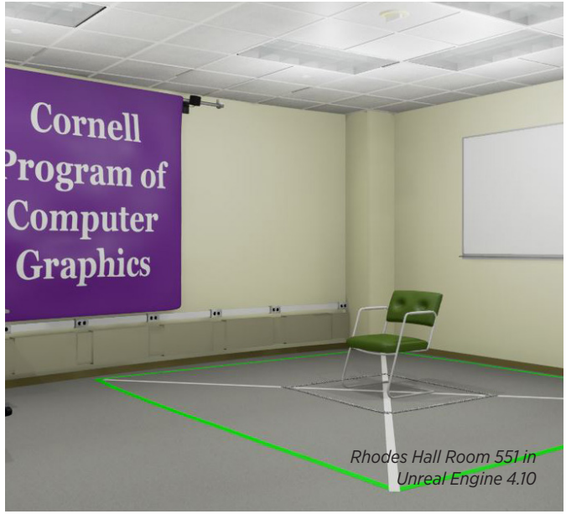
# Rhodes Conference Room

**The Origin Point of the Demo**

The origin of the demo starts in a conference room within Rhodes Hall at Cornell University. This environment was chosen as the starting point of the experience because it mirrors the real environment the vive headset is set up in. This environment was used in the experiment in section 1. The transition between each level plays with your perception of scale. Since the experience begins in Rhodes Hall, it makes an easy transition from the real to virtual world.




*Rhodes Hall Room 551*




*Rhodes Hall Room 551 in Unreal Engine 4.10*



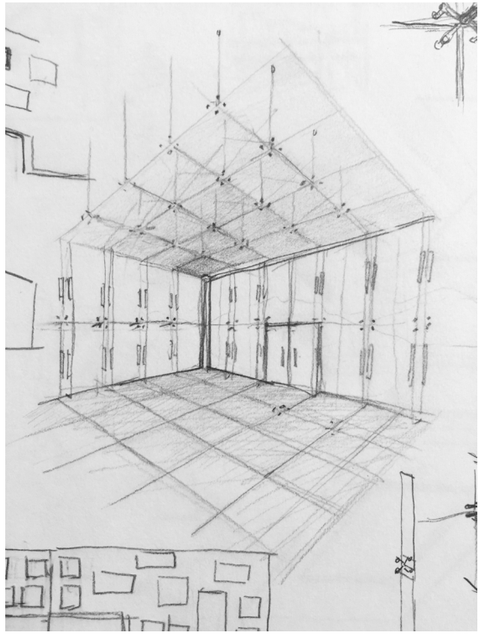
The Rhodes Conference Room virtual environment included all details from the real environment. This included items such as the Microsoft Hub, chairs, outlets, tables, computers, radiators, ceiling panels, and white-board. Pictured in the top row are images from the environment, and on the bottom row are parallel images from the virtual environment.

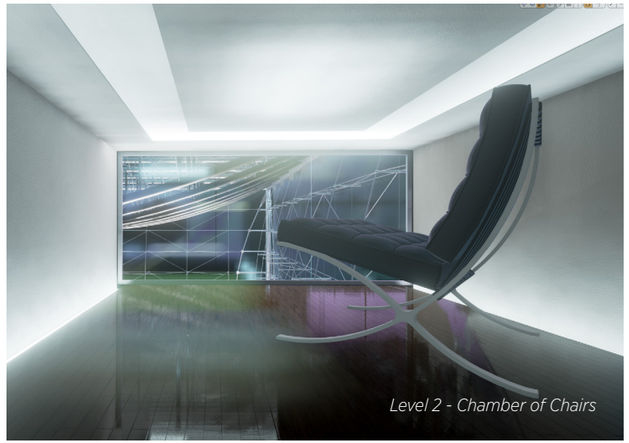

Level 2
Chamber of Chairs

# Chamber of Chairs

**A Room in Outer Space with Iconic Chairs**

The Chamber of Chairs features multiple cubicles that all lead to a centralized open space. Each cubby contains an oversized chair, with one cubby leading to Rhodes conference room.





*Level 2 - Chamber of Chairs*

The transition from Rhodes Hall to Level 2, the Chamber of Chairs, distorts your perception of scale. First the user must remove the white-board in Rhodes Hall (Image 1).

