# Sound Spatialization

# For the Egyptian Oracle

Master's Thesis
In partial fulfillment of a
Masters Degree in Professional Studies,
Department of Digital Media,
Northeastern University

Ajayan Nambiar

Ajayan Nambiar <ajayandn@gmail.com>

Advisor: Jeffrey Jacobson, Ph.D.

Director, PublicVR, http://publicvr.org

Jeff@planetjeff.net

# Table of Contents

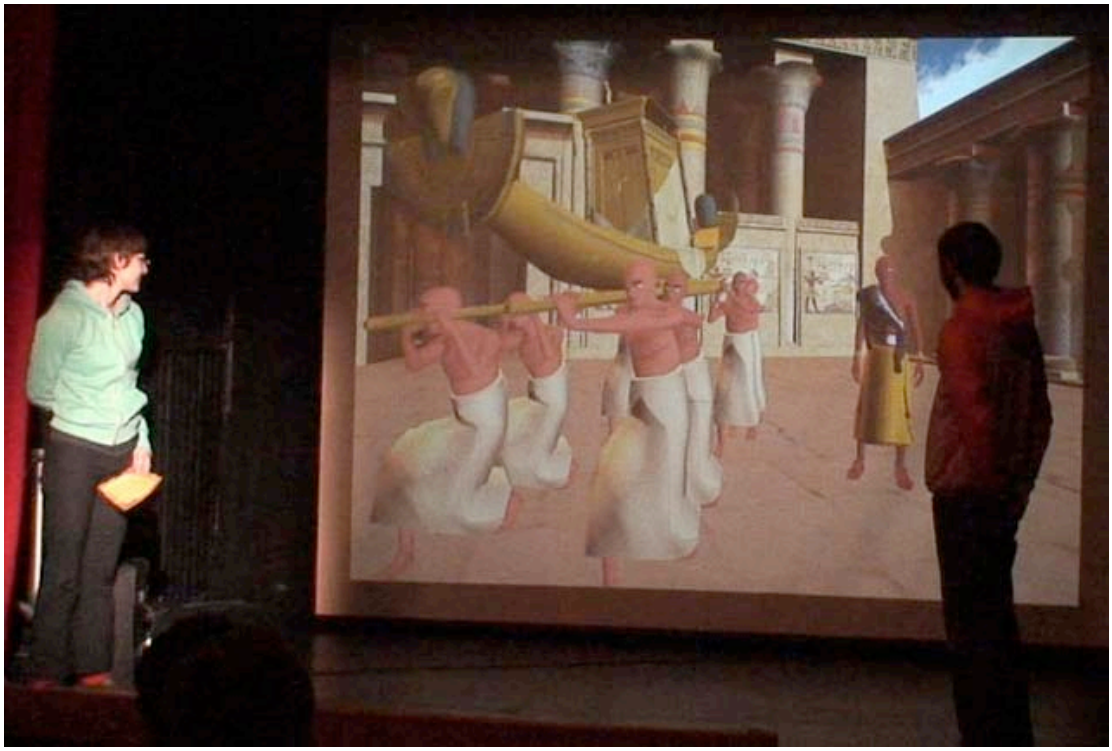
# Preamble

By Jeffrey Jacobson, Ph.D., Thesis Advisor

This document describes thesis work by Ajayan Nambiar in partial satisfaction for his Masters in Professional Studies at the Department of Digital Media at Northeastern University, Jeffrey Jacobson, PhD, supervising. Mr. Nambiar's assignment is to improve the auditory experience for audiences participating in the Egyptian Oracle performance, described here.

The show is a recreation of an authentic Egyptian public ceremony, from ancient Egypt's Late Period. As you can see in the image below, we project our Virtual Egyptian Temple on the wall at life-size scale. It is not a film, not a static image, but a true three-dimensional virtual space. The virtual high priest is an avatar controlled by a live human puppeteer, hidden offstage. The priest, the live actress (in front of the screen, left), and the audience have a three-way interaction. Audience members represent the Egyptian populace and take turns acting out brief roles in the drama. Finally, the sacred boat (left) is another puppet also controlled by the puppeteer; in the drama, it is moved by the will of the temple god. The actress manages the audience who come before the god with questions and problems to be solved. The priest poses questions to the god, and interprets the movements of the boat as divine revelation or judgment. These judgments had the force of law were essential to Egyptian public life.

