Modeling and Simulation of Multi-User Virtual Reality Environments for Emergency Evacuation Drills

By

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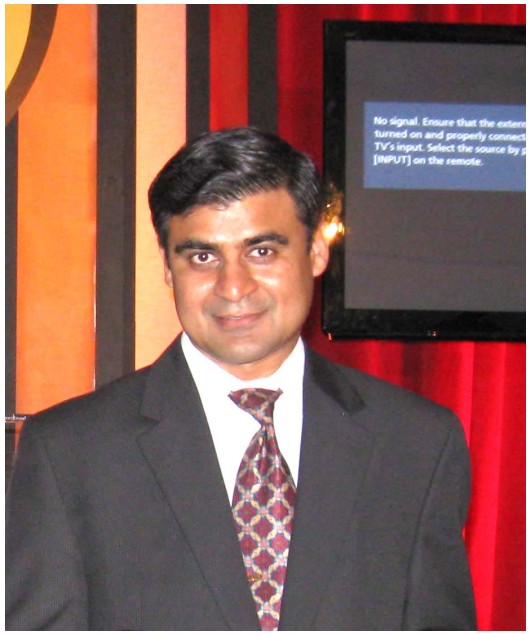
Table of Content

Past and Present

- M.S., Architecture, University of Michigan, Ann Arbor, MI
- PhD, Computer Engineering, Wayne State University, Detroit, MI

  (Dissertation Title: Modeling and Simulation of Multi-Agent Systems for Emergency Scenarios)

Past Grants	Current Grants
1) **NSF**: Virtual and Augmented Reality Laboratory for Research (2011-14) 2) **DHS**: Emergency Evacuation Research (2011-15)	**1)** **NSF**: Gaming Instructional Modules to Enhance Student Learning in Lower Level Core Courses. **2)** **ARL (DOD):** Avatars in Collaborative Virtual Environment (CVE) approach for Decision Making



3 Major Research Areas in Lab

1. **SE: Modeling and Simulation of Multi-Agent Systems for Emergency**
   1) Modeling unpredictability and human emotional behavior using Fuzzy Logic (Java)
   2) Modeling learning and adaptive behavior using Genetic Algorithm and Neural Network (C#)
2. **VR: Multi-User Environment in VR for Evacuation Using Gaming Metaphor (**using unity 3d and Oculus Rift)
   1) Airplane Evacuation
   2) Subway Evacuation
   3) Building Evacuation
   4) Campus Evacuation
   5) Mega City Evacuation
   6) Virtual Reality Classroom
3. **AR: Augmented Reality Mobile Applications (**Android)
   1) Indoor AR Mobile App for Building Evacuation
   2) AR App for Navigation and Learning for Campus Safety

2. Multi-User VR Environment for Emergency Evacuation Using Gaming Metaphor (using unity 3d and Oculus Rift)

Airplane Evacuation
Subway Evacuation
Building Evacuation
Campus Evacuation
City Evacuation

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Background

- Determining and evaluating the characteristics of crowd in emergency situation's is a complex task.
- It is not practical and possible to create a real time emergency situation (Fire/Smoke) where participants life is at risk.
- The cost and risk to determine these crowd characteristics in emergency situation's is very high.

Jammed Flow (Figure from p.90 of Pushkarev and Zupan; space per pedestrian is about 0.35 m^2 – on the lower end of the speed-flow curve).

Pushkarev in his research made aerial counts of urban scenes involving 37500 pedestrians in New York.

Human learning behavior

- To over come this issue the possible way is to create a Virtual Environment that can give a full immersive feel of the situation and allow the user to navigate and communicate in the environment.
- MUVE can lead to different research questions such as
  - How accurate can this evacuation drill be in terms of real-time emergency scenario?
  - What are the most effective approaches for training and testing evacuation scenarios in emergencies for unexpected events?
  - What way the simulation of bots (agents) support the user's decision making?

Modelling Human Behavior

- Human behavior is very difficult to model and simulate in evacuation scenarios as there is uncertainty involved.
- Our proposed CVE offers flexibility to run multiple scenarios and evacuation drills for disaster preparedness and response.
  - Modeling such an environment is very important because in the real-time emergencies we experience in day-to-day life, there is a need for preparation to extreme events.

Virtual Evacuation Drills

- Virtual evacuation drills are necessary to study human behavior under panic or stressful situations that cannot be evaluated in the real world.
- The use of collaborative virtual environments allows to
  - run virtual evacuation drills
  - eliminating risks of injury to participants
  - allows for the testing of scenarios that could not be tested in real life due to legal issues and possible health risks to participants.

Hypothesis

- Our hypothesis is that the “sense of presence” provided by the multi-user virtual environment will allow running simulations and conducting evacuation drills.
- Virtual Evacuation Drills:
  - More Cost Effective
  - Less Setup Time
  - Able to Simulate Real Danger
  - Improved Response Time

Methodology

- Novel Methodology
  - Experimental design approach for assessing human behavior (stress, panic, anger, trust, etc.) in emergency evacuation using Multi-user virtual environment.
  - Participant observation and data capture
  - Social study of evacuation drills in virtual worlds
- The use of avatars (user-controlled characters) or agents (computer-controlled characters) may influence the engagements of the user experience for emergency response, and training in emergencies.

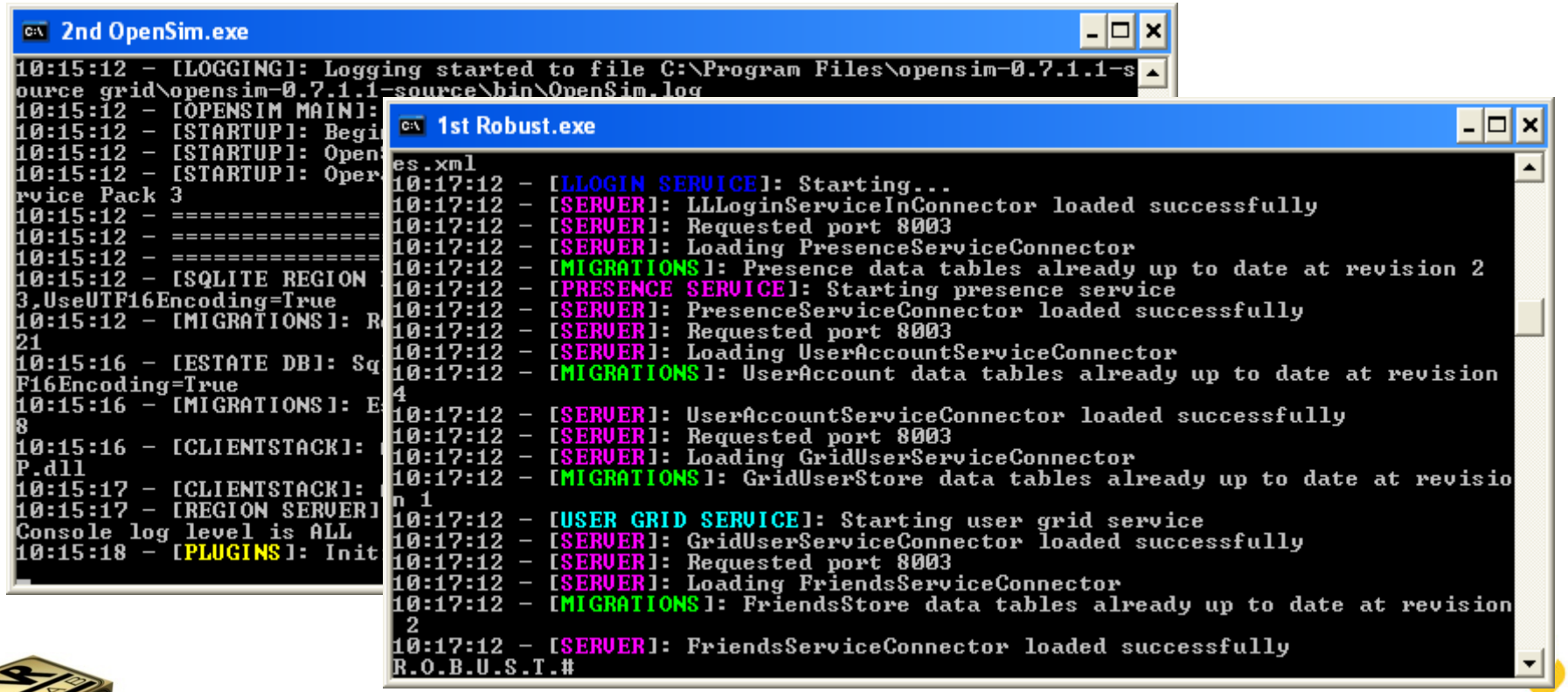
Multi user VR environment

- We have explored four multi user environment to allow participants in different geographical locations to connect and interact in the VR environment.

