CREATING AUTOMATED INTERACTIVE VIDEO PLAYBACK FOR STUDIES OF ANIMAL COMMUNICATIONS

A Thesis

by

TRISHA ANN BUTKOWSKI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Visualization Sciences

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Approved by:

Co-Chairs of Committee,	Frederic I. Parke
	Wei Yan
Committee Members,	Gil Rosenthal
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ABSTRACT

Creating Automated Interactive Video Playback for Studies of Animal Communications.

(May 2009)

Trisha Ann Butkowski, B.S., The University of Texas at Austin

Co-Chairs of Advisory Committee, Dr. F. I. Parke
Dr. W. Yan

Video playback is a technique used to study the visual communication and behaviors of animals. While video playback is a useful tool, most experiments lack the ability for the visual stimulus to interact with the live animal. The limited number of experiments involving interactive video playback can be attributed partially to the lack of software available to conduct instructive interactive video playback experiments. To facilitate such interactive experiments, I have created a method that combines real-time animations with video tracking software. This method may be used to conduct interactive playback experiments. To demonstrate this method, a prototype was created and used to conduct automated mating choice trials on female swordtail fish. The results of the mating choice trials show that this prototype is able to create effectively interactive visual stimulus automatically. In addition, the results show that the interactive video playback has a measurable effect on the female swordtail fish, *Xiphophorus birchmanni*.

To my loving Husband.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Video playback is an experimental technique for presenting test subjects with realistic visual stimuli to study the visual communication systems of animals [1-3]. The increased use over the last decade of video playback to create realistic and biologically accurate video stimuli is partly attributed to the advancement in technology for generating and manipulating video [3]. One of the attributes that makes video playback appealing is that it allows easy manipulation of morphological traits such as size, color, and other visual traits, which would be harmful or impossible to manipulate on a live animal [4-6]. The other important advantage of using video playback is its ability to control and standardize the movement of the visual stimuli [7-9]. By standardizing the visual traits and the movement of the stimuli, experiments provide data that is more clear about what specific behavior or visual morphology affects the live animal's behavior.

Currently there are two different techniques used in the creation of video playback; manipulated video sequences and three-dimensional animated video sequences [3]. Manipulated video sequences rely on using video recordings of live animals in their natural habitat or in a laboratory environment. These videos can be manipulated with a non-linear editing system and/or a video effects program [5]. The other technique is to use three-dimensional animation software to create and animate a virtual animal [3].

This thesis follows the style of *IEEE Transactions on Visualization and Computer Graphics*.

While there are a number of advantages to the use of video playback, there are some disadvantages as well. One of the major disadvantages is the fact that video technology is designed for the human visual system. Animals that perceive ultraviolet light, such as some birds and fish, will have important visual information missing from video playback [10]. To test the validity of the experiment, it is important to verify that the behavior of the live animal in viewing the video stimuli is comparable to its viewing a live animal [6].

Another disadvantage of most video playback experiments is that there is no interaction between the video stimuli and the animal subject. For some behavior experiments interaction is not critical, since the intent is for the movements of the video stimuli to be constant and controllable throughout the experiments [7, 11]. However, when testing behavior that is in reaction to visual movement or a visual display of a live animal, interactive stimuli might be preferred to increase realism [2]. Ord and Evans [2]and Van Dyk and Evans [12] conducted the only two previous interactive video playback experiments that have been successfully attempted. Both experiments involved opponent assessment experiments with Jacky Dragons, *Amphibolurus muricatus*. Ord and Evans [2] used pre-recorded video clips of lizards performing short and aggressive appeasement displays and breaking sequences. To achieve interactivity, experimenters would press a key when they saw an appropriate visual display by the lizard. This would select appropriate video sequences. The disadvantage of these experiments is that they relied on a person to trigger the interactivity. This process could be improved if a tracking computer system were used to trigger the different video clips.

The lack of interactive video playback experiments can be attributed to the lack of software that can create and display realistic animations in real time. To achieve automated interactive playback, a program needs to receive information on the movement and position of the live animal, and to display real-time animations that are a response to the actions of the live animal. Using this approach, I created a prototype that is able to conduct automated mating choice trials on female swordtail fish, *Xiphophorus birchmanni.*

2. BACKGROUND

The use of video playback was successful in a number of behavioral studies such as mating preferences [7, 11, 13-22] and social interactions [2, 12, 23, 24]. These experiments were conducted on various animals including fish [5, 11, 13-22, 25], birds [24, 26], lizards [2, 4, 12, 23] and spiders [7, 27]. While video playback experiments have been conducted on a variety of animals it is essential to test that an animal will respond to video playback as if the live animal were viewing another live animal instead of video stimuli [6]. With this in mind, the interactive video playback experiments were designed for female swordtails, *Xiphophorus birchmanni,* a fish that has been shown to respond to video playback [21, 22, 25].

An early experiments done on guppies [11] to prove the validly of video playback experiments had interesting results that opened up the idea of conducting interactive video playback experiments. The results of experiments done on guppies showed that the female preferred the live male guppy behind clear glass significantly more than a videotaped male guppy or a live male guppy behind a one-way glass, which prevented the live male guppy from seeing the female [11]. The stated reason for this preference was because the male guppy behind the two-way glass was able to interact with the female guppy, while the videotaped male guppy and the live male guppy behind the one-way glass did not interact with the female guppy.

Interactive sound experiments have been performed since 1980 [28] and have become significantly more sophisticated [2]. Interactive sound has been successful in a variety of experiments including dynamic acoustic communications [29], male-female interactions [30, 31] and male-to-male interactions [32].

The first interactive video playback experiment was conducted on Jacky Dragons, *Amphibolurus muricatus*. In these experiments, video clips were changed by pressing a button when experimenters saw a certain behavior. This experiment showed that interactive video sequences can have an effect on the responses of the live animal. With the results from their studies, Ord and Evans [2] stated that interactive video playback could open up new avenues of animal behavior study.

Currently the main drawback to interactive video playback experiments is the lack of software capable of creating and controlling automated interactive experiments. To date, interactive video playback experiments have required an experimenter to observe and press a button to activate different video clips. To avoid human error and response time issues, the interactive display needs to be triggered by a program that is able to track the movements of the live animal.

One of the challenges of creating automated interactive stimulus is being able to create simulated visual fish behaviors in real time. There have been a number of realistic simulated fish displays [33-35]. These use the flocking behavioral model by Reynolds [36] as a guide for creating the behavior of the simulated fish. The basic behaviors of a flocking model are; collision avoidance, velocity matching and flock centering. More complex behaviors such as hunger, fear and mating have been added to fish simulations [34, 35]. However, up to this time, the audience for these simulations has been human beings.

3. GOALS AND OBJECTIVES

The goal of this work is to create an interactive display system that presents video stimuli more consistent with the behavior displayed by real male swordtail than existing non-interactive methods in order to facilitate fish behavior studies. The interactive stimuli generated by the interactive display system must be displayed in real-time, and the displayed stimuli must be a reaction to the motion of the female fish.

3.1 Objectives

To create an effective automated interactive video display system, there were several objectives to be completed.

- Development of a prototype system that integrated a stimulus display system with a live fish tracking system.
- Creation of a behavioral simulation model based on current mating behavior data of male swordtail fish.
- Testing the prototype with proof of concept experiments.
- Evaluation of the results of the proof of concept experiments.

4. METHODOLOGY

The lack of an existing program to create and display interactive visual stimulus required that a prototype be created. In creating a prototype that accomplished the goals and objectives, a set of design guidelines were followed.

4.1 Development of Proof of Concept Experiments

For the prototype to be evaluated, it must follow the protocols used in previous studies on female swordtail fish [21, 22, 25]. As in previous studies females were presented with different stimuli on CRT monitors at opposite ends of an 80-l aquarium (See Figure 1). The protocol that was used to display stimuli to the female happened in 20 minute stages. A stage consisted of four 5-minute segments. The first, acclimated the female to the water for five minutes by displaying a black screen on both monitors. Then two different video stimuli were displayed to the female, one on the left monitor and the other on the right for five minutes. After the video stimuli were displayed, a black screen would be displayed on both monitors to the female again for five minutes. The female then would be presented with the same video stimuli however the stimuli that was on the left monitor would be on the right monitor and the stimuli on the right monitor would be displayed on the left monitor. The stimuli were switched from one monitor to the other to control for end bias.

