A Methodology to Develop a Communication Protocol for Visualizing Simulations in a Collaborative Virtual Reality Environment

Lacey Duckworth

Dissertation Defense
February 21, 2011
The objective of this meeting is to defend my dissertation, *A Methodology to Develop a Communication Protocol for Visualizing Simulations in a Collaborative Virtual Reality Environment*. 

---

*Images of logos and diagrams are present, but their content is not relevant to the natural text.*
**Agenda**

- **Introduction**
  - Problem Statement
  - Dissertation Objective
  - Significance of the Study

- **Review of Related Literature**
  - Simulation
  - Virtual Reality
  - Communication Protocol

- **Research Methodology**

- **Concrete Case Study**
Agenda

● Generalized Communication Protocol
● Test Case
● Summary
  ● Results
  ● Impact
  ● Future Research
● Dissemination
● Adjournment
Introduction

Problem Statement, Significance of the Study, and Dissertation Objective
Problem Statement

A robust and reusable communication method does not exist to connect external simulation languages with the compelling and accessible client-server Virtual Reality Environments.
Introduction

Dissertation Objective

- Develop a robust and scalable communication development methodology that connects external simulation languages with client-server Collaborative Virtual Reality Environments.
Introduction
Significance of the Study

- Implementation of Oil Refinery Process

200 Hours
Non-modular, extendable, or object oriented code

<table>
<thead>
<tr>
<th>46 Major rigs</th>
<th>10 Degree of Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>x 200 Hours</td>
<td></td>
</tr>
<tr>
<td>96,000 Hours</td>
<td></td>
</tr>
</tbody>
</table>
Introduction

Significance of the Study

• Run time of a calculation internal to a CVRE versus External calculations
  • Summation of odd numbers between 1 and 1,000,000 with a display of the results.
  • Results: it was clear that moving the calculation external to the CVRE was key idea

<table>
<thead>
<tr>
<th>Language</th>
<th>Average Run Time (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSL</td>
<td>24.708785</td>
</tr>
<tr>
<td>C++</td>
<td>0.0148</td>
</tr>
<tr>
<td>LabVIEW</td>
<td>0.3314</td>
</tr>
</tbody>
</table>
Review of Literature

Simulations, Virtual Reality, Simulations in VRE and Communication Protocol
Review of Literature

Simulation

• **Definition**
  - Representation of key characteristics or behaviors of a physical or abstract system.

• **Benefits**
  - Learn skills in an interacting way
  - Minimize the risks associated with decision-making, problem solving and strategy implementation

• **Examples**
  - Rendering botanical structures
  - Crowd simulation
  - Smoke Simulation
Review of Literature

Virtual Reality

● Definition

  • A 3D environment
  • Interaction to allow manipulation and exploration of the environment
  • Sense of Immersion
    - Breadth – number of sensory dimensions the user experiences
    - Depth – quality of the data
  • Collaboration
    - Some environments support user representation through avatars
Review of Literature

Virtual Reality

- Environments
  - OpenGL (1980)
  - Direct3D (1992)
  - VRML (1994)
  - Java3D (1996)
  - Second Life (1999)
  - Lively (2008)
  - O3D (2009)
  - WebGL (2010)
● **imseCAVE**

  - Leith K. Y. Chan and Henry Y. K. Lau, Department of Industrial and Manufacturing Systems Engineering, The University of Hong Kong

**imseCAVE**

- A virtual container terminal together with a simulated interactive crane system is developed.
- Realistic simulated environment
- Human-computer interface for learning and training, crane control and operating system design, performance evaluation, and skill quantification.
Review of Literature
Simulations in Virtual Reality Environments

• imseCAVE (Cont.)
  • Low cost computer systems are clustered with high bandwidth communication network to achieve a fully distributed computing environment to realize the concept of distributive virtual reality.
Review of Literature

Simulations in Virtual Reality Environments

- Building Construction Timeline
  - Marc Brana, University of Southern Mississippi (2003)
  - Objective
    - Create a virtual reality environment of a construction project that allows the clients to explore the characteristics of the building
    - Create a VRE that will simulate the construction process timeline
  - Implementation
    - A project plan from Gant Project was brought into VRML to show the status of the building at certain phases.
Review of Literature
Simulations in Virtual Reality Environments

- Virtual Reality for Collaborative e-Learning
  - Teressa Monahan, Gavin McArdle, Michela Bertolotto, University College Dublin (2008)
  - Collaborative Learning Environment (CLEV-R)
  - Objective
    - Web-based multi-user 3D environment
    - Real-time teaching
    - Tool for students to communicate
Review of Literature
Simulations in Virtual Reality Environments

- Virtual Reality for Collaborative e-Learning (Cont.)
  - Graphical User Interface – hosts communication controls for the system
  - VR Environment – host features found in traditional university.
    - Lecture Room
    - Meeting Rooms
    - Library
- Mobile CLEV-R
  - CLEV-R for mobile devices
  - Currently in the works
Virtual Reality for Collaborative e-Learning (Cont.)