1. Open Sim
2. Virtools
3. Vizard
4. Unity 3D

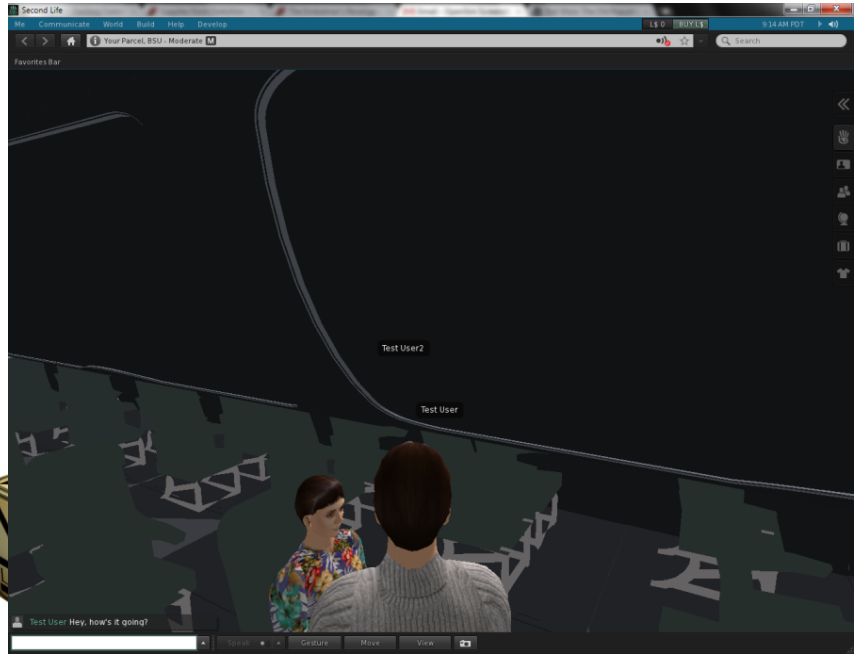
1. OpenSim

- Open Source Multiuser Environment
- Based on *Second Life* Technology




Second Life
Test User
Test User2


Second Life
Test User
Test User2


Second Life
Test User2
Test User
Test User Hey, how's it going?