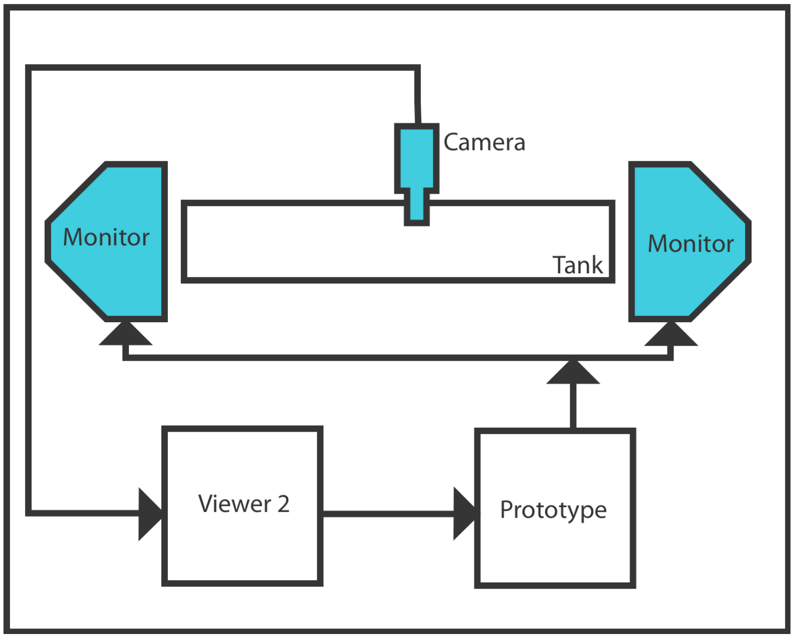

Figure 1. Physical Setup of Choice Trails

Experiment I consisted of two stages, where either stage can be presented first. One of the stages presented females with non-interactive looped sequences of *X. birchmanni* versus non-interactive looped sequences of *X. malinche* as was in Fisher et al. [25] and Wong and Rosenthal [21]. The other stage presented females with interactive stimuli of *X. birchmanni* versus interactive stimuli of *X. malinche.* Experiment II only had one stage and presented the female with interactive *X. birchmanni* vs. non-interactive *X. birchmanni*.

4.2 Development of a Behavior Model for Digital Male Swordtails

For the male swordtail fish to display a biologically realistic courtship behavior to a female swordtail fish, the prototype needed rules to guide the behavior of the virtual fish. Using data collected from underwater video of courtship interactions in the Rio Calnali, Hidalgo, Mexico, three rules were created to guide the behaviors of the male swordtail fish [37]. The rules guiding the mating behaviors needed to conform to the spatial limitations of the system. The X direction refers to the length of the tank; the Z direction refers to the width of the tank.

The three rules were:

Rule 1: The simulated male swordtail fish always follows the female swordtail fish across the screen, tracking her in the Z direction.

Rule 2: The simulated male's dorsal fin is only raised when it is performing a lateral courtship display.

Rule 3: The simulated male swordtail fish will only perform a lateral courtship display for 50% of the total time it is being displayed to the female. The lateral courtship display is triggered by the male fish being close to the female fish in the Z direction. The lateral courtship display is independent of how close the female is to the monitor in the X direction.

4.3 Development of the Interactive Stimulus

The prototype needed the ability to display a virtual male swordtail fish that was able to interact with the live female swordtail fish. For the virtual male swordtail to interact with the female swordtail, the prototype needed to know the position of the live female swordtail. To accomplish this, I used a tracking system that had already been used successfully to track fish, the BIOBSERVE Viewer 2 [38]. The Viewer 2 uses object-tracking software to automatically track and record animal motion. It is easily tailored to specific experiments. This software uses a contrast filter method to determine the animal's body form. It is able to detect the x and y coordinates of an animal's head, body, and tail. Dr. Stephan Schwarz, from BIOBSERVE, created a plug-in for the Viewer 2.0 that sends the coordinates of the animal's head, body, and tail to a specified network IP address.

According to the first rule that guides the simulated mating behavior, the male swordtail fish must follow the female swordtail fish. To accomplish this, I used a flocking algorithm designed by Reynolds, where a character follows a target and approaches it slowly, instead of heading towards the target at full speed (Reynolds 1999). Reynolds describes this behavior as *arrival*. *Arrival* allows the male swordtail fish to slow down when it approaches the female swordtail fish. Viewer 2.0 provided tracked positions for the female.

The second rule states that the simulated male's dorsal fin is only raised when it is performing a lateral courtship display. This makes the second rule dependent on the third rule, which dictates when and how often the simulated male will perform a lateral courtship display. Since the third rule states that a male will only display a lateral courtship display for 50% of the total time it interacts with to the female, the prototype must keep track of the total time that the simulated male has been performing a lateral courtship display, and prevent the simulated male from performing more than 50% of the time. The lateral courtship is triggered by the live female being *close* to the simulated male. *Close* is defined as one-fourth of the body length of the male swordtail.

4.4 Demonstration of Prototype

To demonstrate that the prototype can be used in behavioral studies, the Viewer 2.0 recorded the live female positions in the experiments conducted using the prototype.

The results recorded by the Viewer 2.0 were analyzed to see which stimuli the female preferred. The preference was based on the total amount of time the female spend near to a stimuli. Association preferences have been used in previous preference studies of swordtail fish to determine mating preferences [21, 22, 25]. In addition to the Viewer 2.0 position recordings, the prototype must also record the results of each test. The results consist of information such as the position of the female and digital male swordtail recorded at each interval that information is received from the Viewer 2.0.

5. IMPLEMENTATION

The prototype for the Interactive Display System was created by developing a C# program using Microsoft's XNA Game Studio 2.0. XNA Game Studio was used because it is has free code development libraries that are designed for the development of programs that use 3D models.

5.1 Creating the Digital Male Fish

The prototype has two kinds of male fish, *X. birchmanni* and *X. malinche,* pre-loaded into the system. These prototype swordtail fish are based on the most attractive average features of their type. The dimensions of the *X. malinche* are a length of 38.26 mm, a depth of 11.23mm, a sword of 5.4 mm, and a dorsal fin of 9.80 mm (Figure 2). The dimensions of *X. birchmanni* are a length of 44.79 mm, a depth of 14.91mm, no sword, and a dorsal fin of 12.75 mm (Figure 2).

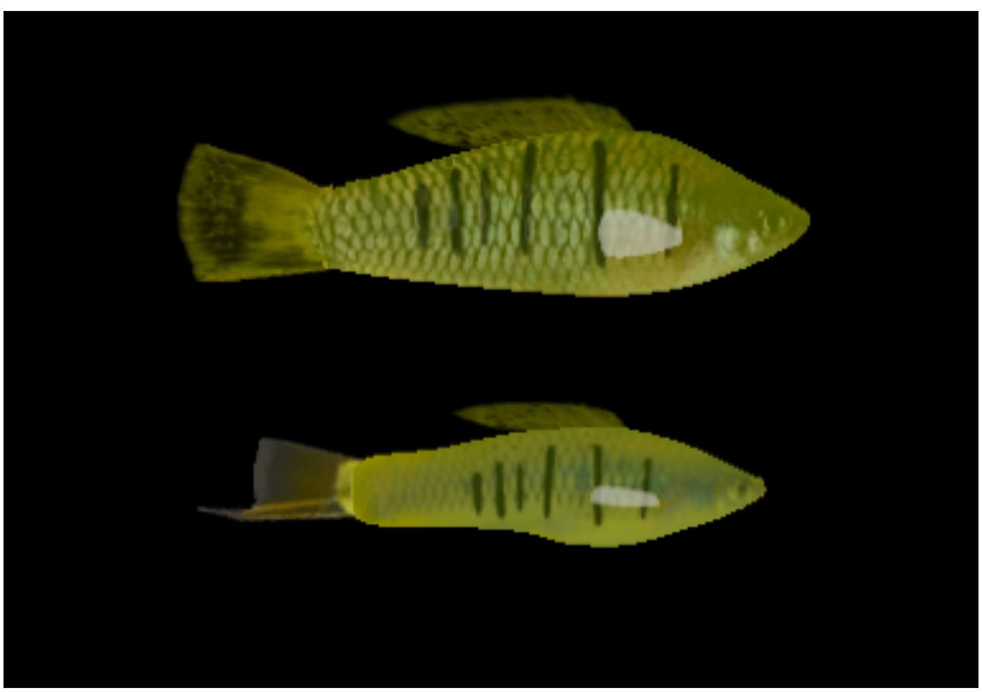

Figure 2. *X. birchmanni (*top*)* and X. *malinche* Models (bottom)

To make the virtual male swordtail fish look realistic, 3D polygon meshes were modeled using textures based on photographs of real *X. birchmanni* and X. *malinche*. The photographs were used to get the correct shape for both fish. The 3D meshes were modeled using Maya 8.0. To capture the realistic textures of the real fish, the same photographs used to model the fish shapes were used to texture the polygon mesh. The 3D meshes had a planar map applied to their UV coordinates. This UV map was aligned with the photograph texture, see Figure 3.