- Results
  - Navigation difficulty – non experienced 3D gamers had difficult times
  - Communication - Successful in both text and voice based
  - Immersion – only 78% of the users experienced this
Review of Literature
Simulations in Virtual Reality Environments

● Virtual Reality Technology in Civil Engineering Education

  • A.A. Sampaio, P.G. Henriques, O.P. Martins (2010)
  • Recognizing the need for CAD and VR Systems in Architecture, Engineering and Construction.
    - Architecture
      – 3D models of houses to be viewed by the client
    - Construction
      – Representation of buildings in 4D, the 3D model + time.
    - Rehabilitation
      – 3D models of the finalized building are key as this works on the building structure for maintenance or remodeling.
Virtual Reality Technology in Civil Engineering Education (Cont.)

- Review of Simulations
  - Lighting System Prototype
- VR System EON
  - Simulation of wall building process
- Bridge construction
  - Visualization of a bridge using the cantilever method.
Review of Literature
Simulations in Virtual Reality Environments

- Virtual Reality Technology in Civil Engineering Education (Cont.)
  - Incremental Launching Method of Bridge Construction
    - Shows the states in this method incrementally with menu interfacing
• **Solipsis: A Decentralized Architecture for Virtual Environments**
  
  
  - **Objective:**
    - Solving the issue of emergence prevention of a truly massive virtual-world infrastructure through use of peer-to-peer technology.
  
  - **Solipsis**
    - platform for massively multi-participant and user-generated virtual worlds
    - **Distributes** communication and computational cost among various nodes present within a virtual space
Solipsis: A Decentralized Architecture for Virtual Environments (Cont.)

- A **Metaverse** consists of entities:
  - Avatars – the main actors
  - Objects – books, furniture, etc.
  - Sites – portions occupied by objects or where avatars roam.

- Each entity consists of a mesh (prim-based model), set of textures, and an animation (avatars only)
Review of Literature

Communication Protocol

- Solipsis: A Decentralized Architecture for Virtual Environments (Cont.)
  - Solipsis Platform
    - Distributed over a set of hosts that maintain information about every entity currently in the metaverse.
  - Each node is associated with a position in multi-dimensional space.
Solipsis: A Decentralized Architecture for Virtual Environments (Cont.)

- Each node records in its entity’s descriptor a list of the hosts that currently hold a copy of any of the files that constitute the associated 3D description.
Modularity for Large Virtual Reality Applications


Focus:
- Design of high performance VR Applications (simulations)

Difficulties:
- Algorithmic issues to run correct simulations
- Software engineering issues (integration)
- Hardware performance limitations

Developed:
- FlowVR – associates a data-flow model with a hierarchical component model.
Modularity for Large Virtual Reality Applications (Cont.)

FlowVR Application

- A set of distributed iterative tasks that get data from input ports, process the data and provide results on output ports.
- FIFO data communication channels
- Tasks are distributed on the target machine
- The run-time environment handles moving the data between tasks
- Examples: one connection between two models and the visu module pull on demand message from compute
Review of Literature

Communication Protocol

- Modularity for Large Virtual Reality Applications (Cont.)
  - FlowVR Front End
Review of Literature

Communication Protocol

- Modularity for Large Virtual Reality Applications (Cont.)
  - Component Hierarchy
Review of Literature

Communication Protocol

- Modularity for Large Virtual Reality Applications (Cont.)
  - Data Flow Graph

![Diagram of Data Flow Graph and NToOne Visualization]
Review of Literature

Communication Protocol

- Modularity for Large Virtual Reality Applications (Cont.)

  • Limitations of FlowVR

    - Need to be a trained FlowVR developer to use this method
    - Hierarchical data-flow model requires a learning effort for developers that are used to the main loop model
      - Update input states, update virtual scene, publishes the new state of the scene for various renderings
    - Relies on C++ - have to develop new runtime code and component code in order to add a new module
    - Data conversion between modules
    - The graph is static - no possibility to dynamically load, connect and start a new module
A Grid-based Collaborative Virtual Geographic Environment for the Planning of Silt Dam Systems.