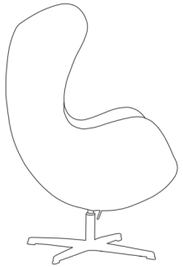
Behind the white board is a hole into  a cubby within the chamber. This one cubby is as large as Rhodes conference room. Within each cubby of the chamber is a chair. These chairs are over scaled sizes (Image 2).

# Chairs

**Iconic Chairs within the Chamber**

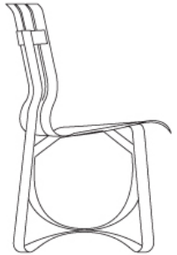
Skeleton Chair
*David Adjaye*

Swan Chair
*Arne Jacobsen*



Egg Chair
*Arne Jacobsen*

Barcelona Chair
*Mies van der Rohe*



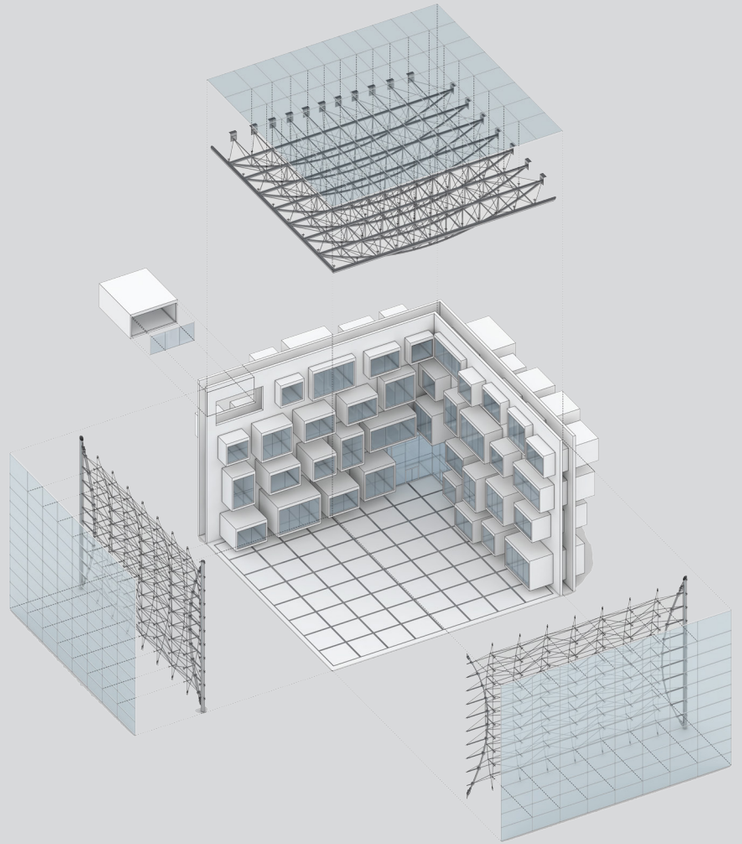
Hat Trick
*Frank Gehry*

Chair_One
*Konstantin Grcic*

Bertoia Chair
*Harry Bertoia*

Womb Chair
*Eero Saarinen*

The Chamber of Chairs is
set in outer space. The floor of the chamber
is glass with floating lights underneath.
This gives the sensation that you are
floating on a sea of lights within the stars.
Additionally, the character scale is small, so
the perception of space is large.