In the scene below, two audience members represent neighbors engaged in a legal dispute. The sacred boat indicates the will of the god, by pointing to the person on the left, a ruling in her favor. The show conforms to a high level of historical accuracy, suitable for any museum setting. For, historical background, please see http://publicvr.org/egypt/oracle/whitepaper.pdf. For a short video demonstrating the interaction, see http://vimeo.com/24297667.



Originally, equipment for the performance included a simple sound system, two speakers, an amplifier, and a microphone for the puppeteer. The software produced ambient sound and background music for each area of the Temple. It also provided musical sound effects for various actions during the performance. Along with the puppeteer's voice, these were fed through the sound system and the speakers.

Mr. Nambiar's Assignment was to construct a more advanced sound system and improve on the software to increase the audience's sense of immersion in virtual space. The goal is to make the physical theater sound like an Egyptian temple. More specifically, there were three scenes in the performance at thee different locations in the Temple. In real life each of these locations would have had different acoustic properties. For example, both of the images depict the Courtyard, which has high walls but an open roof. The previous scene takes place in the Festival Hall, which is half the size, has even higher walls and a roof.

The background music, sound effects, and reverberation effects applied to sound produced by the software, the puppeteer, the live actress, and participating members of the audience all had to sound like they were in the current virtual space. Mr. Nambiar developed an approach to

introduce increasing levels of sonic realism. The most difficult aspect of his thesis is designing the requirements for a practical, partial, solution to this ill-defined problem. Many technical approaches were possible. We needed an approach that

1. artistically produces a good experience for the audience,
2. is aesthetically consistent with other elements of the show,
3. could be achieved within our hardware budget ($1500),
4. is portable for travel to different performance venues,
5. adaptable to the varying requirements of different physical forms spaces,
6. is expandable and friendly to future improvement.

Further requirements for his thesis project are:

1. Learn the structure and nature of the performance. Confirm with senior artists and technical people on the project.
2. Specify the precise hardware needed.
3. Learn how to write software in Unity (www.unity.com), the game engine we employ for this project.
4. Make necessary changes to the Egyptian Oracle software.
5. Construct and test the physical system he has designed.
6. Produce this document, which specifies the system and design approach.
7. Training the next intern (John Hawkins) on the use of the system,
8. Assist with the setup for four performances of Egyptian Oracle, and operate the sound system.

I'm happy to say that he performed all of these tasks, admirably. We will turn this thesis document into a publication in some venue favorable to Mr. Nambiar's career. We will also add this thesis to the documentation for the Egyptian Oracle open source code. (Under the requirements of the grant that funded the project, all software, scripts, and general design for the show is to be released to the public for noncommercial and educational uses.) PublicVR will retain a copyright for the work Mr. Nambiar has produced, but he retains unlimited use of it. We will prominently and specifically credit his contribution in the product documentation, our website, and publications regarding The Egyptian Oracle performance. The project was funded by the Digital Startup grant from the National Endowment for the Humanities, number HD5120910.

For more information, feel free to contact me:

Jeffrey Jacobson, Ph.D.
Director, PublicVR http://publicvr.org
jeff@publicvr.org 617-435-0517
http://www.publicvr.org/JacobsonAcademicCV.htm

## Abstract

The Oracle performance takes place partially in real space, and partially in virtual space. (see “Preamble”, above.) The task is to overlay a soundscape onto a physical space to match the projected visual. More precisely, we wish to create a unified aural space that extends from the physical through the virtual to encompass the entire performance.

The aural contributions come in the form of the ambience, puppeteer, actor and the audience. The ambient music and effects would serve as the base on which the additional sounds would be placed to enhance realism. The additional sounds would be a mix of the sound of the puppeteer, actor and the audience all channeled through separate microphones. The fidelity of the sonic space would further need to be enhanced with the addition of specialized sound effects such as echo, reverb, etc to make the space more believable to the audience. The inclusion of different reverbs for different spaces would be the first major addition and also the most psychologically impactful. The changes in reverb would immediately allow the audience to discern the transition from a big space to a small one or from an open space to a closed one.

Integration of sound with space would not be the only task at hand. Sound must also gel with the performance and hit cues with the actors to provide a sense of realism. Automation of sound is a core goal of this project. However, in a real time project with live actors, automation of sound has certain limitations, which is why an operator to regulate live sounds was deemed necessary. Further efforts would be put in to automate these tasks in future to make the system more self-reliant.