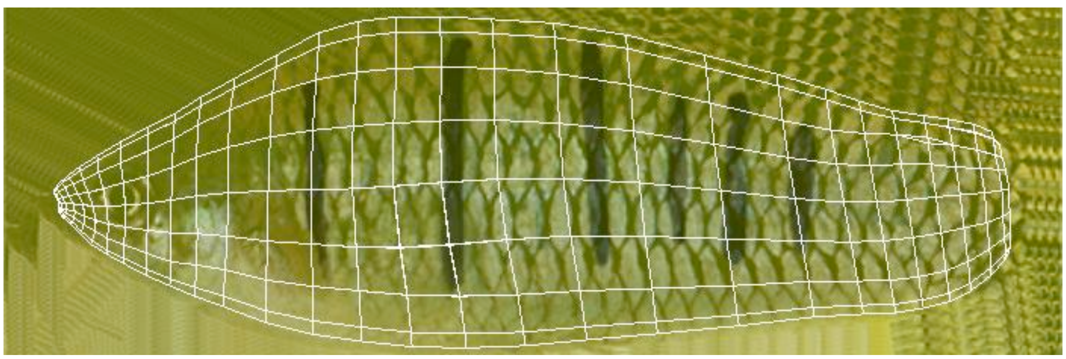

Figure 3. UV Layout of *X. birchmanni*

The next step was to add joints, which are virtual bones, to the 3D meshes. Forty-eight bones were used (Figure 4). The purpose of the joints is to create a virtual skeleton that simulates the skeleton of a polygon mesh. While the dorsal fin, side fins, and tail of real swordtail fish do not have actual bones, they are able to move. Therefore, joints for these fins were added to the model so that the fins could move in ways similar to the fins of real swordtails. The joints were then *skinned* to the mesh. This enables the mesh to deformed when the joints are rotated. To skin the mesh to the joints, each vertex of the mesh is associated with up to four joints using weight values in a range between 0.0 and 1.0. The total of the weights for each vertex must equal 1.0.

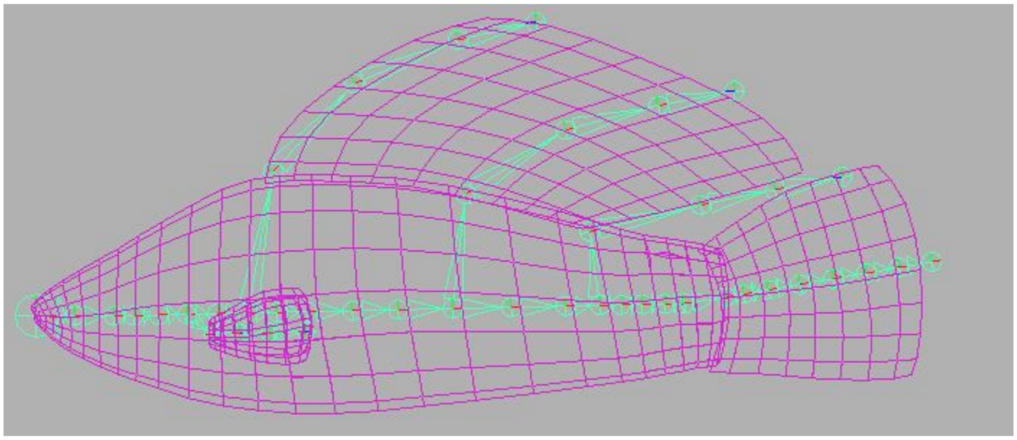

Figure 4. Joint Layout of *X. birchmanni*

For the male fish to be a realistic stimulus, the animated movements of the male fish needed to be accurate. The movements of the male fish include position, velocity and the deformations that the body of the fish makes while moving. To achieve this realism, six key movements that a male swordtail fish makes were animated. Three of the movements were used to represent the different speeds at which a fish would swim. The other three movements were the fish being still, turning, or exhibiting a lateral courtship display. In addition to those six key movements, the dorsal fin could be up or down for the entire cycle or the dorsal fin can go from the up position to the down position or go from the down position to the up position. A total of twenty-four animation cycles needed. Each cycle started and ended with the fish in the same posture so that the animation cycles could easily blend together.

All of the twenty-four animation cycles were created by rotoscoping the desired motion from overhead video of a real male swordtail fish. The key body movements were targeted in the video. Then the model skeleton was overlaid on the video. The joints of the skeleton were rotated to match the movement of the fish on the video. Each animation was exported as an individual FBX file. A total of forty-eight FBX files were exported since each animation cycle had to be created for both the *X. birchmanni* and X. *malinche* models.

5.2 Implementation of the Experiments in the Prototype

As described in section 4.1, the prototype would be used to conduct two different experiments. To conduct different types of experiments, the prototype reads in a text file before an experiments is started. This file tells the prototype what type of fish to display on the left and right monitor. The file also tells the prototype what to do during stage one and stage two. For example, during Experiments I the text file can state that the left side started with *X. malinche* and the right side started with *X. birchmanni* and during stage 1 both swordtails will be an animation. An animation refers to a looped non-interactive sequence, where the female sees a digital male swordtail swim to the middle of the screen, display a lateral courtship display, and then swim off-screen Then the digital male swordtail would swim back on screen to the middle, display a lateral courtship display and swim back off-screen. This sequence would continue for five minutes. For stage 2 the text file could then select simulation, this refers to the interactive video display. For an interactive video display the movements of the male fish would be determined by the position of the female swordtail and the behavioral model controlling the male swordtail (See Section 5.5).

In Experiments I there were four different presentation orders that could be displayed to a female fish (Table 1). Different presentation orders were used for different females to insure that the results from the experiments would not have the females biased to one side of the tank. For example with presentation order one, the female would see five minutes of black on both monitors followed by viewing five minutes of *X. malinche* animation on the left monitor and a *X. birchmanni* animation on the right monitor. Another five minutes of black would be presented on both monitors, and then five minutes of the previous stimuli, but on switched monitors so the *X. birchmanni* animation would be on the left monitor and the *X. malinche* would be on the right monitor. Another five minutes of black on both monitors, and then the fish would be back on their original monitors for five more minutes but would have a different motion. The *X. malinche* would be simulated on the left and the *X. birchmanni* would be on the right. Another five minutes of black on both of the monitors followed by *X. birchmanni* simulation stimuli on the left monitor while the right monitor would display the simulation of the *X. malinche*.

Table 1. Experiment I Intervals

	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5	Interval 6	Interval 7	Interval 8
Presentation Order 1	Black Screen	Malinche Animation vs. Birchmanni Animation	Black Screen	Birchmanni Animation vs.Malinche Animation	Black Screen	Malinche Sim vs. Birchmanni Sim	Black Screen	Birchmanni Sim vs. Malinche Sim
Presentation Order 2	Black Screen	Birchmanni Animation vs. Malinche Animation	Black Screen	Malinche Animation vs. Birchmanni Animation	Black Screen	Birchmanni Sim vs. Malinche Sim	Black Screen	Malinche Sim vs. Birchmanni Sim
Presentation Order 3	Black Screen	Malinche Sim vs. Birchmanni Sim	Black Screen	Birchmanni Sim vs. Malinche Sim	Black Screen	Malinche Animation vs. Birchmanni Animation	Black Screen	Birchmanni Animation vs. Malinche Animation
Presentation Order 4	Black Screen	Birchmanni Sim vs Malinche Sim	Black Screen	Malinche Sim vs. Birchmanni Sim	Black Screen	Birchmanni Animation vs. Malinche Animation	Black Screen	Malinche Animation vs. Birchmanni Animation

Experiment II had only one stage and presented the female with interactive *X. birchmanni* vs. non-interactive *X. birchmanni*. An example experiment text file for Experiment II would specify, X. birchmanni be displayed on both monitors. However for the left monitor would be an animation first and the right monitor would be a simulation first. The animation refers to a looped non-interactive sequence, where the virtual male swordtail would swim back and forth, as in Experiment I. The simulation refers to the interactive video display. Experiment II had only two presentation orders (Table 2).

Table 2. Experiment II Intervals

	Interval 1	Interval 2	Interval 3	Interval 4
Presentation Order 1	Black Screen	Birchmanni Animation vs. Birchmanni Sim	Black Screen	Birchmanni Sim vs. Birchmanni Animation
Presentation Order 2	Black Screen	Birchmanni Sim vs. Birchmanni Animation	Black Screen	Birchmanni Animation vs. Birchmanni Sim

5.3 Implementation of Tracking

The tracking of the female fish is an integral part of the system. To accurately display the interactive male swordtail fish the system needs the position of the female swordtail fish. To determine the position of the female swordtail fish, the Viewer 2.0 tracking system was used. This program tracked the position of the head, body, and tail of the female swordtail fish and then used a plug-in created by Dr. Stephen Schwarz, from BIOBSERVE, to transmit the information to another computer using its network IP address. The prototype received position information from the tracking program about eleven times per second.

5.4 Implementation of the Virtual Tank

A virtual tank was modeled in the prototype. The virtual tank duplicated some of physical testing conditions (Figure 1). Figure 5 shows the layout of the virtual tank. The left swim area corresponds to the left monitor, the right swim area corresponds to the right monitor and the female swim area corresponds to the tank that the live female swordtail was placed in.