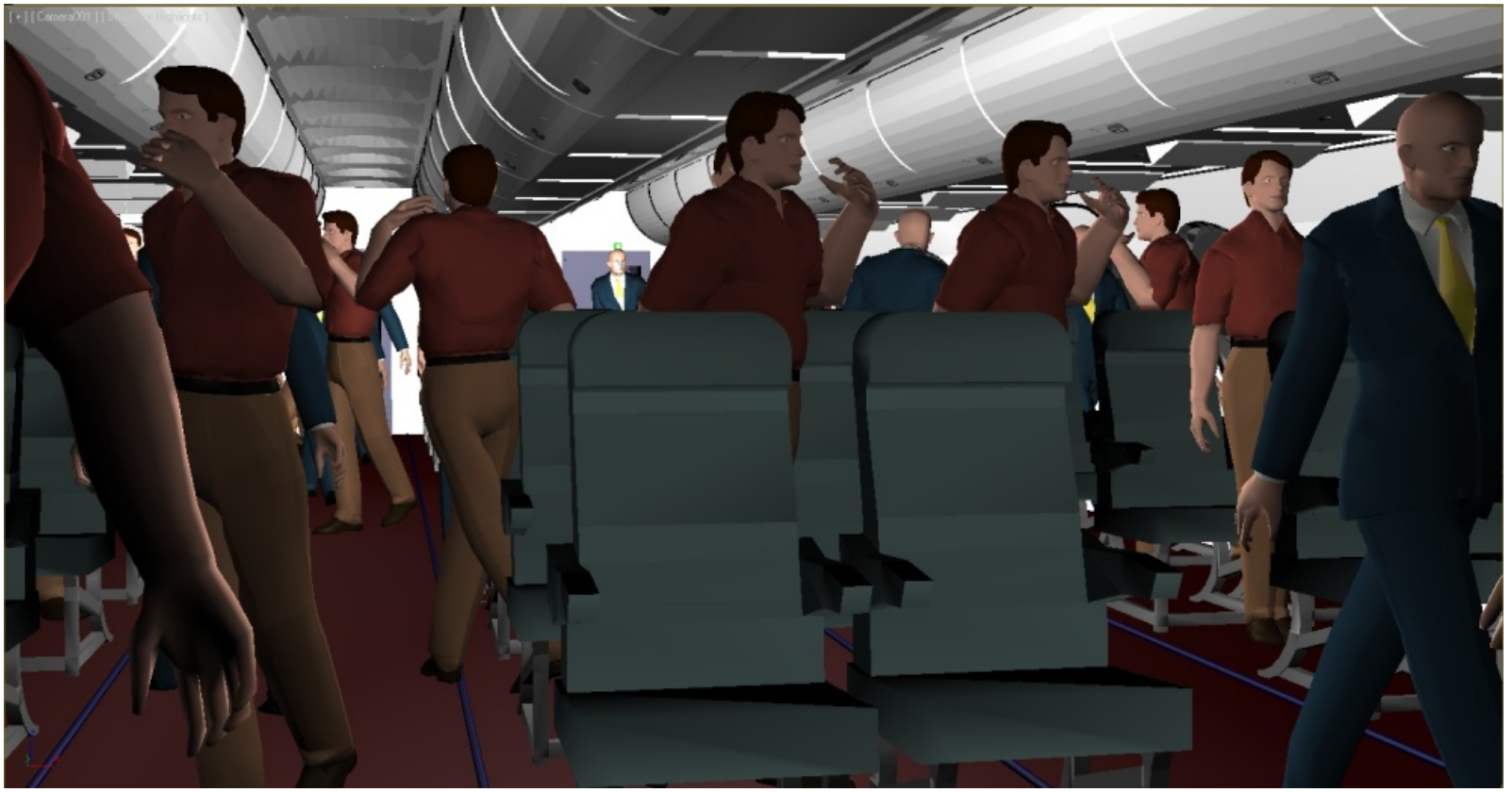
De

1. OpenSim

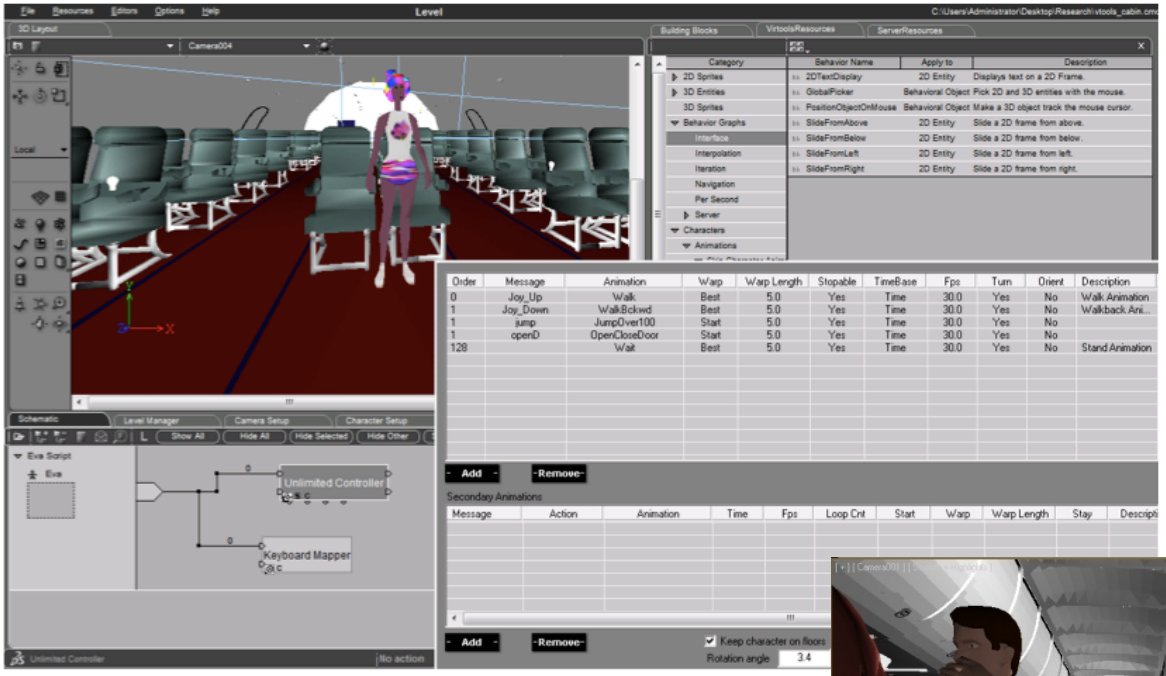
- Advantages
  - Core Multiuser Support
  - Open Source
  - Uses Popular *Second Life* Viewer
  - Free
- Disadvantages
  - Unreliable Technology
  - Limited Support
  - Difficult Design Process
  - Not Designed for Virtual Reality Devices

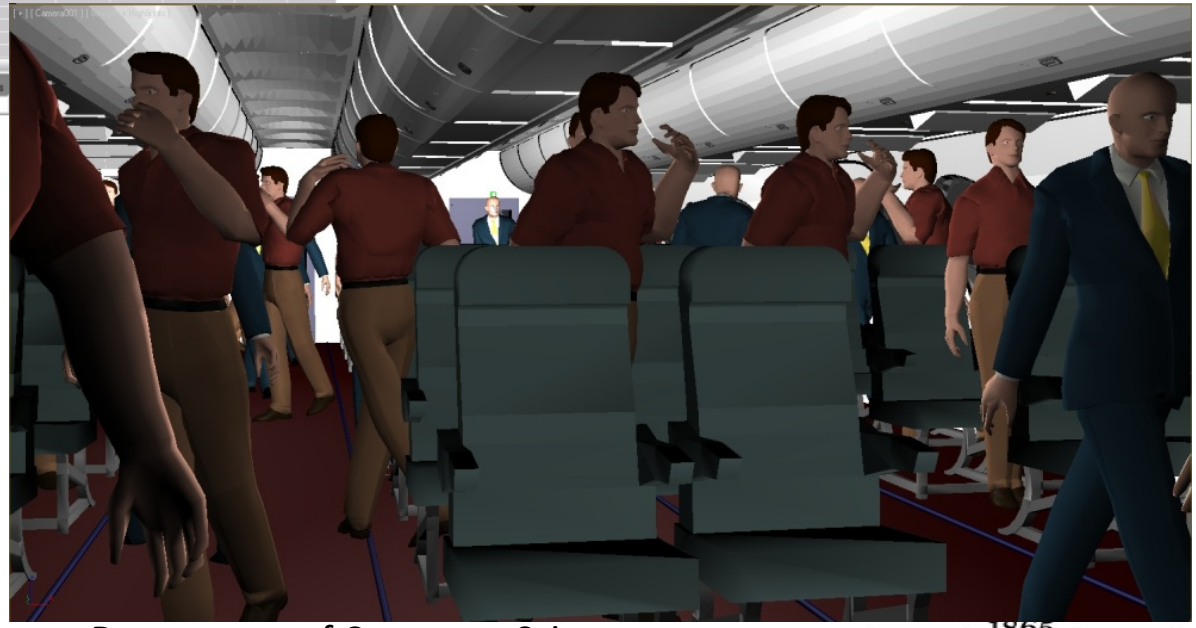
2. Virtools

- Virtools which is a graphical game development platform
- Virtools is used to implement the Character & Environmental behaviors



2. Virtools


Level
Unlimited Controller
Keyboard Mapper
Add
Remove
Secondary Animations



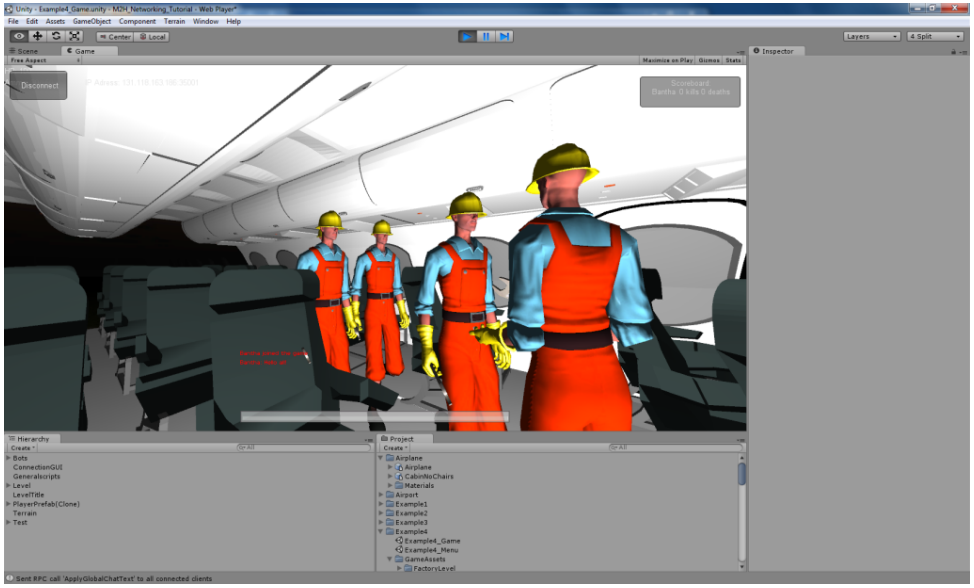
3.Vizard

- Vizard is a 3D development platform.
- Vizard supports numerous devices such as 3D wall, cave, gloves, haptic displays, force-feedback systems, gamepads, and joysticks.
- Avatars included have built-in human face, body models and an accompanying morph designer to instantly insert virtual humans into existing environments.

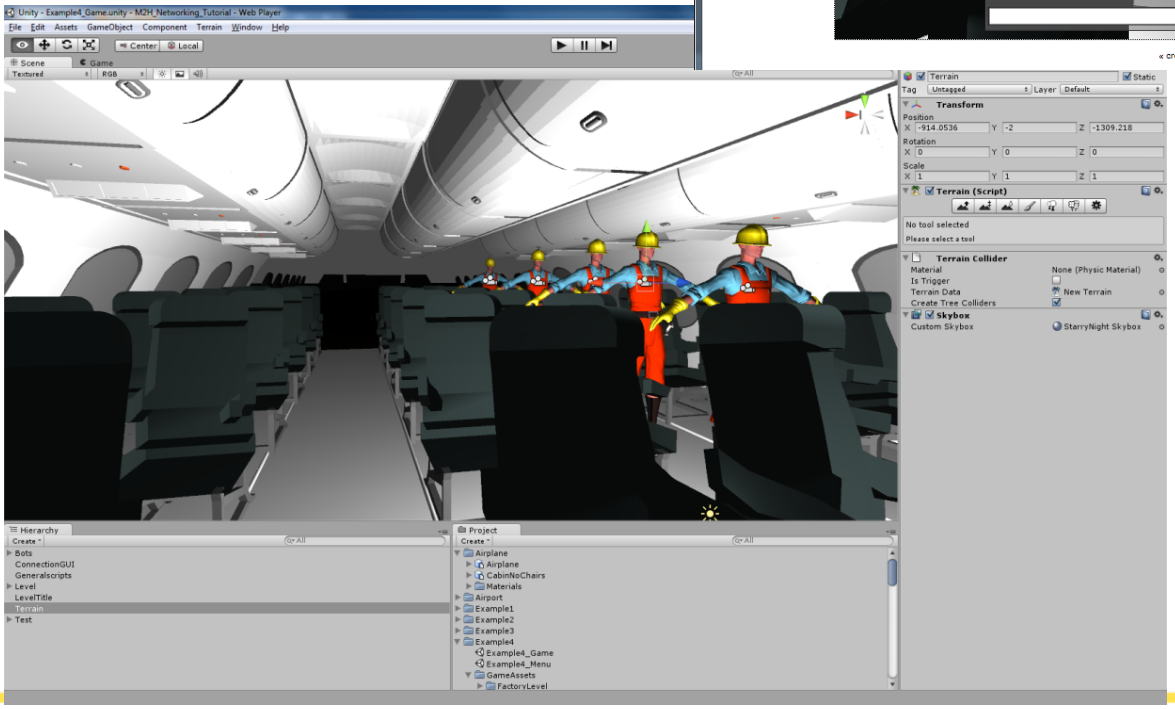
4.Unity3D

- Free Game Design Tool by Unity Technologies
- Advantages
  - Designed for Developers
  - Extensive Support
  - Supports Mobile Publishing
  - Free