- Hui, L. et. al. 9 February 2009

- Collaborative virtual geographic environment (CVGE) system.
  - Geographically distributed users combined with shared virtual space and a collaborative platform for collaborative planning.

- Focus: Aid in the planning and designing of silt dam systems with the requirements:
  - Integrating current distributed data and model resources
  - Creating a visualization environment to improve computing efficiency
  - Supporting the collaborative planning work
Review of Literature

Communication Protocol

● A Grid-based Collaborative Virtual Geographic Environment for the Planning of Silt Dam Systems (Cont.)

  • Idea: integrate agent, grid, and other collaborative tools for the planning of silt dam systems.

  • Prototype: build a grid-based MA CVGE system across the Internet to support spatial planning of silt dam systems
      - MA - an autonomous software entity that can travel freely among the hosts in a heterogeneous network, interact with other agents or share resources.
Review of Literature

Communication Protocol

A Grid-based Collaborative Virtual Geographic Environment for the Planning of Silt Dam Systems (Cont.)

- **Code**
  - **Java** – displaying the scene and online chat room
  - **C++** and **open GL** for fast terrain rendering
  - **Java Media Framework API** for video collaboration

- **Design**
  - **Voyager** – for MA computing to rapidly produce distributed applications of high capability
Review of Literature

A Grid-based Collaborative Virtual Geographic Environment for the Planning of Silt Dam Systems (Cont.)

- MA dynamic route control algorithm
Review of Literature

Communication Protocol

- A Grid-based Collaborative Virtual Geographic Environment for the Planning of Silt Dam Systems (Cont.)
  - Mobile Agent Service Environment
Review of Literature

Communication Protocol

- A Grid-based Collaborative Virtual Geographic Environment for the Planning of Silt Dam Systems (Cont.)
  - Planning flow-chart for the dam system
A Grid-based Collaborative Virtual Geographic Environment for the Planning of Silt Dam Systems (Cont.)

- Results of parallel processing based on MAs
- Computing efficiency increased as the number of MAs increase
References

Papers, Journals, etc. used during the Course of this dissertation
References


References


References


Research Methodology

Steps for completing the dissertation

- Complete Cal Poly Test Case: 23 days
- Review Chapter 1: Introduction: 6 days
- Review Chapter 2: Background on Simulation: 5 days
- Review Chapter 3: Background on Communication Protocols: 4 days
- Review Chapter 4: Background on Virtual Reality: 5 days
- Review Chapter 5: Research Methodology: 5 days
- Review Chapter 6: Design and Testing of the Developmental M: 5 days
- Chapter 7: Results: 14 days
- Chapter 8: Summary, Discussion and Future Research: 14 days
- Appendix: Code: 14 days
- Submit Application for Degree form and Progress to Degree III: 26 days
- Submit Contact Graduate Reader Form: 26 days
- Submit Title page to graduate reader for approval: 53 days
- Defense: 1 day
- Submit results of Oral Defense of Thesis or Dissertation Form: 1 day
- Submit thesis or dissertation to the graduate reader for proof: 63 days
- Submit final 3 copies of dissertation to the Graduate School: 15 days
Research Methodology

- **Stage 1: Concrete Example**
  - A simulation to be implemented in a CVRE was selected, designed and implemented.

- **Stage 2: Define Communication Protocol Methodology**
  - From the concrete example, a communication protocol was defined and a methodology for developing simulations in CVRE using this protocol was designed.

- **Stage 3: Testing and refining of the Communication Protocol Methodology**
  - A more complex simulation to be implemented in a CVRE was selected, designed and implemented using the communication protocol methodology.
Stage 1: Concrete Example

- Qualitative – Case Study
  - Produce **information** from an in-depth, over a long period of time examination **of a single instance** or event.
## Research Methodology