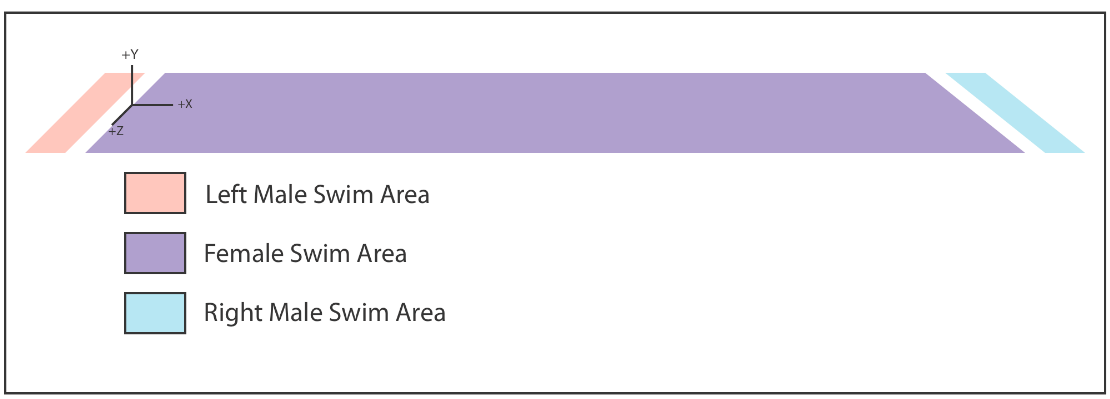

Figure 5. Virtual Tank Layout

The prototype's display stretched over two monitors at a resolution of 2000x600 pixels. Figure 6 is a screen shot of the prototype's display. In Figure 6 the fish on the left side was displayed on the left monitor. The right fish in Figure 6 was displayed on the right monitor.

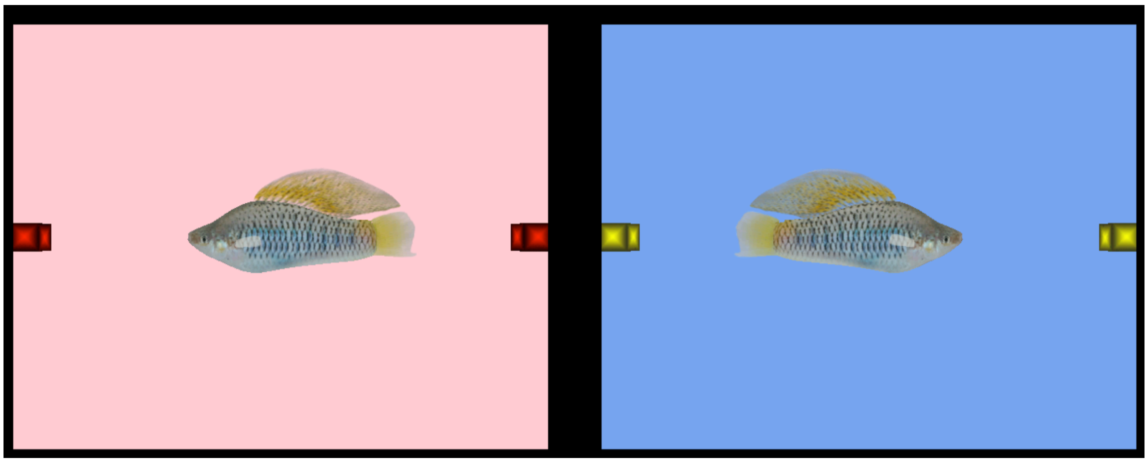

Figure 6. Display of Video Stimuli

To insure that the stimuli were displayed correctly the coordinates from the tracking system were converted to the virtual tank. To convert the tracking data from the tracking system to the virtual tank the display must be calibrate (See Section 5.9).

5.5 Implementation of Interactive Stimulus

To simulate Rule 1 of the male mating behavior (that the male fish follows the female fish in the Z position) I used Reynolds arrived steering behavior [39]. Arrival is a behavior that allowed the male to follow the female and decelerate as it approaches the female.

To calculate the position of the male swordtail fish at each time step, the system was supplied with the current position of the female. Using the female position, the forces that drive the male were calculated.

First, the target-offset vector was calculated by subtracting the position of the male fish from the position of the female fish. Second the distance from the male fish to the female fish was determined by taking the magnitude of the target-offset vector. Third, the desired speed of the male fish was determined by dividing the distance by a constant deceleration value. This allowed the male fish to slow down as it approached the female fish. Last, the desired acceleration was calculated by subtracting the male's current velocity from the desired velocity.

TargetOffset = **FemalePostion** - **MalePostion**
DesiredVelocity = **TargetOffset** / deceleration
Acceleration = **DesiredVelocity** - **Velocity**

The new velocity of the male swordtail fish is calculated by adding current velocity to acceleration times timestep. The timestep is how often I made a discrete calculation in a simulation, which was a value of 0.016. To prevent the male fish from swimming to fast a maximum velocity value is set by the user. It was set to a value of 10 for these experiments. If the magnitude of the new velocity is greater than the maximum velocity, the velocity is set to the maximum velocity. The new position of the male swordtail fish is then calculated by adding the current position to the new velocity times timestep.

VelocityNew = **Velocity** + **Acceleration** * timestep
PostionNew = **Postion** + **VelocityNew** * timestep

The simulations for the Rules 2 and 3 were accomplished simultaneously. The second rule states that the dorsal fin will only be raised during a lateral courtship. This leads into the third rule which details when a lateral courtship display will be triggered. The lateral courtship display behavior will be triggered when the male swordtail fish is close to the female swordtail fish in the Z coordinate. In the prototype, close has been defined as the distance between the male and female being less than one-fourth of the body length of the male. The third rule is that the lateral courtship display will only occur 50% of the time. The female swordtail fish views the male swordtail fish for five-minute intervals. Therefore, the total time that the male courtship displays, in any given interval, is two and a half minutes. Each animation cycle of a lateral courtship was 35 frames long. Because there are 9000 frames in a five minute time period, there can only be a maximum of 128 lateral courtship cycles during a test segment. In accordance with information gathered from underwater video of courtship interactions [37], the duration of a lateral courtship display ranged from 100 – 4000 frames (Table 3). Hence, a male swordtail fish could perform multiple lateral courtship displays during a five-minute interval.

When the virtual male swordtail fish fulfilled the requirement of being close to the female swordtail fish in the Z direction, the male could then show a lateral courtship display. The decision to show the courtship display was random and was based on how long the male swordtail fish had already displayed the courtship display. For example, if the male swordtail fish had already displayed for 65% of the allowed duration for the current interval, then the male swordtail fish had a 35% chance of displaying again. As the total lateral courtship display time increased, the chance for another lateral courtship decreased. In addition, if the male swordtail fish ever reached 128 cycles in a five-minute segment, the prototype would not trigger another lateral courtship display.

Once a lateral courtship display was triggered the length of the lateral courtship display was determined. Table 3 shows the different duration (in frames) of the lengths of lateral courtship displays and a count of how many times that duration was observed from underwater video of courtship interactions [37]. Table 3 shows ten different display durations and the number of times that that was observed. Since the distribution of display lengths was not equal the different display durations were weighted differently. For Example, the male swordtail fish would have a 21% chance of displaying a lateral courtship of 200 frames, while the duration of lateral courtship display of 700 frames only had a 5.26% chance.

Table 3. Lateral Courtship Display Frame Count

Count	Duration in frames
2	0
1	100
4	200
2	300
2	400
1	500
3	600
1	700
1	2000
2	4000

5.6 Animating the Male Fish

When the prototype is running, two different male swordtail fish are being displayed to the female swordtail fish. The animations of the models are handled the same. This section explains how the animation of the male swordtail fish was accomplished. This process was applied to both fish.

I used Microsoft's Skinning Sample Library. This library contains a Skinned Model Pipeline and Skinned Model Windows. This library also reads FBX files. It is able to store the animation data and convert the skinning data so that the model can be rendered on the GPU.

Skinned Model Windows works by creating what is called an animation clip that stores the information of all the keyframes in an animation cycle. This clip then runs though the keyframes, and when it reaches the end of the keyframes it starts back at the beginning. For seamless transitions, a new clip was loaded at the end of the current clip.

During each time step, the prototype not only calculated the position of the male swordtail fish, but also what animation frame to display. When the current clip reached the end of its keyframes, the prototype decided what animation clip it would play next. First, a new position of the male swordtail fish was calculated. Then a new distance between the male swordtail fish and the female swordtail fish was calculated by taking the position of the female minus the new position of the male. If this distance was greater than one-fourth of the body length of the male swordtail fish, and the male swordtail fish had passed the position of the female swordtail fish, this triggered a turn. If the position of the male swordtail fish was greater than one-fourth of the body length, but had not passed the position of the female swordtail fish, this triggered a need to keep swimming. If the distance was less then one-fourth of the body length, and the velocity of the male swordtail fish was almost zero, it triggered a need for the male swordtail fish to be still; otherwise, it triggered a need for the male swordtail fish to swim closer.

If the animation to turn or keep swimming was triggered, and the male swordtail fish was in the middle of a lateral courtship cycle, then the lateral courtship cycle was ended and the dorsal fin was lowered; otherwise the dorsal fin would stay down. If a keep swimming action was triggered, a swim animation would be chosen from swim, slow, and slower. This action selected was based on the speed of the male swordtail fish.

If a still or a swim close was trigged, a number of things could happen. First, if there was a current lateral courtship cycle going on, then the dorsal fin would remain up and a lateral courtship animation would continue. If the male swordtail fish was at the end of a lateral courtship cycle, the dorsal fin would be lowered and the body animation would either be a still or a swim animation based on the speed of the male swordtail fish. If there was no lateral courtship cycle going on, then the prototype would decide if a lateral courtship display should occur. (See section 5.4). If a lateral courtship display does not occur, the dorsal fin of the male swordtail fish will stay down. If a lateral courtship display is started, the dorsal fin will go up. The body animation for both will be a still or a swim animation. If the lateral courtship display is triggered, the actual lateral courtship animation will start during the next cycle. Once the desired action for the body of the male swordtail fish (swim, slow, slower, still, turn, lateral courtship) and the position of the dorsal fin (up, to up, down, to down) have been determined, the correct animation clip was chosen.