Unity3D


Disconnect
Scoreboard:
Bantha 0 kills 0 deaths


Unity Web Player | WebPlayer
Disconnect
Scoreboard:
Fett 0 kills 0 deaths
Bantha 0 kills 0 deaths
« created with Unity »


Unity - Example4_Game.unity - M2H_Networking_Tutorial - Web Player
Hierarchy
Project
Terrain (Script)
Terrain Collider
Skybox

Proposed MUVE Environment

- Consists of two types of agents:
  1. User controlled agents: user navigation
  2. Computer controlled agents: programmed and act as obstacles to the user controlled agents.
- The idea is to have multiple users enter the virtual campus environment as avatars.

Contribution

- We present three ways for controlling crowd behavior.
  1. by defining rules for computer simulated agents
  2. by providing controls to the users to navigate in the VR environment as autonomous agents (non-immersive).
  3. by providing controls to the users with a keyboard/ joystick along with an immersive VR head set in real time (Immersive).
- Our contribution lies in our approach to combine these three approaches of behavior in order to perform virtual evacuation drills in a MUVE environment.

Implementation

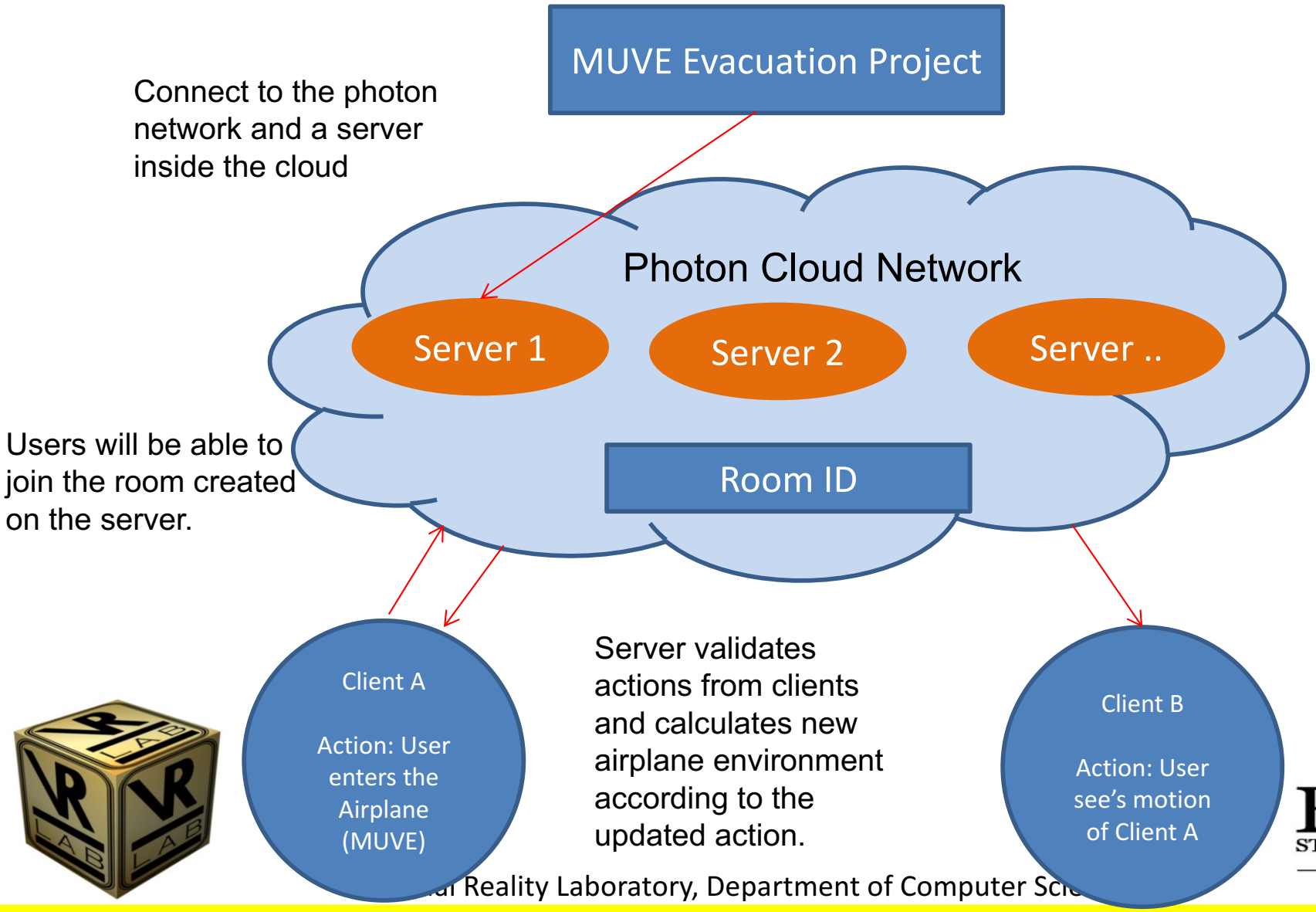
- Proposed multi-user environment was developed using game engine Unity 3D in 3 phases:

1. **Modeling**: Google Sketch Up and 3Ds Max
2. **Unity Programing**:
    1. Trees, buildings and other objects were added.
    2. used C# to program the functionality for the traffic lights, the police sirens, and behavior modelling.
3. **Multi-user platform**: The platform can be used in two ways.
    1. **Non-Immersive:** computer to explore the platform
    2. **Immersive:** use of Head Mounted Display - Oculus Rift.