*Chamber of Chairs*
*Axonometric Drawing*

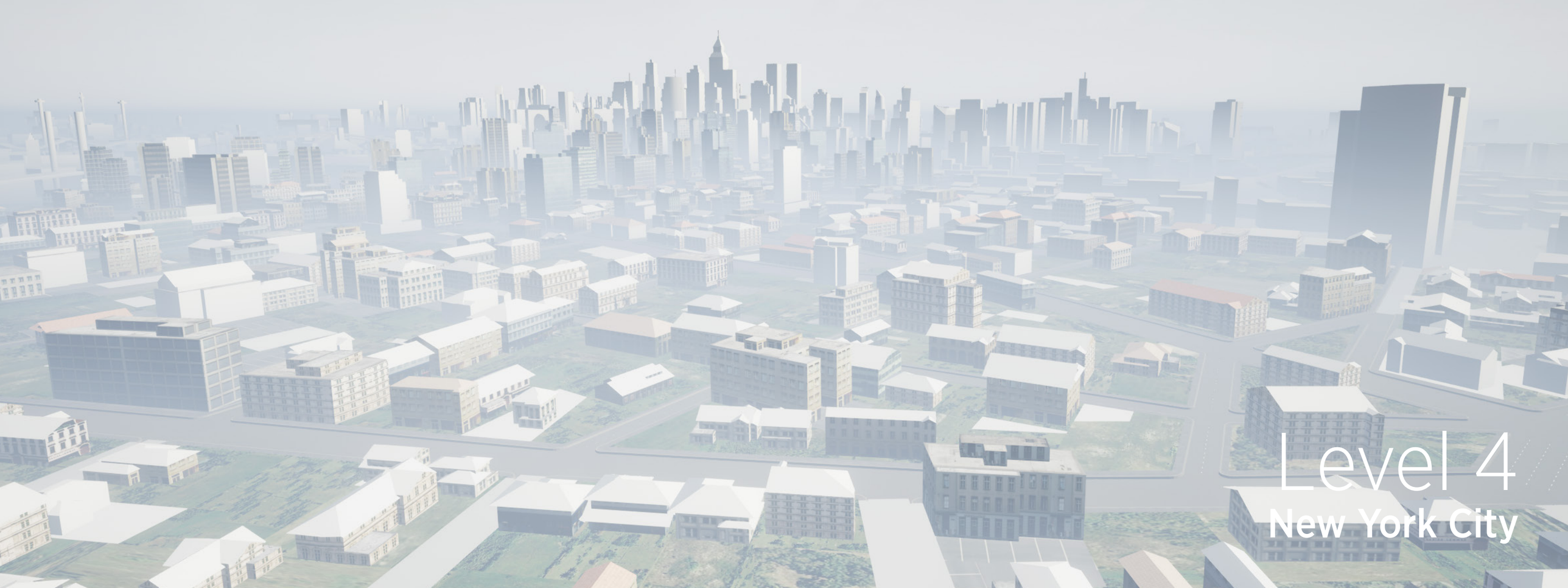

Level 3
Gallery Room

# Gallery Room

**An Art Museum within the Chamber of Chairs**

The gallery room is located in one of the cubicles within the Chamber of Chairs. This room includes three paintings on the walls, and a sitting area. By transitioning from a large space to a smaller space, the viewers perspective is drastically changed.

Each painting within the Chamber can lead to a different level. Both the NYC skyline and Statue of Liberty painting lead to the NYC city level, while the picture of Milstein Hall leads to the Milstein level. The view outside the gallery is a cityscape. This gives the user a transition from outer space to the top of a city. Additionally, on the side of the gallery facing the Chamber of Chairs is a diving board, allowing the user to walk out and view the glass floor and chair cubicles.



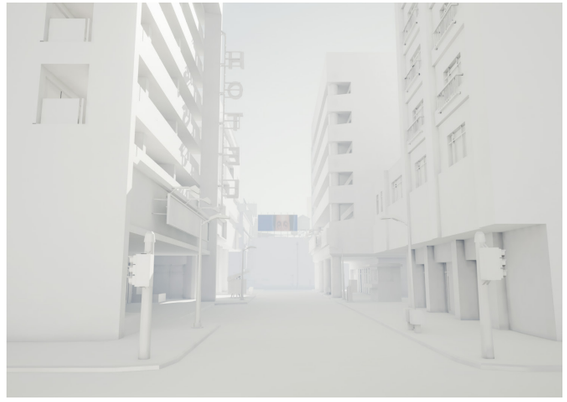
# Level 4

## New York City

# New York City

**Flying Through the City**

This level offers an animated fly-through of New York City. First the user starts out by flying to the statue of liberty. They then fly over the city and land in a detailed city block environment. In this environment, the user can explore the street scene.




The transition from New York City to Level 5, Seinfeld's Apartment is done through a billboard on building. While walking through the city, if the user hovers over the billboard they can use the level change button to transport into Seinfeld's apartment.

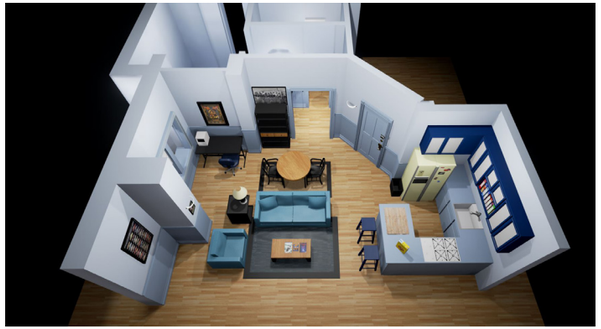

# Level 5

## Seinfeld's Apartment

# Seinfeld's Apartment

**An Immersive TV Experience**


Jerry Seinfeld's Apartment from the hit TV series ***Seinfeld***, is one of the most recognizable TV sets from the 20th century. This level recreates the apartment to experience in virtual reality. Parts of the apartment for this experience include the kitchen, living room, dinning area, and office alcove.