If the male swordtail fish was to remain still, or the male swordtail fish was turning, its velocity was set to zero and its position is kept the same as in the last time step. The position remained the same for the turn, to simplify the turn animation.

During most of the timesteps, a clip is running. A set of rules is applied when an animation is not complete. If the current clip was a still or turning animation, the position and the velocity of the male swordtail fish is the same as the previous timestep. If the velocity of the male swordtail fish reversed, indicating a change in direction, the change was prevented by using the position and velocity of the previous timestep. The reason for this is that the male fish can only turn around when a turn animation is started. For every other situation, the male swordtail fish uses the calculated position and velocity.

5.7 Extra Feature of the Prototype

An additional feature was added to the prototype so that it can be used for additional mating behavior experiments.

This is the ability to control when the dorsal fin is raised and lowered. When the user sets up the experiment file, there is an option to use the default dorsal. When it is set to default, the dorsal fin is only raised during a lateral courtship display. There is another option available. That is to have the dorsal fin raised or lowered when the female swordtail fish is swimming on the same side of the tank as the male swordtail fish. The same side is determined by how close the female swordtail fish is to the monitor.

5.8 Prototype Startup File

Before the prototype is run, a text file named InteractiveDisplaySetup.txt must be edited. This file contains three important pieces of information: the monitor information, the program type and the experiment name.

```
#Monitor Info
screenWidth 1140
screenHeight 900

#Program Type: calabration, liveTesting
programType liveTesting

#Experiment Name
experimentName testA01
```

This file determines what the prototype will be doing. All lines that begin with a pound sign (#) are ignored. The monitor information is used to tell the prototype what resolution will be used. This can be changed, since the prototype is designed to work with different computer and monitor set-ups. The program type is used to start the program up in calibration or live-testing mode. The experiment name is used only in the live testing mode. It tells the prototype what experiment file to use. Once the InteractiveDisplaySetup.txt file has been edited and saved, the user can then run the prototype.

5.9 Prototype Calibration Mode

The purpose of the calibration mode is to create files that will be used by the live testing mode to perform the experiments. Since the system is designed to run on different computers with different monitors, and the experiments themselves have different parameters, an experiment file is used so that each experiment is properly executed.

The calibration mode has two functions. The first is described in Section 5.4, which enables the prototype to correctly display the male swordtail fish on both testing monitors. When starting the calibration mode, it asks you for the minimum and maximum tank X and Z dimensions. These values need to be determined before calibration begins. The next step is to set up the first viewport (see Figure 7). To move the viewport around, the user uses the arrow keys. To increase or decrease the width of the viewport, the Z and X keys are used. To increase or decrease the height, the A and S keys are used. The purpose of this step is to align the viewports with the ends of the tank. Once the first viewport has been adjusted, the user presses enter, and adjusts the second viewport. There is also a helpful feature that will match the width and height of viewport 2 to viewport 1 by pressing the M key. Once the second viewport has been adjusted, then press enter again.

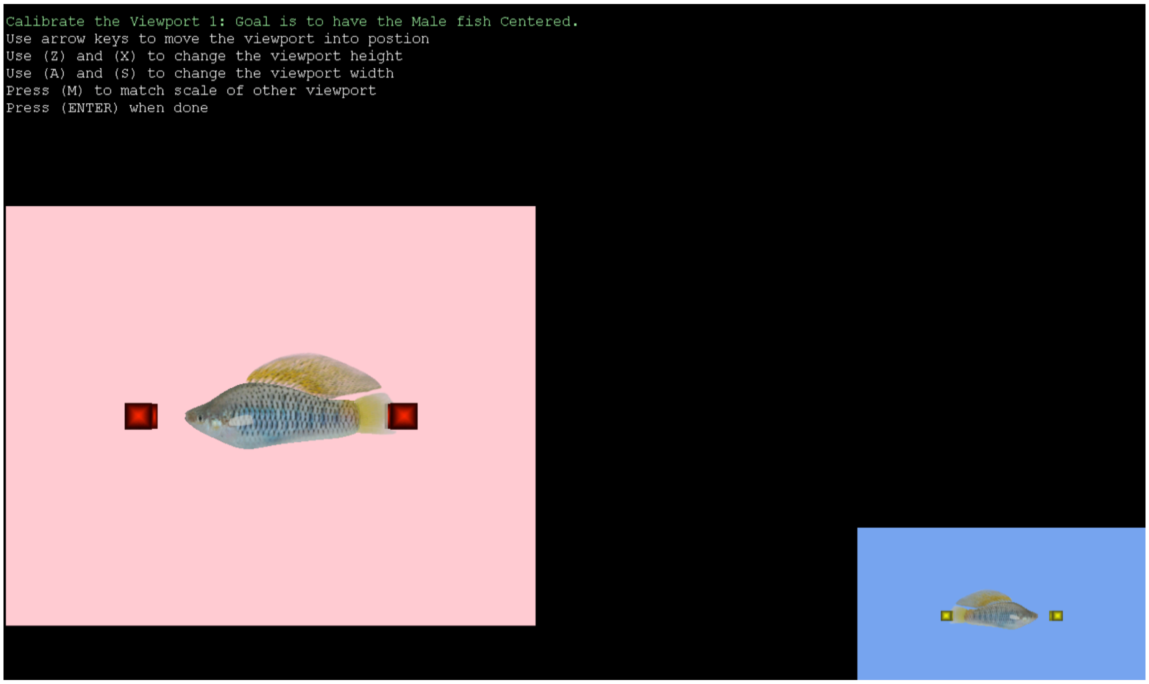

Figure 7. Viewport Calibrations

Once the viewport has been calibrated, the next step is to insure the proper display size of the male swordtail fish (Figure 8). The display male swordtail fish must be 66.7 mm in length from the tip of its nose to the start of its tail. 66.7 mm was used so since the calibration model was created in Maya as 66.7 mm and it insures that any other model created in Maya brought into the prototype will be displayed at its correct length. To change the size of the male swordtail fish on viewport 1, the user presses the Z or X key to increase or decrease the scale of the displayed fish. To change the male swordtail fish on viewport 2, the user presses the A or S key. To make the process quicker, the user can press the 1 key to have the viewport 2 fish be scaled to the same amount as viewport 1 fish, and pressing 2 will make viewport 1 fish match viewport 2 fish.

The boxes displayed on both viewports correspond to the edges of the real tank. The user uses the Q or W keys to move the boxes toward or away from the center of the fish until the boxes are correctly shown right inside of the tank. If at this stage, the user wants to re-calibrate the viewports, the user presses the V key and will be taken back to the calibration of viewport 1. Once both male swordtail fish have been calibrated, then the user presses enter.

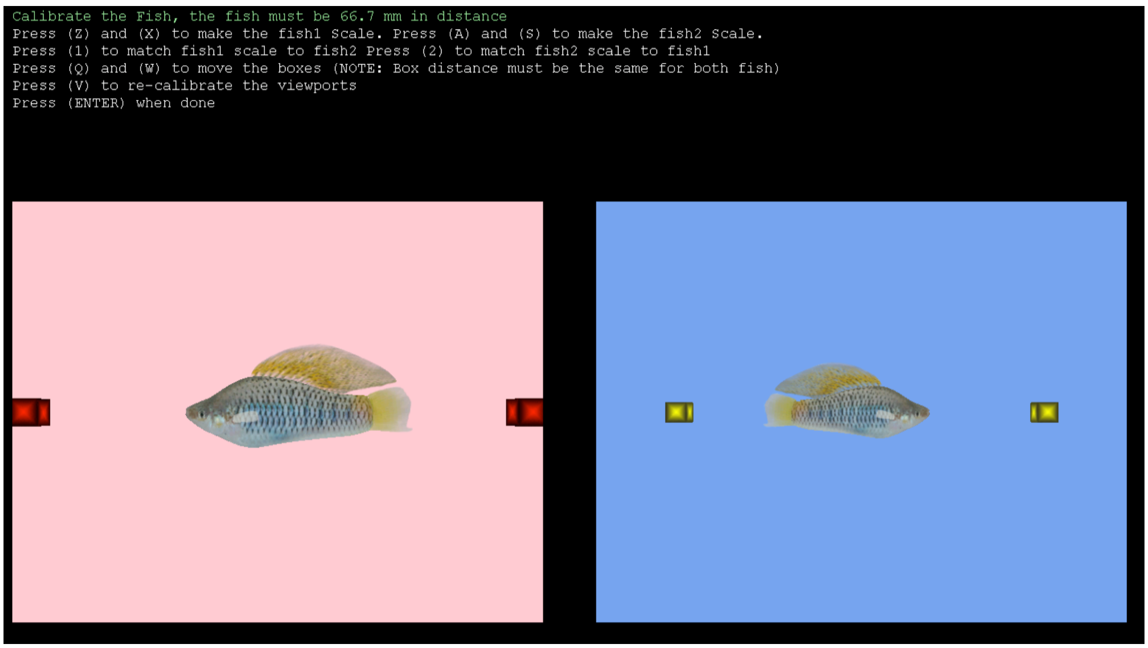

Figure 8. Calibrations of Male Swordtail Fish

Once the viewport and the scale of the male swordtail fish have been calibrated, then the user to enters the parameters of the experiment. The first question asked is, “What is the name of the experiment?” The next question asks, “What is the name of the first fish?” The name of the fish must be fish01, fish02, or fish03. These are the preloaded models that the prototype has available. Fish01 is a hybrid fish that has only been used for debugging and is the calibration fish. Fish02 is the *X. birchmanni* model, and fish03 is the *X. malinche* model. The next question asks, "What will fish 1 do in stage 1?" This can be either "sim" or "animation", where "sim" refers to interactive stimuli and animation to non-interactive stimuli. The following question then asks, "What will fish 1 do in stage 2?"; this can be "sim", "animation", or "nothing". The prototype then asks, "What side of the tank fish 1 will start on?", and "What is the body length of fish 1 (in millimeters)?" The next question asks the user if he or she wants to use the default values for a simulation. All of the test experiments used default values.