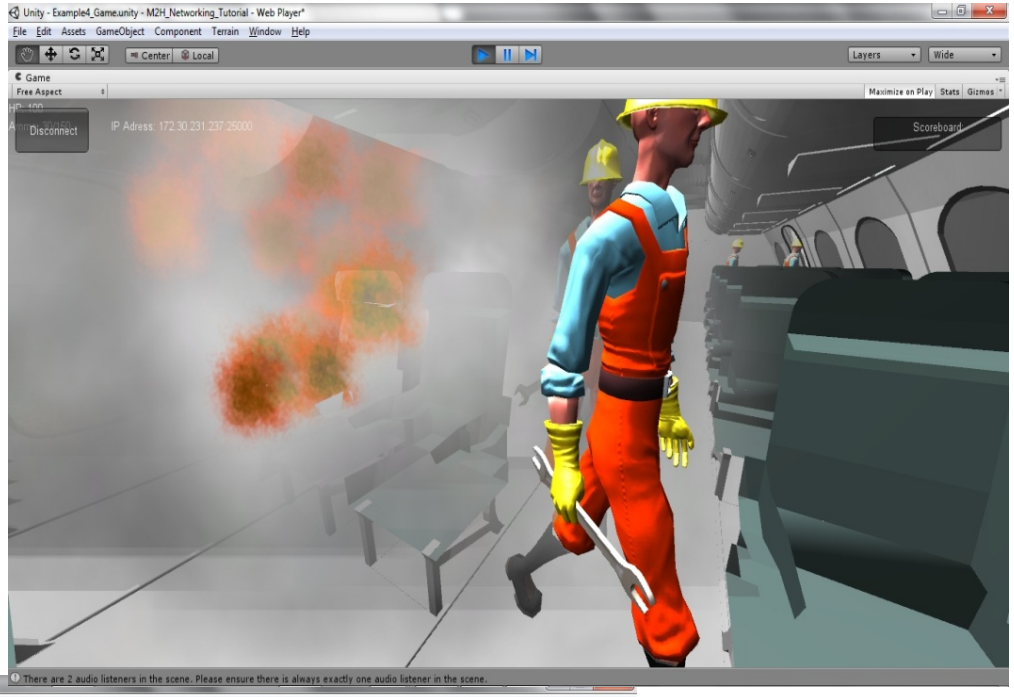
Multi – User Cloud Implementation

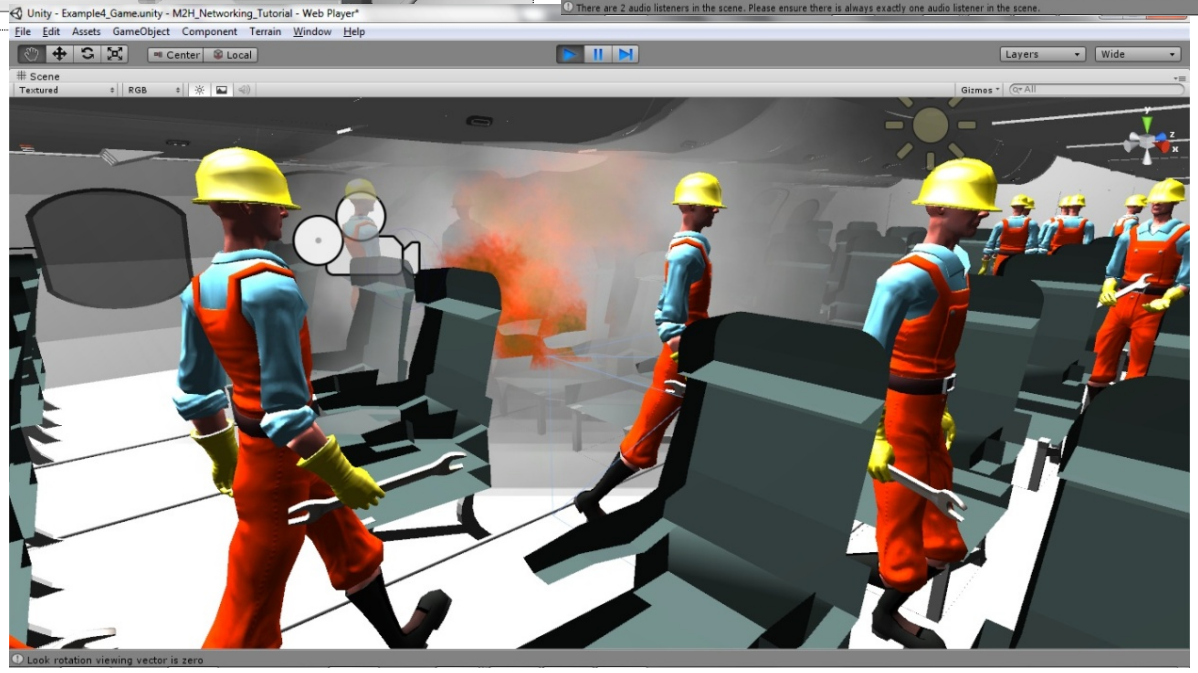
- We have implemented the server client feature through the use of Photon Unity Networking (PUN)
- The cloud of servers offers as hassle-free service for hosting multiplayer games.
- The photon server links the environment to one of its internal servers.
- After connection is established, the photon network monitors movement change in the environment so that everyone's motion is visible to all the clients.

Multi – User Cloud Implementation



Airplane: Simulation of fire and smoke in VR





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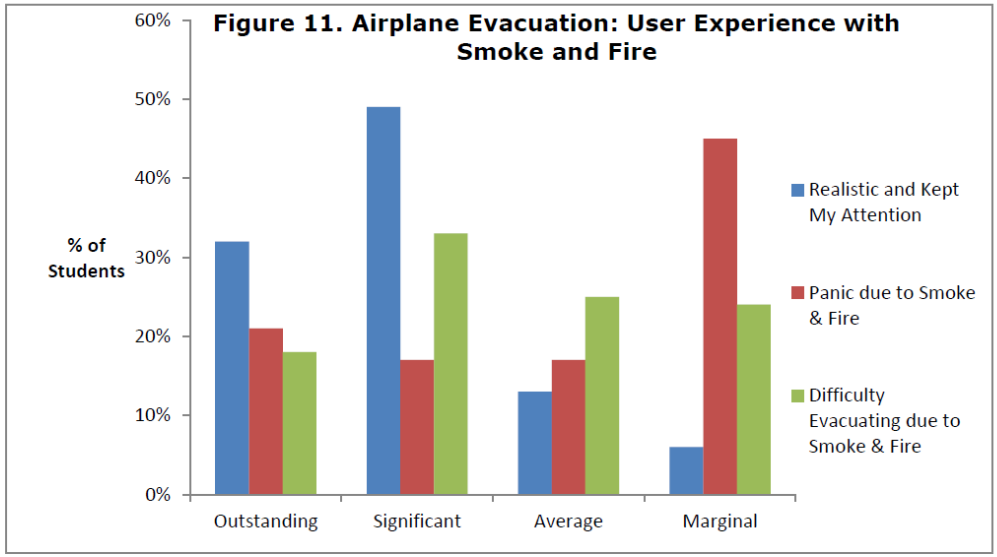
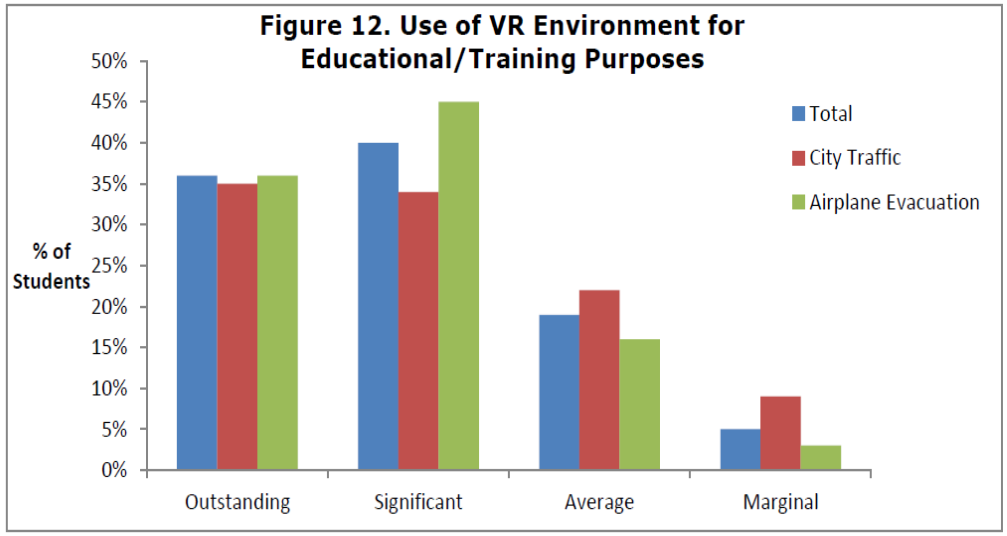
Evaluation of multi-user Airplane Evacuation and City Traffic VR Environment

- Conducted user studies for 2MUVE.
  - (1) City Traffic VR Environment

    (Virtual City Game: Safe driving to an assigned goal in a city by obeying traffic laws)
  - (2) Airplane Evacuation VR Environment.
- 30-50 sessions involving two-four users each session.
- Users experienced the virtual environment in two formats
  - Non-Immersive environment: desktop computer
  - Immersive environment: with a head mounted display
- More than 100 respondents participated in this first phase of the user studies.