### Stage 1: Concrete Example

<table>
<thead>
<tr>
<th>Steps</th>
<th>Implementations in this Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization of details about the case –</td>
<td>Selecting and describing a motivational large scale simulation</td>
</tr>
<tr>
<td>specific facts about the case are</td>
<td>problem</td>
</tr>
<tr>
<td>arranged in a logical order</td>
<td></td>
</tr>
<tr>
<td>Categorization of data – categories are</td>
<td>The data to be gathered can be divided into the following categories:</td>
</tr>
<tr>
<td>identified that can help cluster the data</td>
<td>Size, complexity and performance of Simulation-driven VR, and the</td>
</tr>
<tr>
<td>into meaningful groups</td>
<td>development time as the Simulation-driven VR scales to large sized and</td>
</tr>
<tr>
<td></td>
<td>increases in complexity relevant to the chosen motivating example.</td>
</tr>
</tbody>
</table>
## Stage 1: Concrete Example

<table>
<thead>
<tr>
<th>Steps</th>
<th>Implementations in this Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpretation of single instances – specific documents, occurrences, and other bits of data are examined for the specific meanings they might have in relation to the case</td>
<td><strong>Design</strong> VR, Simulation and Network Technologies</td>
</tr>
<tr>
<td>Identification of patterns – The data and their interpretations are scrutinized for underlying themes and other patterns that characterize the case more broadly than a single piece of information</td>
<td><strong>Test</strong> the performance of the developed communication protocol</td>
</tr>
</tbody>
</table>
Stage 1: Concrete Example

<table>
<thead>
<tr>
<th>Steps</th>
<th>Implementations in this Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesis and generalizations - An overall portrait of the case is constructed. Conclusions are drawn that may have implications beyond the specific case that has been studied.</td>
<td><strong>Write up of results</strong> which would include time tables of run time versus complexity, build time versus complexity, etc.</td>
</tr>
</tbody>
</table>
Stage 2: Define Communication Protocol Methodology

- Qualitative - Content Analysis
  - Produce a general conclusions, hypotheses, from a detailed and systematic examination of the contents of a particular body of material for the purpose of identifying patterns, themes, or biases.
### Research Methodology

#### Stage 2: Define Communication Protocol Methodology

<table>
<thead>
<tr>
<th>Steps</th>
<th>Implementations in this Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify the specific body of material to be studied in its entirety</td>
<td>The following body of knowledge will <strong>be studied</strong>: Virtual Reality, Simulation, and Network Technology</td>
</tr>
</tbody>
</table>
| Define the characteristic or qualities to be examined in precise, concrete terms. | 1. Virtual Reality will **be examined as a state machine** that encompasses states (1a), alphabet (1b) and responses (1c) which will be defined.  
2. **Simulation will be examined as a state machine** that encompasses states, alphabet and responses. Specific states (2a), alphabet (2b) and responses (2c) will be defined. Mixed, Discrete and Continuous simulation types are expected.  
3. The properties of Network Technology will be examined to determine the best choice to **propagate events and responses between VR and simulation state machines.** |
## Research Methodology

- **Stage 2: Define Communication Protocol Methodology**

<table>
<thead>
<tr>
<th>Steps</th>
<th>Implementations in this Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break down each item into small manageable segments that are analyzed separately</td>
<td>1. The <strong>Virtual Reality</strong> states (1a) will be <strong>categorized</strong> (ex: 1a1. touch 1a2. General applications). The VR alphabets (1b) will be categorized following a change of state inputs. The VR responses (1c) will be categorized using the organization and documentation provided by LindenLab as a starting point and then addition extensions will be included (Ex: Shadows from realXTend).</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>2. The <strong>Simulation</strong> states (1a) will be <strong>categorized</strong> (ex: 1a1. touch 1a2. General applications). The Simulation alphabets (1b) will be categorized following a change of state inputs. The Simulation responses (1c) will be categorized using the organization and documentation provided by LindenLab as a starting point and then addition extensions will be included (Ex: Shadows from realXTend).</td>
</tr>
<tr>
<td></td>
<td>3. Necessary <strong>services</strong> to <strong>propagate events</strong> and <strong>responses</strong> between the VR and simulation using Network Technology will be examined. Examples are “wait_for_read”, “opne socket”, etc.</td>
</tr>
</tbody>
</table>
Stage 2: Define Communication Protocol Methodology

**Steps**

- Scrutinize the material for instances of each characteristic or quality defined in step 2.

**Implementations in this Research**

1. For each of the **Virtual Reality states** (1a1..1an), **scrutinize and identify** the accepting alphabets (1b1.. 1bn) and resulting responses (1c1..1cn). This will lead to a comprehensive set of “skeleton adapters” which represent an organization of the code needed to move the VR state machine across the network to the “Simulation side”.