For the experiments that were tested, parameters that were used are flocking type, velocity maximum (Vmax), speed maximum (Smax), and acceleration maximum (Amax). The default flocking type is follow. It is the only value that is currently recognized by the prototype. Velocity maximum (Vmax), speed maximum (Smax), and acceleration maximum (Amax), are constants used by the prototype to determine the position of the fish. While testing, the value of 10 was used for Velocity maximum (Vmax), speed maximum (Smax), and acceleration maximum (Amax). These values were determined to display the best results.

Once the simulation values have been set for fish 1, the same questions are asked about fish 2. The next question asks if the user wants the fish movements to be mirrored. This was used in experiment I, so that both male fish were doing the exact same movements. However, in experiments like experiment II where one fish is interactive and the other fish in non-interactive, the fish cannot match movements.

The final questions concern the movement of the dorsal fin. The user can select default dorsal; this would make the dorsal only raise during a lateral courtship display. If the dorsal is not set to default, the user can decide if fish 1 wants its dorsal fin to rise when the female swordtail fish is close or far away; the same option is available for fish 2.

Once all of these steps have been completed, the prototype writes out the information gathered during the calibration into separate file that will be used in the live testing mode. In addition to writing out the file, the prototype asks if the user wants to create another experiment file. If the user chooses "Yes", then the user goes back to setting up the parameters of the experiment, and the saved values are used to set up the virtual tank.

5.10 Prototype Live Testing Mode

The live testing mode is used to run the experiments on the female swordtail fish. To start a live testing mode, an experiment name must be entered in the InteractiveDisplaySetup file. The next step is to start the prototype, which then automatically loads the experiment parameters and waits for the user to start the test. Once the tracker is started, the user presses the M key to begin the experiment. At the top left of the screen there is text to inform the user that the prototype has been started and what stage of the experiment it is on (Figure 9). While the experiment is running, the prototype writes the current time, the position of the head, body, and tail of the female swordtail fish, the position of both male swordtail fish, the male body animations, the dorsal animations, and the direction the male swordtail fish are swimming to an output file. These values are written for each timestep.

Once the experiment is finished, the prototype continues running until the user presses the escape key.

Figure 9. Display of Live Testing Mode

6. RESULTS AND CONCLUSIONS

6.1 Results

For all of the experiment trials, Viewer 2.0 recorded the movements of the live female swordtail fish and the prototype recorded the movements of the live fish and the digital male swordtail fish. The recorded results were analyzed by Dr. Gil Rosenthal.

Experiment I presented nine female swordtail fish with stimuli of non-interactive *X. birchmanni* vs. non-interactive *X. malinche* and with stimulus of interactive *X. birchmanni* vs. interactive *X. malinche*. As in previous studies (Fisher and others 2006; Wong and Rosenthal 2006), female swordtail fish significantly preferred the non-interactive male conspecific (*X. birchmanni*) over the non-interactive heterospecific (*X. malinche* (one-tailed paired $t = 1.923$, $N = 9$, $p = .046$). They failed to show a preference, however, when presented with simulated interactive conspecific and heterospecific males. In fact, the numerical trend favored *X. malinche* ($t = .737$, $N = 9$, $p = .48$). Due to the small sample size, the difference in preference between interactive and non-interactive treatments was marginally nonsignificant (Wilcoxon signed-ranks test, $Z = 1.60$, $N = 9$, $p = .11$). Figure 10 show the association time the female swordtail fish spent with each stimulus.

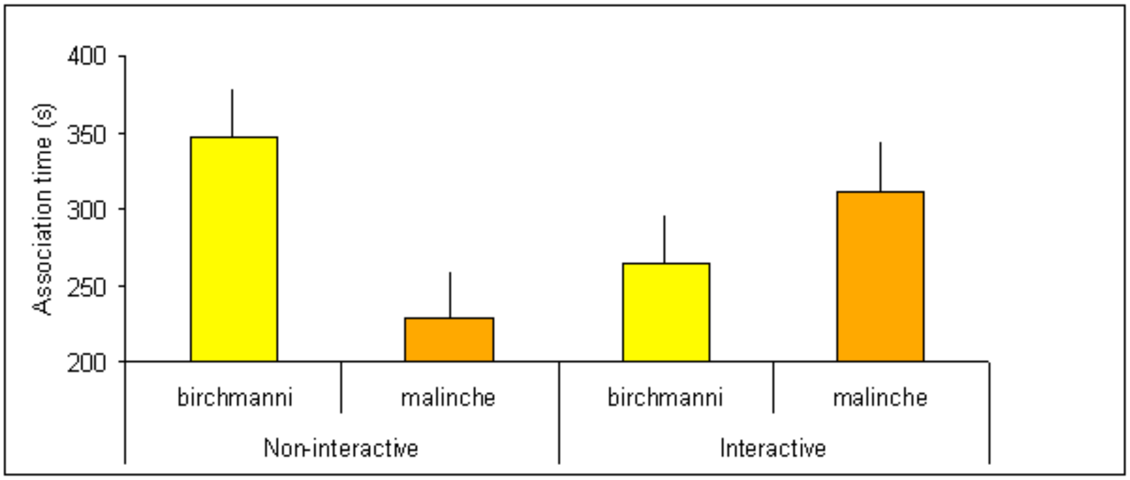

Figure 10. Experiment I Association Graph

In addition to analyzing the data from the experiments, I created 3D time plots of the paths of the female and male swordtail fish, from each experiment (Figures 11, 12, 13). The control vertices of the line segments in the 3D plots correspond to the position that were recorded by the prototype. In the images, the blue lines refer to the position of the female swordtail fish, the yellow lines to the *X. birchmanni***,** and the red lines to *X. malinche.* Each plot is created from a five-minute record of the positions output by the prototype. In these plots, time progresses in the vertical Y direction from 0 to 5 minutes. Each sequential control vertex had its Y (time) value increased incrementally by .45 milliseconds. Figure 12 shows a side view of a five-minute interval where the red line is an interactive *X. malinche* . This figure shows that the digital male swordtail fish is tracking the female swordtail fish and following her position. This plot shows that the prototype was able to correctly implement Rule 1, that the simulated male would always follow the live female swordtail. Figure 13 shows two different five minute segments of interactive *X. birchmanni* vs. interactive *X. malinche* from the results of experiment I.

Figure 13 was created to show a close up view of the interaction between the live female swordtail and the two interactive swordtail