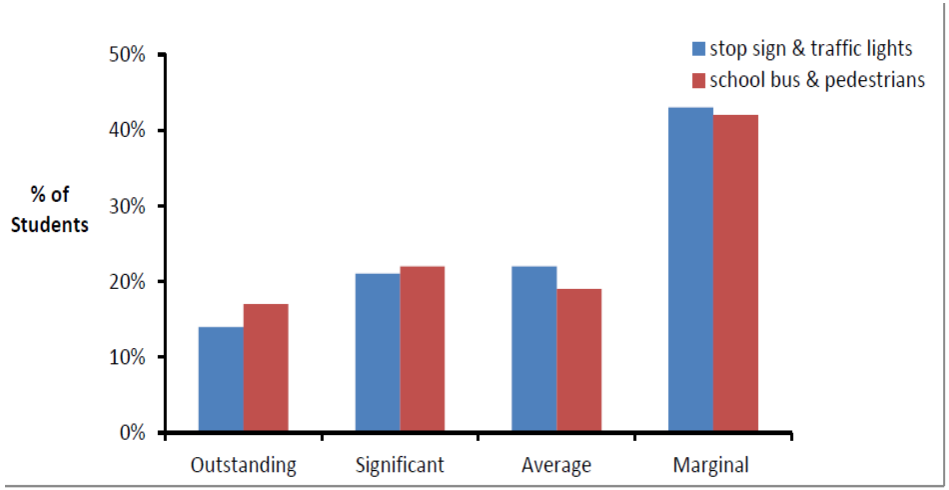
Airplane Evacuation User Experience



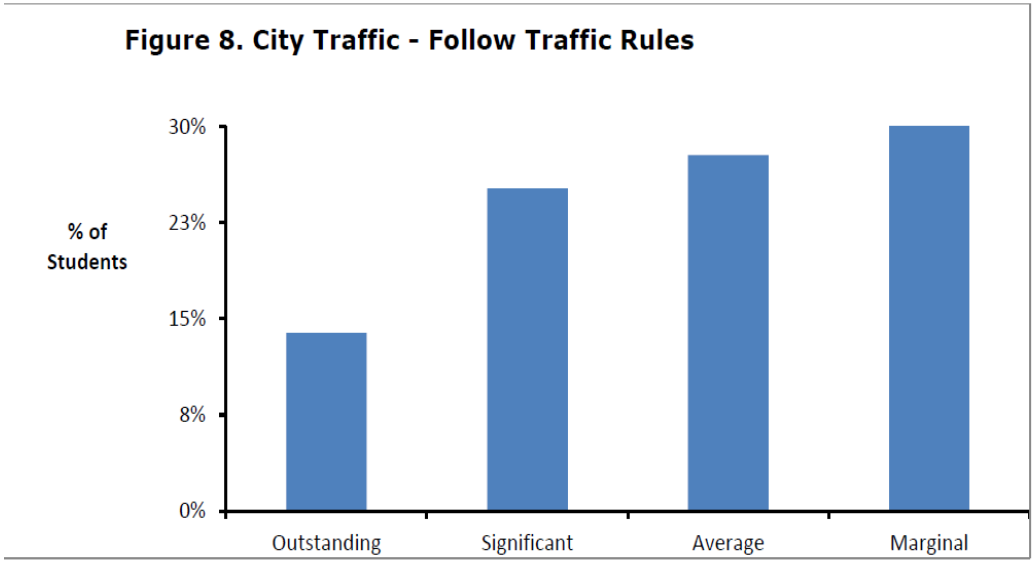


- *The majority (81%) reported that the use of smoke and fire was realistic and kept user attention.*
- *Most (62%) felt the use of smoke and fire did not cause much user panic with 45% reporting panic due to smoke and fire at only a marginal level and 17% at an average level.*
- *One would expect a realistic environment with smoke and fire to cause panic so the cause for this inverse relationship in results needs to be explored further*

City Traffic VR Environment

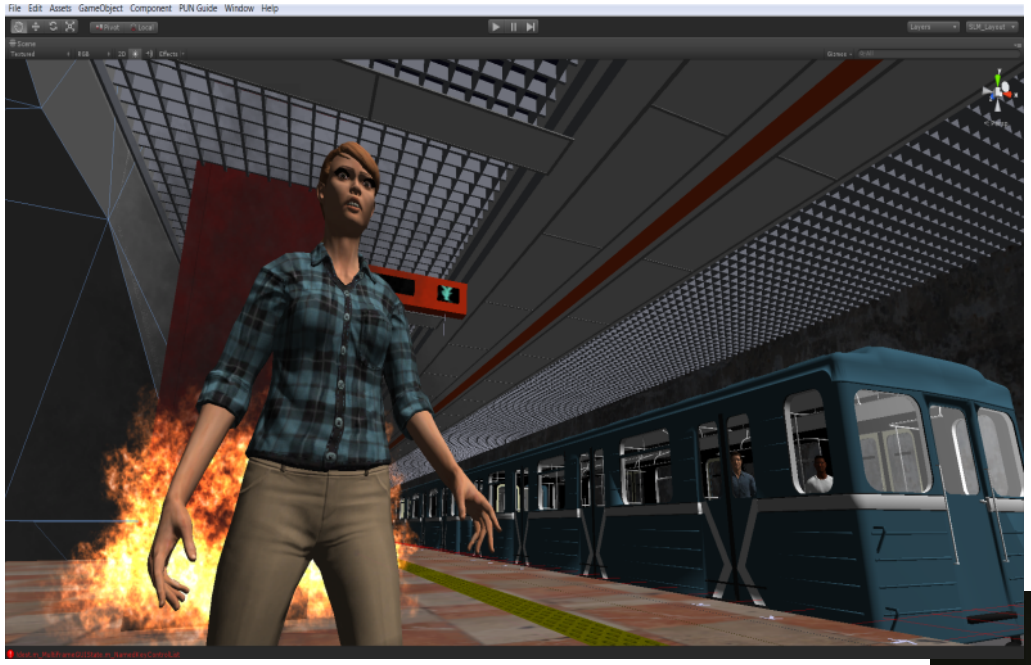


- When users did not obey traffic rules
  - 43% did not stop at stop signs and traffic lights,
  - 42% did not stop for school buses and pedestrians.
- When traffic rules were obeyed, more users followed at a significant level for the traffic rules or average level for the stop sign and traffic lights.

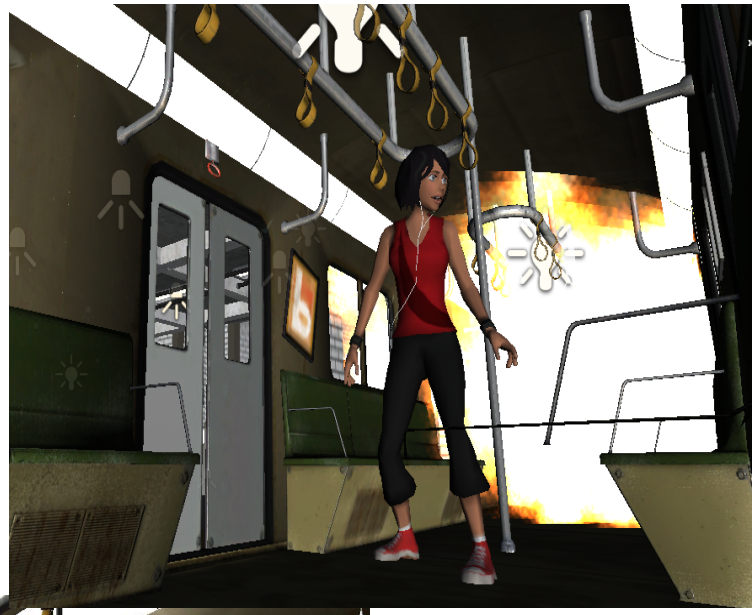


- More than a third of the participants indicated they adhered to traffic rules only marginally, followed by 28% obeying traffic rules to an average extent, 25% at a significant level