# Introduction

The sound system is being implemented for an existing visual experience designed on the Unity Game Engine. The process starts with the intention of the piece and depending on the various sound elements, a basic system is designed which is ideally modularized and scalable. Each component is then specified and the system is assembled based on the design. The whole developmental process follows an iterative methodology.

New components help augment the depth of the performance space. Reverb is introduced with the aid of a 32 bit sound effects processor which gives a wide range of effects such as echo, chorus and double slap to name a few. The amplifier output would be increased from 80 watts through 2 channels to 130 watts through a 5 channel surround system. Powered amplifier along with a separate low frequency line out would give more bass control. A mixer gives more control over sound and eliminates floor noise.

Tasks are split according to priority and the most important tasks are addressed first. The implemented designs are tested while discovering and implementing additional requirements through the process. Descriptions also cover the connection process along with operational procedures. The entire procedure is outlined so as to aid in proper operation as well as future upgrades and adaptability of the system to different venues.

The final system is tested at different venues to understand its range and limitations. It also helps to simulate real world scenarios much more clearly.

# Purpose of Internship

1. Exploring the dynamics of the mixed reality performance. Understanding the importance and position of various elements within the final piece. Experiment with effects of reverb in changing the perception of space.
2. Understanding how a mixed reality performance is assembled and staged. What are the limitations, challenges and requirements of the project from various perspectives – actors, software, audience, and director.
3. Work with the project director, actors, composer and programmers to realize the sonic space.
4. Design and outline hardware and software requirements for the final system with specifications for power, number of channels and number of sources. Detailed explanation of manual operations required.
5. Implementation of the solution at the hardware level as far as possible, thereby making the system adaptable to other performance scenarios.
6. Upgrading stereo system to a powerful 5.1 surround system with increased wattage.
7. Introducing reverb into sound environment using a dedicated sound effects processor.
8. Implementing a multi-channel mixer to gain better control and eliminate floor noise.
9. Automation of the system to aid in minimal user intervention.
10. Design the system to be as portable as possible to allow in ease of transportation.
11. Participate in live performances at different venues – Atlantic Wharf, Puppet Showplace Theater and Boston College. Gather data on how different spaces exhibit different acoustic qualities. How to work within constraints and maximize the opportunities at different locations.
12. Use iterative developmental approach.

# Components

1. Mixer
2. Amplifier
3. Woofer Unit
4. Surround speakers – ( Four surround and one center speaker)
5. Wireless headset system
6. Wireless handheld system
7. Laptop
8. Projector
9. Xbox controller
10. Connecting wires
    a. XLR male to female connectors – 3
    b. ¼ inch plug to RCA connector – 1
    c. 3.5mm plug to ¼ inch connector - 1
    d. VGA cable (Laptop to projector)
    e. RCA cable (Amplifier to Woofer)
    f. Speaker wires – 5

# System Specifications

## Hardware:

1. Onkyo HT-S6300 Theater System
   - 1200 Watt system (130 Watt * 7 Channels plus 290 Watt powered sub-woofer)
2. Mackie ProFX8 Mixer

- Professional 8 channel mixer
- 4 low-noise mic pre-amps with LED metering
- 32-bit Sound FX processor with reverb, chorus and delay
- Precision 7-band graphic EQ for tuning mains
- USB I/O for recording and music playback via Mac or PC

3. Audio 2000 Dual Channel Wireless Microphone Headset

- UHF Band 670MHz – 695MHz
- Two control knobs (One for each channel)
- Two independent XLR balanced output and one ¼ inch unbalanced audio output
- Two Lapel & Two Headband Headset Microphone

4. PylePro PDWM2600 Dual UHF Wireless Microphone System

- Operating range of up to 150 feet
- ¼ inch mixed unbalanced output
- Frequency range: UHF 600 – 700 MHz
- Two wireless microphones

5. Laptop

- Microsoft Windows 7
- Intel or AMD 2 GHz processor
- 128 MB dedicated graphics card

- 80 MB Hard Disk

6. Xbox controller

- USB 2.0 connector

7. Projector

   Standard LCD or DLP projector

## Software:

1. Unity game engine v3.3 to deploy final compilation
2. Logic Pro 8 used for sound composition
3. 3ds Max 2011 for modeling and rendering

   Please refer to the documentation for Egyptian Oracle Project Software for details, which is pending completion.