2. For each of the **Simulation states** (2a1..2an), **scrutinize** and **identify** the accepting alphabets (2b1.. 2bn) and resulting responses (2c1..2cn). This will lead to a comprehensive set of “skeleton adapters” which represent an organization of the code needed to move the VR state machine across the network to the “VR side”.

3. For each required **network service** the **necessary inputs** and **output** and relationship among services will be determined resulting in a block diagram level skeleton implementation of the networking for our protocol including the response adapter for the VR objects.
Stage 3: Testing and refining the communication protocol methodology

- Qualitative – Case Study
  - Produce **information from an in-depth**, over a long period of time examination of a single instance or event.
● **Stage 3: Testing and refining the communication protocol methodology**

<table>
<thead>
<tr>
<th>Steps</th>
<th>Implementations in this Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization of details about the case – specific facts about the case are arranged in a logical order</td>
<td>Stage 3 - This step involves selecting and describing a motivational simulation problem</td>
</tr>
<tr>
<td>Categorization of data – categories are identified that can help cluster the data into meaningful groups</td>
<td>The data to be gathered can be divided into the following categories: Size, complexity and performance of Simulation-driven VR, and the development time as the Simulation-driven VR scales to large sized and increases in complexity relevant to the chosen motivating example.</td>
</tr>
</tbody>
</table>
**Stage 3: Testing and refining the communication protocol methodology**

<table>
<thead>
<tr>
<th>Steps</th>
<th>Implementations in this Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpretation of single instances – specific documents, occurrences, and other bits of data are examined for the specific meanings they might have in relation to the case.</td>
<td><strong>Design</strong> VR, Simulation and Network Technologies using <strong>skeletons</strong> provided in stage 2 – specific to the chosen motivating example in 1.</td>
</tr>
<tr>
<td>Identification of patterns – The data and their interpretations are scrutinized for underlying themes and other patterns that characterize the case more broadly than a single piece of information.</td>
<td><strong>Test</strong> the <strong>hypothesis</strong> using the case study. Does this methodology allow larger, more complex Simulation-driven VR environments (with good performance) to be built more rapidly?</td>
</tr>
<tr>
<td>Synthesis and generalizations - An overall portrait of the case is constructed. Conclusions are drawn that may have implications beyond the specific case that has been studied.</td>
<td><strong>Write</strong> up of <strong>results</strong> which would include time tables of run time versus complexity, build time versus complexity, etc.</td>
</tr>
</tbody>
</table>
Ten minute break with refreshments
Concrete Case Study

Selecting a simulation to implement in a virtual reality environment
Concrete Case Study
Selecting the Concrete Case

● Selected Concrete Example for Deriving Methodology

● Dr. Randy Rapp
  • Associate Professor, Purdue University
  • Disaster Restoration and Reconstruction Management, concentration
  • Ex-military commander US-ACE

● Interest: Simulate the phases of construction project excavation allowing students to make selections and provide feedback in response to their actions.
Concrete Case Study

Implementation

- Implemented an earthworks simulation.
  - CVRE: RealXtend
  - Simulation Language: LabVIEW
  - Communication Language: Iron Python
Given the desired simulation a solution was developed to connect LabVIEW with RealXtend.
Concrete Case Study

Testing

- Dr. Rapp’s Construction Site Planning Class
  - 26 Students
  - Demonstration and tutorial
  - Independent testing
  - Surveys
    - Motivational
    - Usefulness
  - Assessment of Server logs
Generalized Communication Protocol

Using the implemented simulation to derive a communication protocol and methodology for developing other simulations in virtual environments.
Generalized Communication Protocol

- This was derived from the ad-hoc experience of implementing the case study.
## Generalized Communication Protocol

- **Specialized Components of the communication protocol diagram**

<table>
<thead>
<tr>
<th>CVRE</th>
<th>Simulation Language</th>
<th>Middleware</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) CVRE Event Triggers</td>
<td>Server-Side State Machine</td>
<td>(10) Condition Transfer</td>
</tr>
<tr>
<td>(2) Primary Event Adapter</td>
<td>(6) State keeper and next state determination</td>
<td>(11) Action Transfer</td>
</tr>
<tr>
<td>(3) Secondary Event Adapter</td>
<td>(7) Action and transition update</td>
<td></td>
</tr>
<tr>
<td>Adapters:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- (4) CVRE → Network</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- (5) Network → CVRE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8) Simulation → Network</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9) Network → Simulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10) Condition Transfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(11) Action Transfer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Generalized Communication Protocol

Methodology

● Step 1: Determine the languages for the CVRE, Middleware and Simulation language