Virtual evacuation drills in Subway



Subway Evacuation



Virtua

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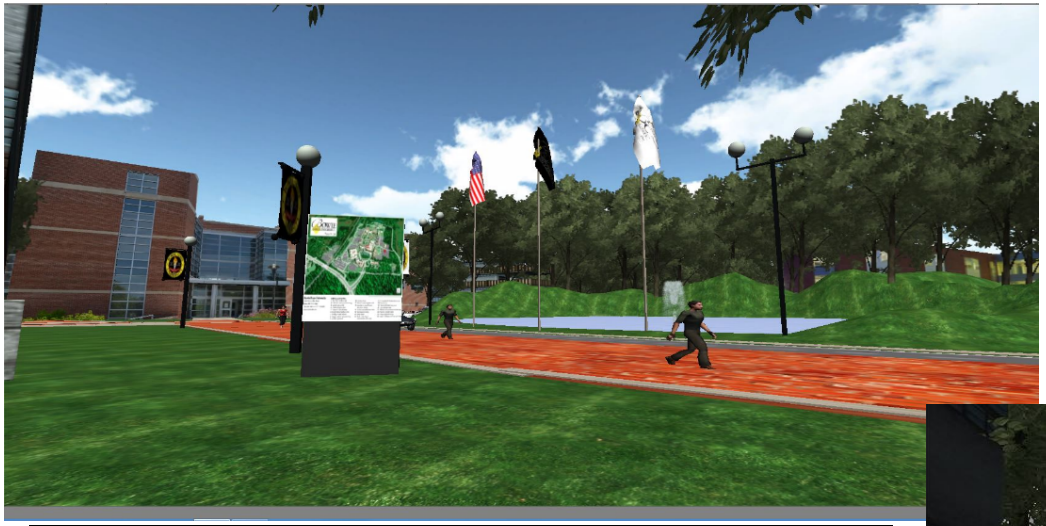
Urban Evacuation

Server (left-side) and Client (right-side)

BSU Campus Evacuation



Megacity

Megacity in CVE shows an officer, a patient lying on the ground in need of care, emergency response vehicles, and police car for an emergency situation

Sharma, S., Devreaux,P., Scribner, P., Grynovicki, J., Grazaitis, P., ***"Megacity: A Collaborative Virtual Reality Environment for Emergency Response, Training, and Decision Making****, IS&T International Symposium on Electronic Imaging (****EI 2017), in the Visualization and Data Analysis****, Proceedings Papers, Hyatt Regency San Francisco Airport, Burlingame, California, pp. 70-77(8), DOI: https://doi.org/10.2352/ISSN.2470-1173.2017.1.VDA-390, 29 January- 2 February 2017.*

Mega City

DOD Collaboration: *Scribner, P., Grynovicki, J., Grazaitis, P., Human Research and Engineering Directorate (HRED) division in Army Research Laboratory (ARL) at Aberdeen Proving Ground (APG), Aberdeen, Maryland.*

- We have used game creation as a metaphor for creating an experimental setup to study human behavior in a megacity for
  - emergency response
  - decision-making strategies
  - what-if scenarios.
- Our proposed collaborative VR environment includes
  - immersive (use of Oculus Rift)
  - non-immersive environments (Desktop Environment)
- The participant can enter the CVE setup on the cloud.

Modeling emergencies in CVE

- In a city block emergencies could be the result of
  - Fire
  - smoke
  - gunman threat
  - bomb blast.
- The collaborative virtual environment (CVE) can act as a platform for training and decision making for
  - SWAT teams
  - fire responders
  - traffic clearance personnel
  - medic

Phase 1: The Modeling Process

- Modeled three kinds of threat scenarios
  1. bomb threat
  2. gunman threat
  3. biohazard threat
- added realistic street color and street signs to the roads.
- imported police vehicles, fire trucks, and ambulances
- added components to the city such as fire hydrants, stop signs, trees, grass, rocks and rocked pathways, streetlights, trash cans, benches, statues, fire, smoke, a central water fountain in the middle of the park, and active humanoid agents.

Phase 2: Unity Programming Including Photon

- Used C# to program the functionality for the traffic lights, the police sirens, and human behavior.
- Developed algorithm for the
  - logic of a traffic light's color order and the logic of two-way intersection traffic lights' correlation to one another.
  - police sirens consisted of a red light and a blue light flashing each alternately for 0.5 seconds.
- Incorporated oculus HMD and connection to the Photon client/server network.

Phase 3: Agent Behavior

- We have implemented triggered responses for agents.
  - the presence of smoke or fire may cause the agents to panic (trigger panic behavior),
  - presence of a user-controlled agent, it may illicit calm behavior in the agent (trigger calm, or goal-seeking behavior).

Red and blue computer-controlled agents together with a user-controlled agent.

Agent Behavior

- We are implementing different behaviors such as the following:
  1. **Hostile Agent Behavior** (red agents)
     - create diversions and distractions for user-controlled avatars.
     - are aggressive agents who distract the avatars during evacuation.
     - Characteristics of their hostile behaviors include refusal to follow emergency response leaders, pushing other agents out of their way, and the displaying of panic body language.
  2. **Non-Hostile Agent Behavior** (green agents)
     - They have group behavior and goal-following associated with them
     - During evacuation they navigate toward the assigned goal.
     - A secondary goal of group behavior is also associated with the non-hostile agents. As a result, the non-hostile agents try to group together while navigating toward the goal.

Agent Behavior (cont/-)

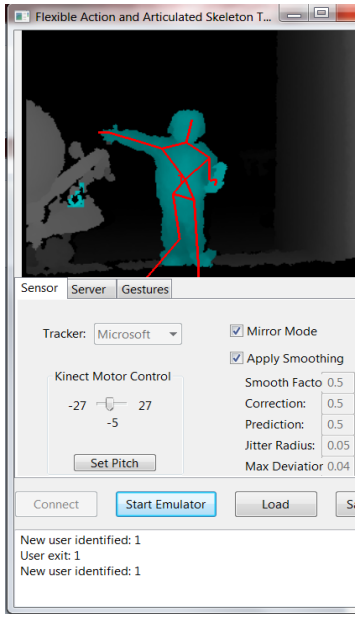
3. **Leader-Following** Agent Behavior (blue agents)
   - They have a proximity sensor associated with them. As a result, when the user-controlled avatars are in proximity, they follow the avatars.
4. **Goal-Following** Agent Behavior (purple agents)
   - These agents are calm agents.
   - They calmly navigate to an assigned goal when triggered.
5. **Selfish Agent** Behavior (orange agents)
   - Selfish agents may give false information and it will be up to the user-controlled agent to determine which information is useful in completing their current objective (evacuation).

Results

- The users are able to wear Oculus Rift to immerse themselves in the VR environment and are able to turn around a 360 degree.
  - The motion sensor detection on the Oculus rift allows tracking the user head moment.
    - This leads the user to visualize the Megacity environment and other agents in the VR environment.
- Stress, panic, and anger could be induced in the CVE through the inclusion of smoke and fire.
  - It is not possible to include smoke and fire in real-time evacuation drills due to legal and safety considerations, whereas in a CVE environment one can.
- From our current tests, we have been able to observe that some participants do not exhibit behaviors consistent with the notion that they were responding to the crowd realistically.

Virtual Reality Classroom

with 3D interaction and real-time motion detection



The Flexible Action and Articulated Skeleton Toolkit (FAAST), a middleware to facilitate integration of full-body control with virtual reality applications

Sharma, S., Chen,W., "Multi-user VR Classroom with 3D interaction and real-time motion detection", proceedings of *IEEE the International Conference on Computational Science and Computational Intelligence (CSCI'14)*, Las Vegas, USA, page 187-192, Volume II, March 10-13, 2014.