# Assembly

The system is built around the mixer as the central point. All the sound inputs from different sources are routed to the mixer, which then outputs the final processed sound to the amplifier. For the purpose of this project, importance has been given to the fact that there should be a single point of manipulation to all sound sources and also to the fact that it should be real time.

Refer to Diagram


Connection Diagram

1. The connections and the respective wires used are depicted in the diagram.
2. Where two parallel wires connect to a single device (e.g. L and R for a standard speaker), the wires are shown in and black and red.
3. Since it is a 5-speaker setup. Speakers must be arranged accordingly for the right effect. Mount speakers on stands and adjust height to match the listeners (audience).
4. Speaker positions are Front left, Front right, Center, Rear left, Rear right. The connections for these speakers are labeled accordingly behind the amplifier. Make sure the connections match the position of the speaker.
5. Wireless headset system has dual receivers and can be used by 2 users at a time. There is an option for headset or lapel microphone. Either can be used where appropriate. Connect the output from the headset receiver to the mixer at the indicated location on the diagram.
6. Wireless hand held system also provides the user with 2 hand held microphones and works similarly to the headset system. However there is only output from the receiver that connects to the mixer.
7. Make the appropriate connection from the mixer main out to the game port behind the amplifier. Make sure the “Game” option is selected from the amplifier front panel.
8. Run the video connection (DVI, HDMI, Display port) from the laptop to the projector.

# Sound System Operations

Manipulation for sound is easiest when done at a single location. This is true especially when the changes to be made have to be in real time. For the purpose of the designed system this must be done at the mixer to balance the sound of the actor, puppeteer and audience with the ambient sound produced from the oracle environment.

**Amplifier Controls:**


1. Input Selector

   - Always select the option “Game” here, as the output from the mixer would be connected to this port.

2. Master Volume

   - Keep the master volume at 40dB and use master volume control on Mixer to regulate the volume. This allows for real time control at a single location.

**Mixer Controls:**


1. Input Gain Controls

- Used to boost or trim volume of signals coming in to the mixer. The user must take care to see that the sound does not clip while boosting.

2. Equalizer

- Used to control highs, mids or lows within each input source. This helps to give a certain degree of control in the final mix.

3. FX Controls

- These controls help regulate the amount of effects such as reverb within each input signal.

4. Pan Controls

- Helps pan the respective source input to the left or right.

5. Individual volume controls

- Helps balance the volume of each input in the final mix.

6. Stereo Graphic equalizer

- Helps vary the level of various frequencies in the final output.

7. 32-bit Fx Processor

- 32-bit effects processor helps select the kind of effect required. Effects like echo, reverb etc., can be selected. The degree of each selected effect can also be varied as a whole and within each input source.

8. Main volume control

- This is the global volume control and regulates the volume for all sources across the board.