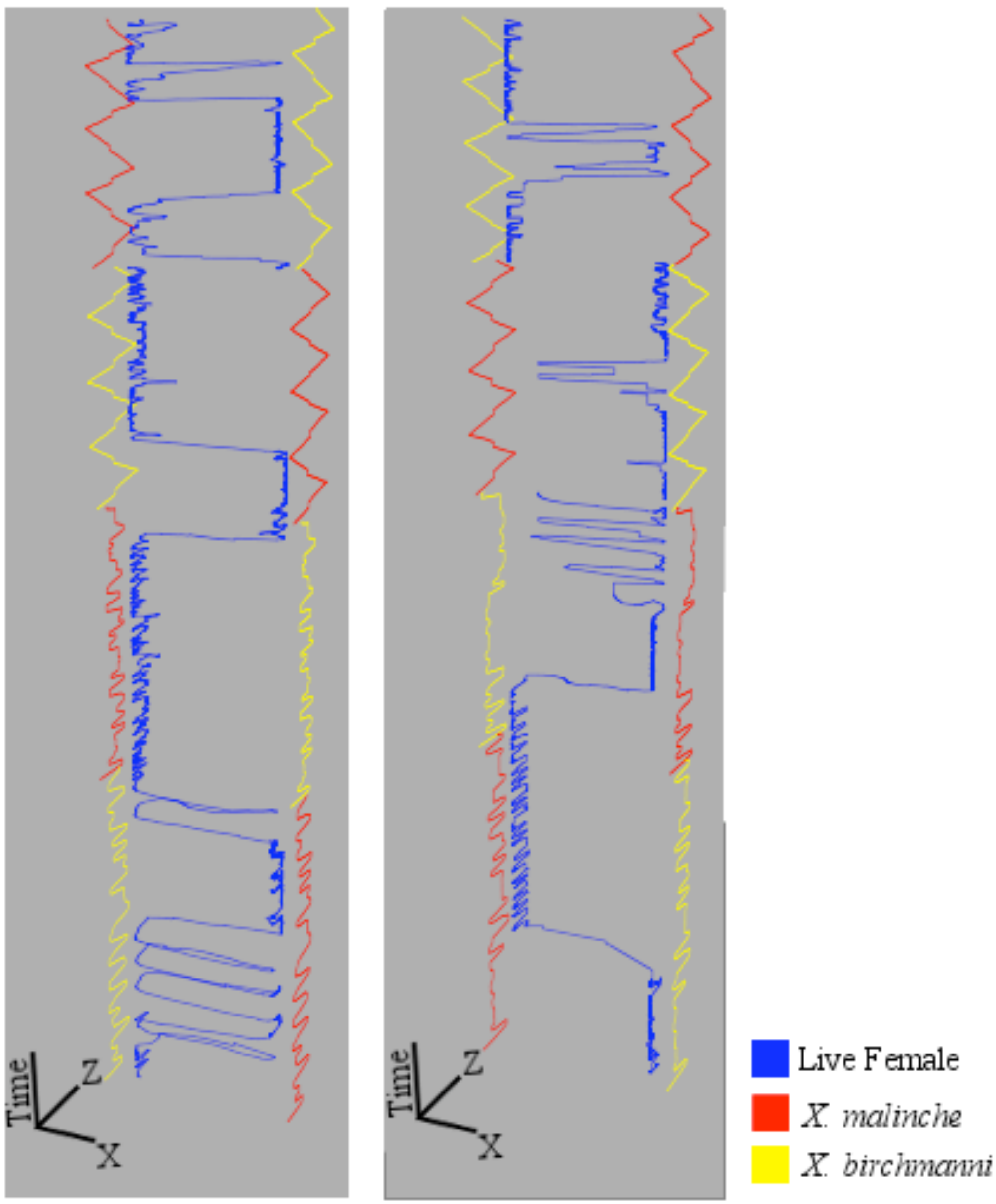

Figure 11. Experiment I Visual Results

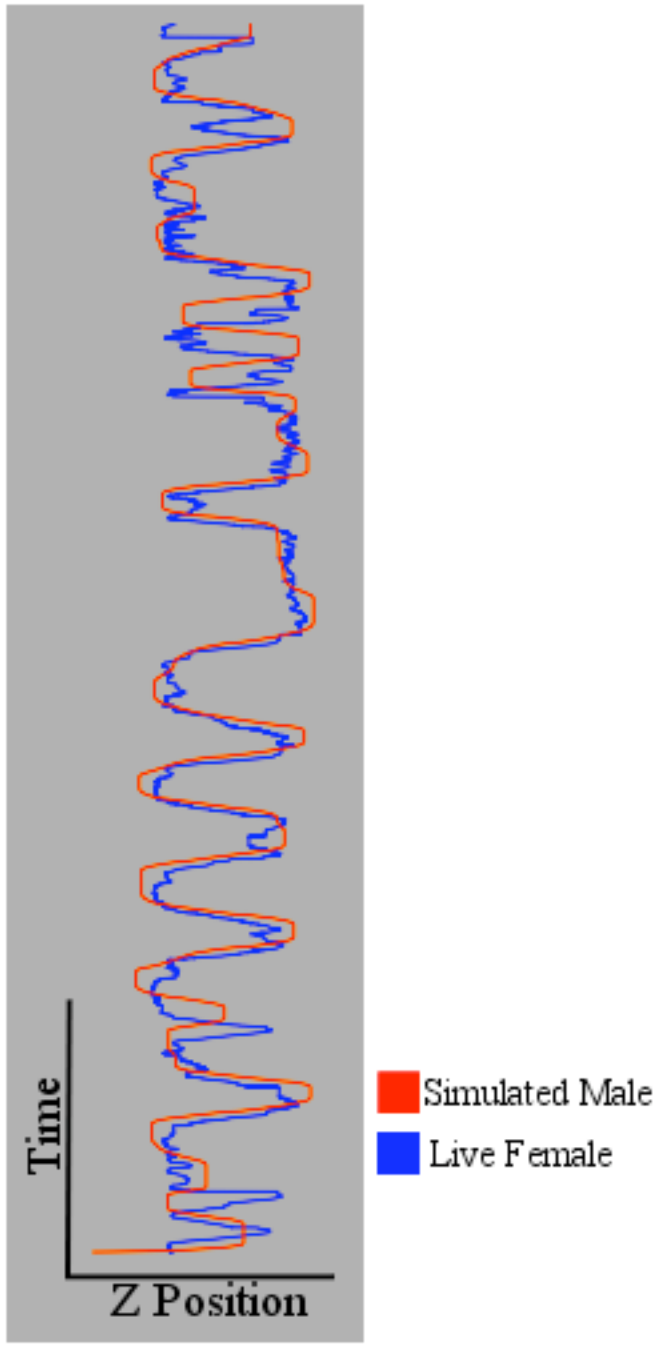

Figure 12. Experiment I Side View of Interactive Stimulus

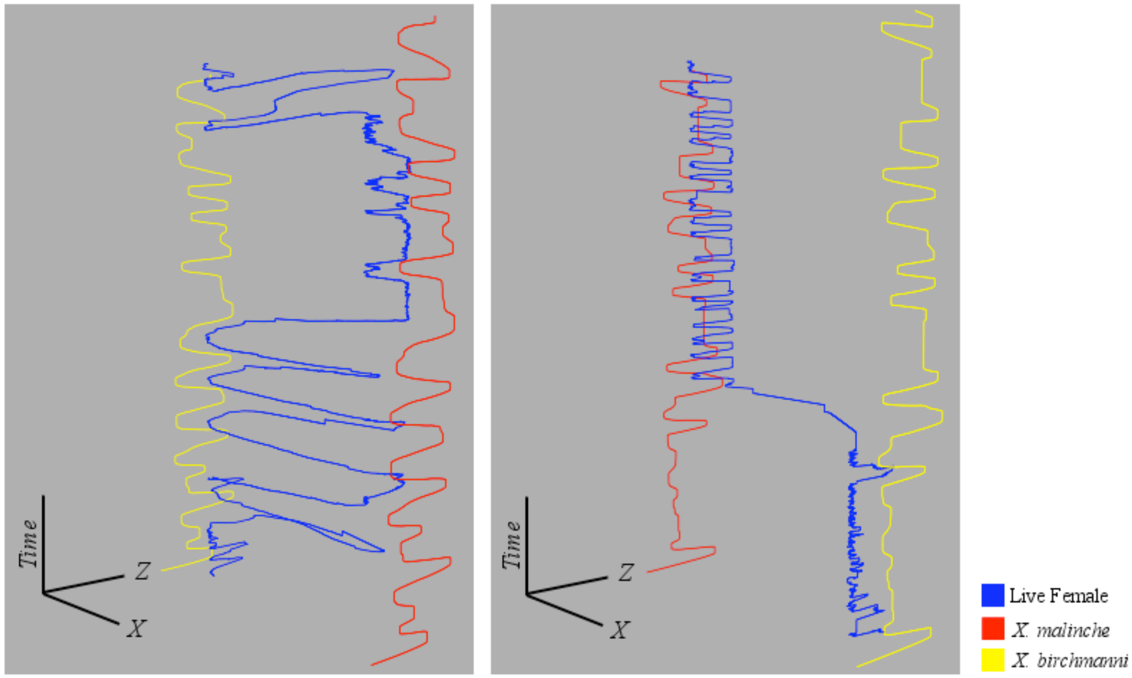

Figure 13. Experiment I Excerpts

Experiment II presented nine female swordtail fish with stimuli of interactive *X. birchmanni* vs. non-interactive *X. birchmanni*. In this experiment, the female swordtail fish failed to prefer the interactive *X. birchmanni* stimuli over the non-interactive *X. birchmanni* stimuli ($t = 1.05$, $N = 9$, $p = .324$). Figure 14 shows the association time the female swordtail fish spent with each stimulus. 3D time plots of the fish motions were also created from the prototype data of Experiment II (Figures 15 and 16).