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Features Explained (1)

Kinect Code

```
def kinectfunc():
    import viz
    import vizact
    import vizshape
    import math

    HEAD = 0
    NECK = 1
    TORSO = 2
    WAIST = 3
    LEFTCOLLAR = 4
    LEFTSHOULDER = 5
    LEFTELBOW = 6
    LEFTWRIST = 7
    LEFTHAND = 8
    LEFTFINGERTIP = 9
    RIGHTCOLLAR = 10
    RIGHTSHOULDER = 11
    RIGHTELBOW = 12
    RIGHTWRIST = 13
    RIGHTHAND = 14
    RIGHTFINGERTIP = 15
    LEFTHIP = 16
    LEFTKNEE = 17
    LEFTANKLE = 18
    LEFTFOOT = 19
    RIGHTHIP = 20
    RIGHTKNEE = 21
    RIGHTANKLE = 22
    RIGHTFOOT = 23

#store trackers, links, and vizshape objects
    trackers = []
    links = []
    shapes = []
```

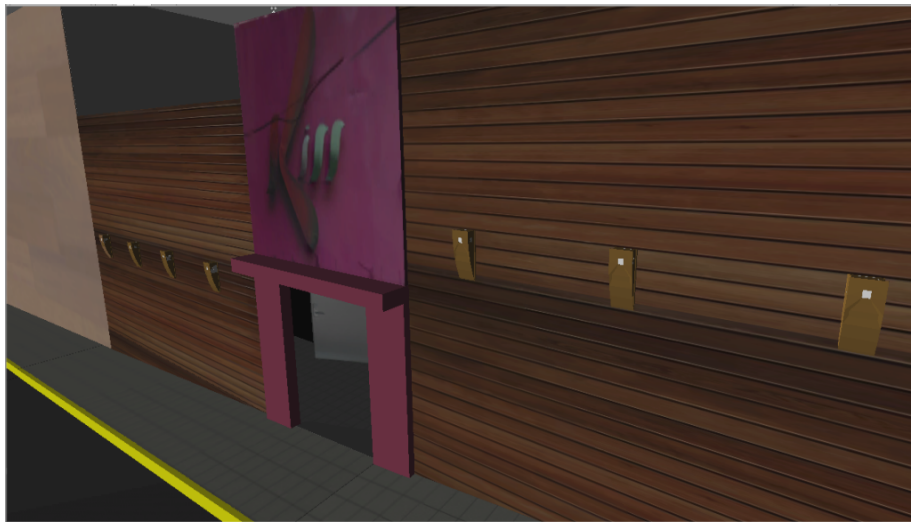
Kinect is integrated into system for checking movement of the instructor

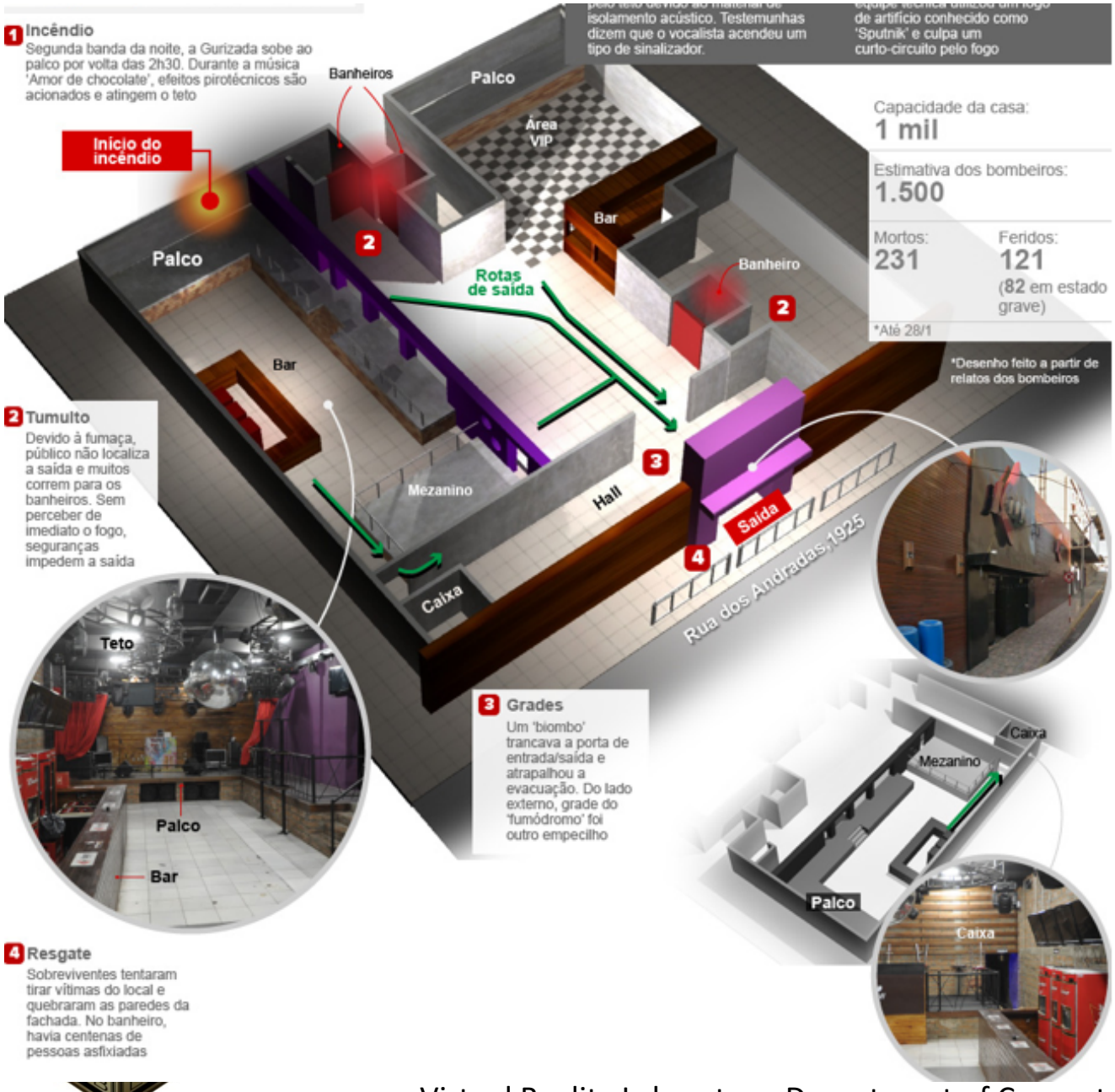
Re-Creating Nightclub Fire disaster in Santa Maria, Brazil

- Emergency preparedness is achieved by planning, training, equipping, and exercising the emergency response.
- The preparation and training for emergency events is critically important for safety in our day to day lives.
- We can learn a lot from previous disasters which is valuable for accuracy in decision making strategies.

Hypothesis

- The CVE would allow learning from existing disasters to prepare for similar events
  - should decrease safety risks
  - allow users to evacuate safely during emergency responses.





Disaster at the night club had the following fatalities:

- 234 deaths at scene
- 622 injuries

- 145 hospital admissions w/ 8 deaths

- Estimated attendance: 864 – 2000 civilians

- Single available exit, second exit inaccessible due to metal bars.

- Restrooms: 180 victims

- Firefighters responded to scene within 3-5 min

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Conclusion

- We have presented an experimental design approach to gather data on human behavior and emergency response in a CVE among a set of users as avatars (user-controlled agent)
  - This platform can be used as a teaching and educational tool for navigation and performing virtual reality drills.
- CVE drills can also help to see how long it takes emergency responders to report to a certain location and respond to emergency situations.
  - The data collected can be used to educate emergency personnel on how to reduce response times.
  - Emergency personnel can be trained to respond to a variety of emergencies safely and securely without ever being exposed to real-world dangers.

Future Work

- We will be conducting user studies for VR evacuation drills (subway, school bus, & airplane) to study human behaviors (panic, anger, stress, trust, leader) that cannot be evaluated in real life.
  - Implement a rewards system whereby users can earn points for completing certain objectives.

Acknowledgements

- NSF grant:
  - Award Number: HRD-1238784
  - Award Number: HRD-1137541.
- DHS grant:
  - Award Number: 2011-ST-062-000050

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Thank you

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Outreach: Virtual Reality Laboratory booth

1. USA Science Festival for STEM at Walter E. Washington Convention Center, Washington DC on April 16 & 17, **2016**.
2. Bowie State University Day in Annapolis - March 3, **2015**.
3. International Festival at Largo Town Center, Largo, MD on July 12-13th, **2014**.
4. USA Science & Engineering Festival at the Walter E. Washington Convention Center in Washington, D.C on April 26 -27, **2014** and April 27-29, **2012**