● Step 2: Develop a state diagram and transition table

● Step 3: Complete the Communication Protocol Diagram using the specialized components table

● Step 4: Implement the simulation in the CVRE using the

● Step 5: Test the simulation in the CVRE
Selecting and implementing a more complicated simulation in a virtual environment using the communication protocol methodology
Test Case

Project Selection

- Partnership
  - Hal Johnston
  - Professor, Cal Poly Tech
  - The Building Industry Game
    - A Computer simulation of a realistic business environment where participants play the role of contractors, competing in a market with variable demand for construction work

CAL POLY | College of Architecture & Environmental Design
Test Case

Project Selection

- Create a Simulation to represent the job size, type, and method selected by the user.
Test Case

Objective

- Design the simulation in a CVRE using the hypothesized communication protocol methodology, then implement, test, and make revisions to the methodology if needed.
Test Case

State Diagram

- BID_DB Entry?
  - BID_ID, UFLAG
  - Wait
    - Query Fail
      - Network or Query Fail
        - Simulation → Network : Success
  - Method
    - Method Determined
      - CEU
      - CEU Determined & Excavation Visualization Determined
  - Bid Made
    - Method
      - Method Determined
      - CEU
      - CEU Determined & Excavation Visualization Determined

- Method
  - Method Determined
    - CEU
    - CEU Determined & Excavation Visualization Determined
## Test Case Design

- **Transition Table**

<table>
<thead>
<tr>
<th>State</th>
<th>Bid Database Entry</th>
<th>User, BID_ID, UFLAG</th>
<th>Method</th>
<th>CEU</th>
<th>Simulation -&gt; Network Success Sent: User and Excavation Visualization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wait</td>
<td>Query for user, Bid_ID and User flag</td>
<td>User has made a bid. Query for the user, Bid_ID,</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bid Made</td>
<td>-</td>
<td>-</td>
<td>Query for CEU</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Method Determined</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Determine the Excavation to be made</td>
<td>-</td>
</tr>
<tr>
<td>CEU and Excavation Visualization Determined</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Feed message to simulation adapter and transition to wait state</td>
</tr>
</tbody>
</table>
Test Case

Design

- Determine languages and Test communication
  - Step added to existing methodology
  - Choose a CVRE, Middleware and Simulation Language
  - Determine how the CVRE and Simulation Language can communicate
Test Case
Design

O3D (CVRE)

Capture:
User wants to excavate but are these values the same as the last visualization calculated?

Implement:
An excavation is made based on the js specifications.
A certain amount of people and/or equipment is shown based on the js specifications.

Message:
Show excavation button pressed
Slave:
Excavation is made based on script file

PHP (Middleware)

Transition:
User made their selection and needs a visualization

Transition:
These are the user selections that need to be displayed

BIG (Simulation Language)

Keeps:
The job size, type and possible methods for all jobs available for bid.

Interprets:
What were the job size, type and method selected by the user?

Determines:
This is the job size, type, ad method that was selected by this user

Makes:
A js files containing the job size, type and method to be displayed.
Test Case
Implementation
Test Case
Testing with Professor Johnston

- Teleconference with Professor Hal Johnston
  - December 16, 2010
- Brief Training Session
  - Hands-on tutorial
- Independent Testing
Test Case

Results

- Comments from Hal Johnston
  - Change wording of a few buttons
  - Written letter of support
  - “When this first started I had no idea how this could impact my simulation. I now see how this could be extended for the rest of my simulation.”
Test Case
Results from Testing with Dr. Rapp

- Time to implement
  - It took about three months to implement the test case.
    - Took nine months to implement the case study
  - Technologies were completely different

- Determined Communication Protocol Methodology needed to be refined
Test Case

Refinement of the Communication Protocol Methodology

Steps for designing the Simulation in the CVRE

- **Step 0**: Understand project at hand
- **Step 1**: Determine the languages for the CVRE, Middleware and Simulation language
- **Step 2**: Build a test communication between the CVRE and Simulation language selected.
- **Step 3**: Develop a state diagram and transition table
- **Step 4**: Complete the Communication Protocol Diagram using the specialized components table
- **Step 5**: Implement the simulation in the CVRE using the
- **Step 6**: Test the simulation in the CVRE
Test Case

Refinement of the Communication Protocol

- Communication Protocol Diagram Refinement
## Test Case
### Refinement of the Communication Protocol