**Operator Notes:**

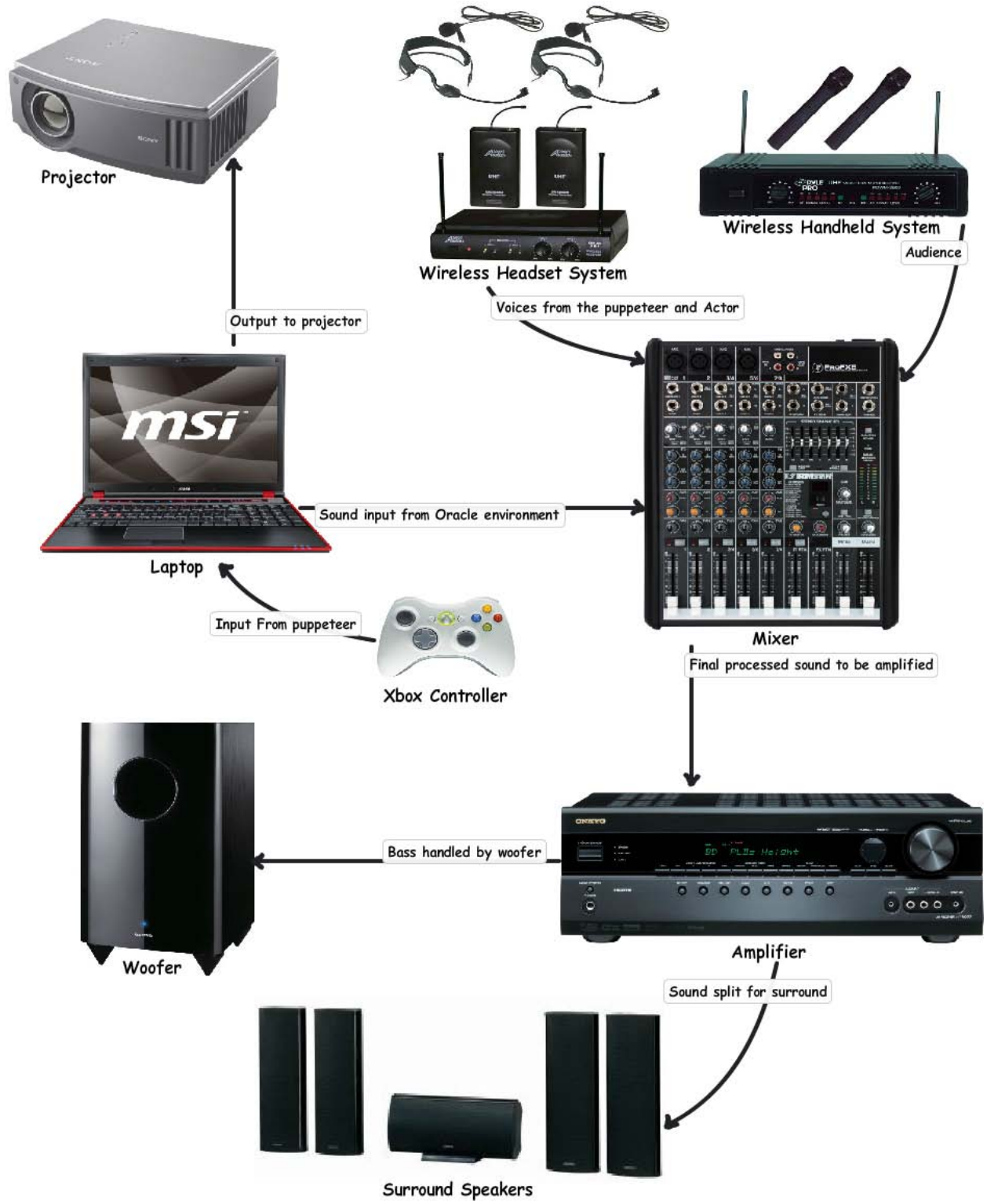
Connections were made as outlined in the assembly diagram. Care was taken to see that the mixer was retained as the central point of control for sound.

- Set volume on the amplifier to **40 dB**.
- Settings on the mixer for FX presets range from 1 – 16. Choose the one that suits the space the best.
- FX master knob adjusts the amount of sound effect (reverb, echo, etc) that is mixed with the original sound.
- Individual yellow FX knobs regulate how much reverb effect is mixed with each source such as the actor, puppeteer, audience or the ambience. As a general rule of thumb it is better to have more reverb on the ambience compared to other elements in the sound.
- Too much reverb on voice sources clouds the speech making it hard to understand.
- The ambient sounds already have mild reverb tuning programmed into Unity.
- The sound operator would have to manually add reverb to the live voices as they would contain no reverb before being input into the mixer. The reverb must be added to match the performance space.
- It would also generally be a good idea to shape the Stereo Graphic EQ on the mixer in a slightly U-shape. This arrangement generally has a tendency to project the illusion of a wider space and a bigger sound.
- Individual pan controls would allow the user to localize the source if required.
- Balance the volume of each source by using volume slider switches.
- Take care to see that the main meters LED indicator does not stray into the red zone. This shows that there is distortion in the output. Keeping the main meters out of the red zone ensures a clear sound at all times.
- Care must be taken to balance the voice of the actor, puppeteer and the audience. Since microphones are held at different distances and each user speaks at different volumes, the mixer would have to be balanced manually to compensate for spikes in volumes.
- Each source also has a mute button, which would aid in blocking the sound completely if the need arises.