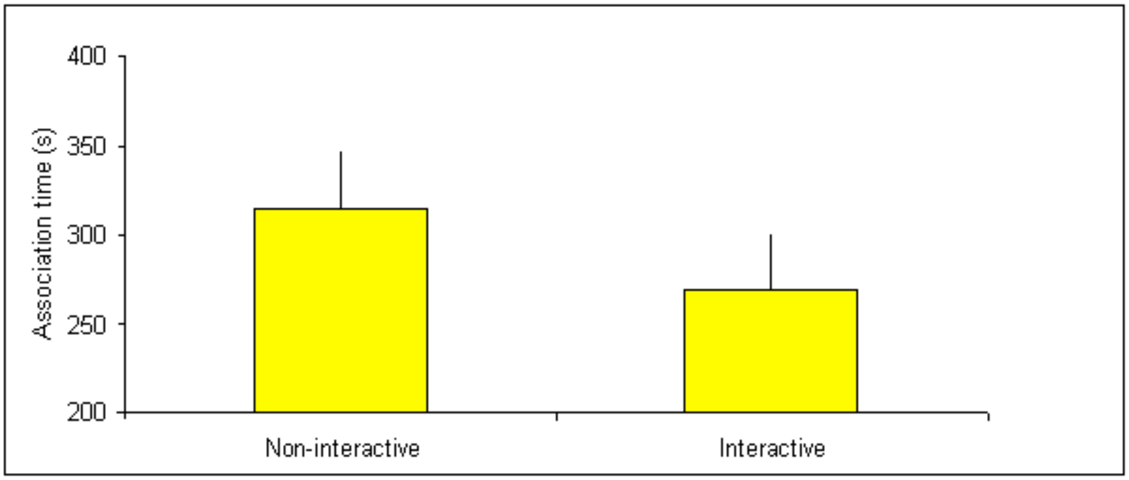

Figure 14. Experiment II Association Graph

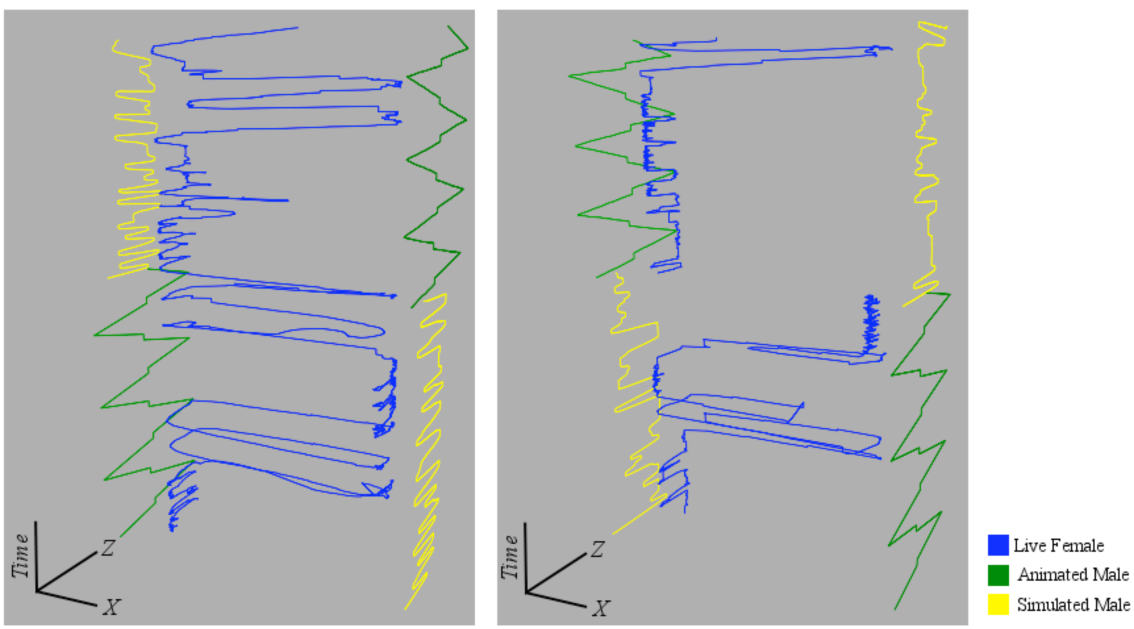

Figure 15. Experiment II Visual Results

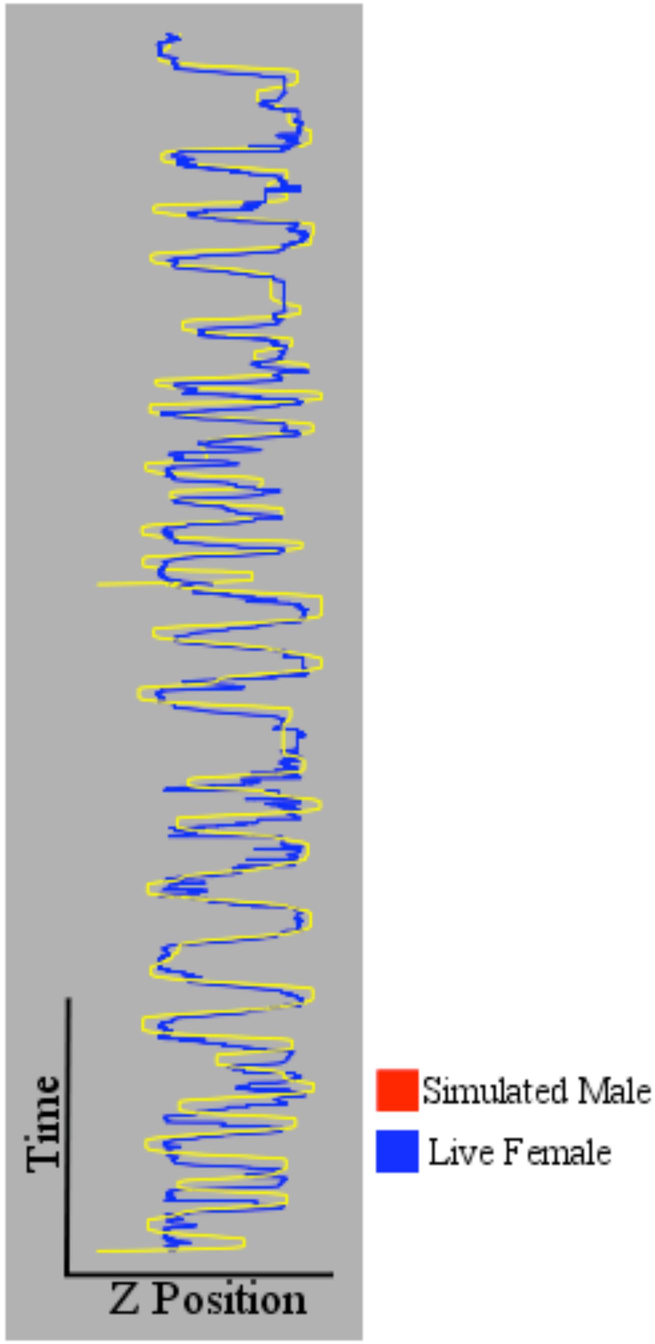

Figure 16. Experiment II Visual Results Side View

6.2 Conclusions

The goal of this research was to create a prototype interactive display system that could to present female swordtail fish with a visual display of simulated behavior consistent with male swordtail fish. This was achieved by developing simulated behavior of the digital male swordtail fish based on the behaviors displayed by real male swordtail fish that are courting female swordtail fish. One of the key aspects of the simulated behavior was the ability for the digital male swordtail fish to track the position of the female swordtail fish. From the 3D time plots of the test data (Figure 12 and 16), it is visually apparent that the digital male swordtail was tracking the female swordtail fish.

In addition to seeing the 3D display of the data, the analysis of the Viewer 2 tracking results also indicates that the interactive stimuli did have an effect on the female swordtail fish. Experiment I shows that when the female swordtail fish was presented with non-interactive stimulus of *X. birchmanni* vs. *X. malinche*, she preferred the *X. birchmanni* as in previous studies (Fisher and others 2006; Wong and Rosenthal 2006). However, when the female swordtail fish was presented with the interactive simulated male swordtail fish of the same species, her preferences between the males changed. While we do not know why the preferences of the female swordtail fish changed, the contributing factors to this change were the interactive stimuli.

While there is more work to be done in understanding how the interactive stimuli affected the female swordtail fish, this research has shown that interactive stimuli can be used as a new tool to understand the mating habits of female swordtail fish.

7. FUTURE WORK

Since this prototype is the first of its kind, there is much work that could be done to improve the prototype. While the simulated male animation cycles developed are usable for testing, the more complex movements, the lateral courtship display and the turn animation could be improved. In addition to improving these animations, the prototype is currently limited in its ability to add new animation behavior models. Currently the process for adding new models requires that the user compile the original program. It would be far more efficient for the prototype to load in new models. Other visual improvements that could be added include: improved lighting, secular highlights on the models, and the addition of a graphical user interface.

Currently there is only one behavior model implemented in the prototype. A critical improvement would be to add other behavior models that can be used to simulate the male swordtail. One of the behaviors I am planning to implement is to modify the behavior of the male swordtail fish so that instead of following the female swordtail fish, he will want to avoid her. Other behaviors will be developed once further testing of the effect the prototype on female swordtails has been conducted and analyzed.

Additional work that could be done is to adapt this prototype to other fish species. Other visual fish models could be created and specific behaviors of those fish could be added to the program. If the selected fish share some of the same behaviors as the swordtail fish, the adaptation of the prototype to the new fish would be easier.

Another potential is to create prototypes designed for use with animals such as lizards, spiders or birds. This process would possibly be more complicated, since the interactive stimulus requires automated tracking of the live animal. Tracking is probably simpler with the fish because of their simple shape; however, if a tracking system was able to accurately track another animal and its key movements could be determined, then similar systems could be designed for other animals.

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