- **Specialized Components Refinement**

<table>
<thead>
<tr>
<th>CVRE</th>
<th>Simulation Language</th>
<th>Middleware</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) CVRE Event Triggers</td>
<td>Server-Side State Machine</td>
<td>(10) Condition Transfer</td>
</tr>
<tr>
<td>(2) Primary Event Adapter</td>
<td></td>
<td>(11) Action Transfer</td>
</tr>
<tr>
<td><strong>(3) Secondary Event Adapter(s)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapters:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- (4) CVRE → Network</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- (5) Network → CVRE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- (6) State keeper and next state determination
- (7) Action and transition update
- (8) Simulation → Network
- (9) Network → Simulation
Steps for implementing the simulation in the CVRE

- Once you have settled on the state diagram the next step is to build the components in the following order:
  - Simulation Language
  - CVRE
  - Middleware
Summary

The result, limitations, impact and future research of this dissertation
Results

- A robust and scalable communication development methodology to connect external simulation languages with client-server Collaborative Virtual Reality Environments.
The communication protocol methodology:

- Easy to understand by non-experts
- Provides an easy interpretation of the simulation to be implemented.
  - Programmer – step by step implementation diagram
  - Client – visual to determine appropriate design objective
- Reduces the amount of time required to implement a simulation in a CVRE
- The methodology is scalable as modules can be added to the simulation with minimal changes to the existing methodology.
Keeps:
The job size, type and possible methods for all jobs available for bid.

Interprets:
What were the job size, type and method selected by the user?

Determines:
This is the job size, type, and method that was selected by this user.

Makes:
A .js files containing the job size, type and method to be displayed.
Design and Implementation as in Test Case

Capture: User wants to excavate and has cleared the scene?

Index.php (menu driver in O3D)

```html
<div id="removeEquipment">
  <img src="images/earthworks.png" alt="newTerrain" />
</div>
```

Adding the foundation function to the Test Case

Capture: User wants to visualize the foundation and has cleared the scene?

Index.php (menu driver in O3D)

```php
// create a button for the user to push that will trigger the foundation building
// indicate an image to designate this button
```
Results

Design and Implementation as in Test Case

Define.js (functions to manipulate the environment)

```
$(
newTerrain
).click(function () {

    // flatten the terrain using the appropriate network.send() command
    // Example: network.send({"action": what is being modified, what model action : what to do});

    // remove all models using the network.send() command as seen below
    // Example network.send({'action': what is being modified, "command":2 (indicates delete),
    // "model":model number form database});

    .........

```

Transition: User made their selection and needs a visualization

Adding the foundation function to the Test Case

```
Envir.js (functions to manipulate the environment)

$(
newTerrain
).click(function () {

    // flatten the terrain using the appropriate network.send() command
    // Example: network.send({"action": what is being modified, what model action : what to do});

    // remove all models using the network.send() command as seen below
    // Example network.send({'"action": what is being modified, "command":2 (indicates delete),
    // "model":model number form database});

    .........

    // needs the addition of the removal for old basement items
}
```
Design and Implementation as in Test Case

Adding the foundation function to the Test Case

The only change is to add another variable to store the foundation method selected as the method for getting the job size and type remain the same.
Design and implementation as in Test Case

The only thing to change at this point would be the names being sent to the write.php as the method selected needs to be indicated as foundation method selected.
Design and Implementation as in Test Case

Adding the foundation function to the Test Case
This requires no change as the data is already formatted.
**Design and implementation as in Test Case**

**Implement:**
An excavation is made based on the .js specifications.
A certain amount of people and/or equipment is shown based on the .js specifications.

**Data.js**
```javascript
var jobSize = 20937; var jobID = 1; var jobType = 1; methodSelected = 'Excavation1';
```

**Adding the foundation function to the Test Case**

**Implement:**
The foundation is made based on the .js specifications.
A certain amount of people and/or equipment, and basement materials are shown based on the .js specifications.