**Dynamics of reverb:**

- Introducing reverb as an effect must be done carefully.
- Reverb has the ability to change the perception of size with relation to space.
- Reverb in a room will vary depending on a number of factors. Some of the factors are size of the room, shape of the room, materials used for the walls, elements in the room, amount of sound absorption, amount of existing reverb in the room and height of the ceiling.
- It is always best to have a test run at the performance venue to determine the best possible adjustment for reverb.
- The dynamics of reverb vary wildly depending on a variety of factors. This makes a single constant software solution hard and requires human intervention to balance. This is one of the major reasons that reverb control was solely assigned to the mixer. This gives flexibility and real time adjustments at the performance venue.
- Another task would be to make the performance space sound like how the virtual space would sound. This would require some experience and finesse on the part of the sound operator. Therefore the operator should take some time to familiarize himself with the equipment and test its boundaries.
- In the future, we hope to automate as much of this process as possible. However, we have to understand it first, which requires doing manually.

# Functional Flow Diagram



# Internship Narrative

**Initial Setup:**

In the beginning, the Egyptian Oracle had a basic setup starting with a 13 inch Macbook Pro. Video was sent out through the display port to a projector. Sound was channeled through the headphone out of the laptop to a powered mixer. The powered mixer combines sound output from the laptop with the sound of the wireless microphone used by the puppeteer. The mixer has sound coming out from two 80 watt speakers placed in the front of the audience, on the left and right of the performance space. The puppeteer would have access to laptop and Xbox controller during the performance.

Observations:

- Final sound lacked immersion due to lack of being able to surround the audience in the space being visualized.
- Minimal control over individual sound. No EQ to tweak the voice of the puppeteer or the sound output from the laptop.
- No echo or effects control.
- Weak positioning of sound.
- Limited sound scalability with respect to space.
- Portability was an issue due to the speakers being big and unwieldy.
- Video was choppy at times due to frame rate dropping below 24 fps. This was a direct consequence of the weak integrated graphics card.

**Pass 1:**

The Oracle system was given a serious sound upgrade with a home theater system. The higher 130 Watt per channel sound system gave the final sound more depth and authority. The attempt was made to bring the audience into the space of the Oracle. Rear speakers helped envelope the audience in the space while the dedicated powered sub-woofer helped create a sense of environment as a backdrop. USB microphone used for sound input from the puppeteer instead of the wireless system.

Improvements:

- Much more audible sense of space observed.
- System helped visualize both closed and open spaces well.
- Higher system wattage also helped create more depth and authority in sound.
- Sound positioning was highly improved due to 5 channel surround with bass assist from the woofer.
- System was more powerful and portable at the same time.
- Better control in sound due to customizable options available on the amplifier.
- Theater system was scalable and could adapt to varying room sizes and room acoustics better.

Observations:

- A disconnect in the space was observed between the ambient sounds and the sound of the puppeteer.
- The USB microphone produced an unnatural robotic sound. The laptop sound card was clearly not good enough to process the puppeteer's voice.

- The laptop only gave volume options for the microphone. There was still no EQ to change the characteristic of the microphone.
- Since the laptop was being used as the mixer in the new setup, not many sources could be mixed together. In fact only 2 sources at any given time could be mixed. More particularly a pre-recorded sound and a single microphone input with weak options for customizability.
- Effects control in terms of echo and reverb for the space was lacking once again.
- Wired microphone restricted the freedom of movement of the puppeteer.
- Real time processing was hard to achieve. Most of the sounds had to be pre-processed or compiled during run time to match the space and could not be altered in real time.
- Since the puppeteer fully occupied the laptop, any change in sound during the performance was impossible.

**Pass 2:**

The Egyptian Oracle had already been built on the Unity Game Engine. Unity has a number of built-in sound processing options, which had to be explored to assist in automation. The sound from the USB microphone was routed to the Unity Game Engine for real time processing within the laptop.

Improvements:

- There was more control over the sound of the puppeteer as Unity allowed volume control, panning and reverb control for the sound of the puppeteer independent of the ambient sound.
- Real time sound processing achieved.

Observations:

- Even though real time sound processing was achieved, the amount of effect or the kind of processing on the sound could not be altered during run time.
- There was no way to handle distortion.
- Analog to Digital conversion of real time sounds seemed to still suffer considerably. Sound was still robotic in nature and unnatural. This was dependent on the sound card in the system and therefore was too arbitrary and made it difficult to port to different computers.
- Real time sound processing also took quite a toll on system resources depending on the number of effects incorporated. This also affected visual processing as the sound processing was consuming too much system resource.
- Real time sound processing dependency as a consequence was avoided on the computer. This helped reduce the computer processing power required to run the Egyptian Oracle satisfactorily.
- Pre-programmed sound processing in real time sounds presented certain limitations. If the performance space in question had a tendency to produce an echo, it would disturb the balance of sound generated by Unity. As a result causing an overwhelming echo within the room breaking the realism of the space and rendering the speech slightly unintelligible.