*Seinfeld's Apartment in Unreal Engine 4.10*




*Cheerios UV Map*


# Seinfeld's Cereal Collection

## Highly Detailed Environment

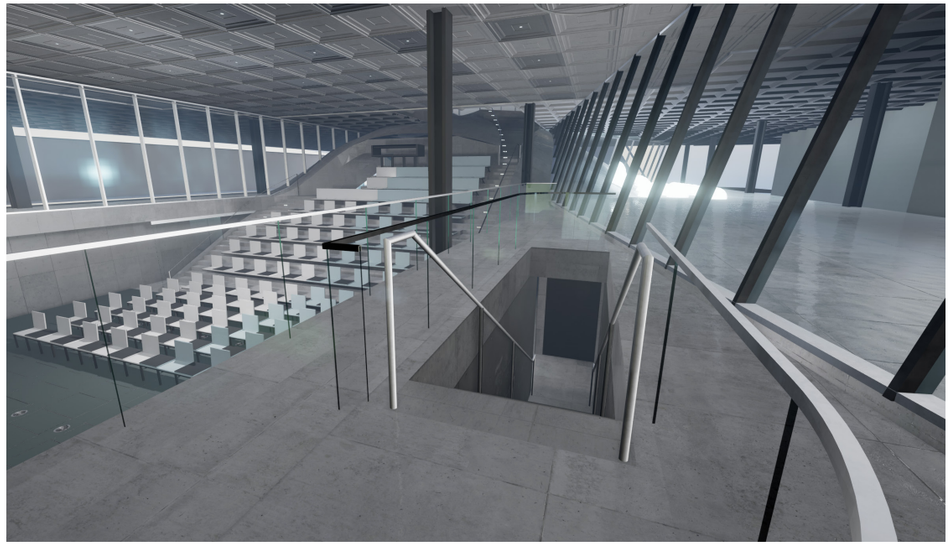
This experience featured a highly detailed environment. Every detail from the Seinfeld TV set was carefully analyzed and recreated. On the top of the opposite page is Jerry's cereal collection from the set and on the bottom is the collection recreated in Unreal Engine 4.10. This page features the UV map and grid for the Cheerios cereal box. Each side of the box was first scanned and placed into the UV grid to recreate the cereal box from scratch.

On top is a scene from Seinfeld with Jerry, Kramer, Elaine, and George in his apartment. The opposite page features Seinfeld's office alcove, kitchen, and living room. Each space features special artifacts from the TV show including artwork, the original Mac computer, New York Magazine and Time from 1999, and Jerry's bike.

*Seinfeld's Office Alcove in Unreal Engine 4.10*

# Level 6

## Milstein Hall Auditorium

# Milstein Auditorium

**An Iconic Academic Structure from a New Perspective**

This level features the auditorium space of Milstein Hall at Cornell University. Seinfeld's Apartment is at a miniature scale within Milstein Hall. When you leave the apartment, you realize that you are at a small scale within the space.

*Milstein Hall*
*in Unreal Engine 4.10*

Milstein Hall was completed in 2011 as part of the College of Architecture, Art, and Planning (AAP) at Cornell University. Designed by Rem Koolhaas and OMA, the building connects Rand Hall and Sibley Hall and provides flexible studio space, critique space, and a state of the art auditorium.

# The Team

**Don Greenberg**
*Professor*

**Joseph Kider**
*Teaching Assistant*

**Ethan Arnowitz**
*MSc Human Factors + Ergonomics '16*

**Jeremy Paton**
*BSc Computer Science '18*

**Steven Ren**
*B'Arch '19*

**Zachary Zimmerman**
*BSc Computer Science '17*

# Sponsors

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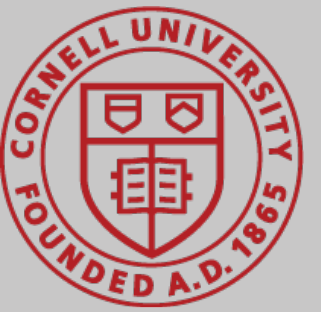


## Team Members

*Ethan Arnowitz*
*Jeremy Paton*
*Steven Ren*
*Zachary Zimmerman*