**Data.js**
```javascript
var jobSize = 20937; var jobID = 1; var jobType = 1; methodSelected = 'Excavation1';
```

//add variable for foundation method selected.
Design and implementation as in Test Case

Slave:
Excavation is made based on script file

Adding the foundation function to the Test Case

Slave:
Foundation is made based on script file
Design and implementation as in Test Case

Adding the foundation function to the Test Case

```
$('#PreviewExcavation').click(function () {
    if cases for all ranges of the job sizes (CUs)
    {
        if cases for all methods selected by the user
        {
            //use the network.send() commands to create a model and locate the model in the desired location
            //Example network.send({"action":"model", "command":1, "model":"EE0A569CB7D14996B101B338DE749EFE", "url":"post/inventory/wheelbarrowman.o3dtgz"});
            // network.send({"action":"model", "command":3, "model":"EE0A569CB7D14996B101B338DE749EFE", "matrix":[[0.029999999329447746,0,0,0],[0,3.5774641582442257e-10,-0.029999999329447746,0],[0,0.029999999329447746,3.5774641582442257e-10,135.13965743956678,-2.842170943040401e-14,-18.50815467143633,1]]});
        }
    }
});
```

```
$('#PreviewExcavation').click(function () {
    if cases for all ranges of the job sizes (CUs)
    {
        if cases for all foundation methods selected by the user
        {
            //load and place the foundation models
        }
    }
});
```

Slave:
Equipment and/or people are shown

Slave:
Foundation Elements, equipment, and/or people are shown
Limitations

The methodology does not include:

- **Multi user**
  - Although the methodology should extend to multi-user interactions this feature has not been fully researched.

- **Language compatibility**
  - Will not work if the languages selected for the CVRE, simulation, and middleware are not compatible

- **Scalability**
  - The issue of scalability has been tested with complex simulations but not on a factor of users
Limitations

● The methodology does not include (cont.):
  • Communication
    - The communication sent between the CVRE and simulation language has been small
  • Methodology Testing
    - The methodology has only been tested by myself not others.
Future Research

- Incorporating the ability for multi-user interaction
- Mobile systems
  - Simulations for mobile devices
- Parallel Communication
  - For very large scale simulations in CVRE
- Visual Conflation
  - Getting the simulation data from different sources and putting them together
  - One to many communication
Future Research (Cont.)

- **Scalability**
  - Testing the scalability in respect to more individuals
- **Communication**
  - Test sending larger packets of data between the simulation language and the CVRE
- **Methodology**
  - Allow others to implement simulations in CVREs and add to the existing simulation using my methodology.
Impact

● What can be done?
  • Simulations in need of a visualization can **quickly** and **cost effectively be implemented** in a CVRE for single users to visualize their interactions.

● What does this result in?
  • **Better and more effective software development** among simulation and training applications developed in CVREs.
What is the impact of this dissertation?

- More simulation and training software that would be better than the existing.

How will this better the world?

- A better trained workforce equipped with better decisions making tools based on better and more widely available simulation and training software.
Dissemination

Publications and accomplishments during doctoral career
Dissemination

- 2011 Associated Schools of Construction 47th Annual International Conference
  - Title
  - Motivation through Collaborative Virtual Reality Environments Earthwork Exercises
  - Co-Authored with: Dr. Tulio Sulbaran, Dr. Andrew Strelzoff, and Dr. Randy Rapp
  - Grant to Attend Conference
Dissemination

● 2009 International Conference on Enterprise Information Systems and Web Technologies
  • Title
    - Virtual Reality Simulation Objects For Plant Shutdown Training And Visualization, International
  • Co-Authored with:
    - Andrew Strelzoff and Tulio Sulbaran
  • Title
    - Collaborative Technology in Virtual Reality for Plant Shutdown Planning
  • Co-Authored with:
    - Andrew Strelzoff, Tulio Sulbaran, and James Ross
● The Journal of Management and Engineering Integration
  • August 2010
  • Authors
    - Daniel Bond, James Ross, Nan Wang
  • Title
    - Relating White Papers Using Word
    - Frequency and Clustering
Dissemination

- The 2011 International Conference on Software Engineering Research and Practice
  - In the works
  - To be co-authored with
    - Professor Hal Johnston,
      Dr. Strelzoff, Dr. Sulbaran
  - Application of Communication Protocol to Embed Collaborative Virtual Reality Environment in Building Industry Game
Dissemination

- iTech Update, Technology at Southern Miss
  - iTech Supports Teaching and Research Collaboration Between Southern Miss and Perdue
  - Co-Authored with Andrew Strelzoff and Tulio Sulbaran.
Adjournment

● Special Thanks to:
  • Dr. Andrew Strelzoff, Chair
  • Dr. Tulio Sulbaran, Co-chair
  • Dr. Joe Zhang, Director
  • Dr. Ray Seyfarth
  • Dr. Nan Wang
Adjournment

- Questions
- Comments
- Signatures
  - Dissertation Title Page
  - Results of Oral Defense