**Pass 3:**

Since the Egyptian Oracle is a live performance piece, real time sound processing must be considered. Any spikes in sound would have to be monitored and controlled depending on the space by the sound engineer. Individual control was of paramount importance therefore a mixer was introduced into the sound setup. It had 8 channels of input with individual sound control for each. There was also a 32-bit onboard effects processor, which allowed altering the sound to suit the space in real time. A wireless headset system was re-introduced into the mix giving the puppeteer more freedom to move around.

Improvements (mostly through the addition of the mixer):

- Single point of sound manipulation achieved.
- Sound effects such as echo could be introduced and changed in real time depending on change of space.
- Individual sound control on every source. 8 independent sources could be input into the mixer giving the system higher scalability for future projects.
- Each input also had individual effects and EQ control making the system extremely customizable.

Observations:

- The actor at the screen seemed disconnected as she talked to the audience directly and it broke the illusion of the space. Depending on the size of the room, it was difficult to hear the actor beyond a particular distance.
- Audience participants also had the same problem as they were talking directly in the space.
- The problem got better or worse depending on the size of the space. System had to be made adaptable to different spaces, both shape and size.
- Video was choppy at times as the laptop graphics was not powerful enough to handle the frame rate required.

**Pass 4:**

A wireless handheld system was introduced for the benefit of the audience and to maintain the sonic integrity of the space projected. The actor was also provided with a microphone to bring her into the space. A new laptop with a dedicated graphics card was used to increase frame rate thereby improving visual quality.

Improvements:

- All the participants in the Oracle performance now seem to be in the same space.
- All sounds or sources could be modified in real time.
- Use of better performing laptop shows marked improvement in visual performance.
- Ambient sound reverb was automated through Unity. However, the mixer would still be able to introduce more reverb if required.
- All the live voices were channeled through the mixer in such a way that manual reverb and effects could be added individually.

# Collaborations

1. **Dr. Jeffrey Jacobson – Program Director**

- Project requirements and structure
- Design process instructions and training
- Report writing
- Equipment support and project funding

2. **Brad Shur – Puppeteer & Brenda Huggins - Actor**

- Discussed expectations on final sound treatment.
- Assisted in getting accustomed with the new microphone system.
- Trial sessions to help simulate the performance environment.
- Scheduled performances.

3. **Jon Hawkins – Music Composer**

- Creative discussion on the nature of music to be employed.
- Re-adjusted tracks to remove spikes.
- Included mild sound effects and normalized the sounds.
- Trained Jon Hawkins on the assembly and dynamics of the new system.
- Unity walkthrough for Jon to allow for commonly used functions.

# Conclusion

The Egyptian Oracle sound spatialization project began with a purely software based solution in mind. Performance at different venues made it apparent that a purely software based solution was incapable of handling all the demands of live sound.

Therefore a hardware solution had to be devised which would make real time processing a reality. The one disadvantage being the experience of the sound operator would also play a big role in the final sound produced. While a live operator can exercise more judgment and far greater flexibility than any automated system, it is more costly than a turnkey software solution.

The thesis managed to address most of the sound goals of the Egyptian. At the end, what we have is a much more real and elevated sound experience for an excellent visual depiction of the Egyptian Oracle.

# Future Work

The sound system for the Egyptian Oracle has been designed in modules and therefore is scalable and easily serviceable. The flexibility of the system would also allow it to adapt to other future projects very easily. The system still has shortcomings which when addressed could make the experience even better. It would also help reduce operator dependency by the system.

- Better wireless microphone systems would help control distortion much more efficiently without the need for an operator to regulate it at the mixer.

- Better microphones would also handle the issue of feedback when it is accidentally pointed directly at the speaker during a performance.

- Better sound cards would have better sampling rates, thereby producing much better sound with minimal loss in quality. These would also have the hardware to handle considerable sound processing which would in turn take the load of the main CPU. This would open up the possibility of another attempt to re-route the responsibility of the mixer through the sound card.

- A studio grade speaker would provide a deeper sound with better authority. It would also work better in a bigger space and even better in an open space compared to a home theater system.

- Incorporating more environmental sounds into the Unity platform would help support the ambient sounds. Better sound triggers and sound placement would be another area that could be improved on.

# References

1. http://www.audioholics.com/
2. http://www.soundboard.com/category/Sound-Effects.aspx
3. http://www.mackie.com/
4. http://www.onkyo.com/

# Sound System Connection Diagram

Projector

Wireless Headset System

Wireless Handheld System

Output

Input

Input

Laptop

Input

Mixer

Input

Xbox Controller

Output

Woofer

Amplifier

Surround Speakers

# Mackie ProFx8 Mixer Connections

First XLR connector from wireless headset system

Second XLR connector from wireless headset system

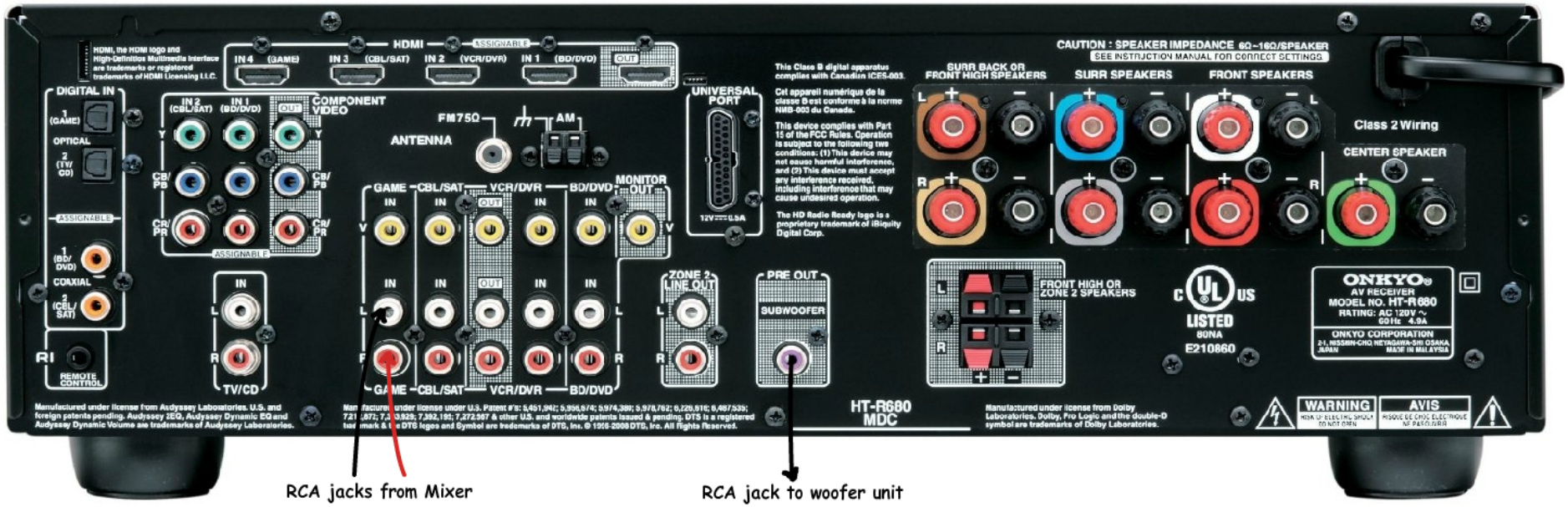
Third XLR connector from wireless hand held system

3.5 mm jack to 1/4 inch jacks from laptop


1/4 inch jacks to RCA jacks which connect to amplifier

Back

# Onkyo Home Theater Amplifier Connections




Back

# Audio 2000 Wireless Microphone System Connections


XLR jack from wireless receiver to mixer

Back

# PylePro PDWM2600 UHF Wireless Microphone System


XLR jack from wireless receiver to mixer

Back

Stereo RCA to Stereo 1/4 inch Plugs


Back

Stereo RCA to Stereo 1/4 inch Plugs


Back

3.5 mm to Stereo 1/4 inch Plugs


Back

XLR Male to Female Connector

Back

XLR Male to Female Connector

Back

XLR Male to Female Connector

Back

RCA Jack for Woofer Unit

Back