THE ILLUSION OF LIFE: LEVERAGING TECHNOLOGY FOR REAL-TIME UNDERWATER ANIMATION

A Thesis Project
Presented to
The Academic Faculty

by

Erica Penk

In Partial Fulfillment
of the Requirements for the Degree
Digital Media in the
School of School of Literature, Media, and Communication

Georgia Institute of Technology
May 2014

Copyright 2014 by Erica Penk
Approved by:

Dr. Celia Pearce, Advisor
School of Literature, Media, and Communication
Georgia Institute of Technology

Dr. Ali Mazalek
School of Literature, Media, and Communication
Georgia Institute of Technology

Dr. Brian Magerko
School of Literature, Media, and Communication
Georgia Institute of Technology

Date Approved: May 2014
To the Emergent Game Group
ACKNOWLEDGEMENTS

I wish to thank Celia Pearce, Brian Magerko, Ali Mazalek, Jay Telotte, Karen Liu, Jie Tan, Kristin Siu, Sehoon Ha, Rose Peng, Colin Freeman, Chris Bregler, Matthew Maloney and Greg Azzopardi. I couldn’t have done it without everyone's contribution. It truly does take a village to raise a mermaid.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ACKNOWLEDGEMENTS</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>4</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>5</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>7</td>
</tr>
<tr>
<td><strong>CHAPTER</strong></td>
<td>10</td>
</tr>
<tr>
<td>1 Background</td>
<td>10</td>
</tr>
<tr>
<td>Early Animation Study</td>
<td>10</td>
</tr>
<tr>
<td>Disney Mermaids Character Study</td>
<td>12</td>
</tr>
<tr>
<td>Why Study Film?</td>
<td>12</td>
</tr>
<tr>
<td><em>Merbabies</em> (1938)</td>
<td>14</td>
</tr>
<tr>
<td><em>The Little Mermaid</em> (1989)</td>
<td>15</td>
</tr>
<tr>
<td><em>Pirates of the Caribbean: On Stranger Tides</em> (2011)</td>
<td>18</td>
</tr>
<tr>
<td>Conclusion</td>
<td>20</td>
</tr>
<tr>
<td>Swimming Games</td>
<td>21</td>
</tr>
<tr>
<td>What's Already Out There?</td>
<td>21</td>
</tr>
<tr>
<td>Kingdom Hearts</td>
<td>21</td>
</tr>
<tr>
<td><em>Super Mario Galaxy</em></td>
<td>22</td>
</tr>
<tr>
<td><em>Second Life Mermaids Sim</em></td>
<td>24</td>
</tr>
<tr>
<td>Endless Ocean</td>
<td>25</td>
</tr>
<tr>
<td>Assassin’s Creed IV Black Flag</td>
<td>26</td>
</tr>
<tr>
<td>Lit Review</td>
<td>28</td>
</tr>
</tbody>
</table>
Action Analysis for Animators 28

Articulated Swimming Creatures 29

Finding the Right CG Water and Fish in 'Nemo 30

Turning to the Masters: Motion Capturing Cartoons 31

Principles of Emergent Design in Online Games 31

2 Approach & Methodology 32

Overview 32

Evaluation Criteria 33

Motion Capture Research 34

Embodied Research 36

Procedural Animation Research 37

Basic Animation Technique Research & Implementation 39

Procedural Animation Implementation 42

Keyframe Animation with Procedural Reference 45

Procedural Animation with Embodied Reference 46

Keyframe Animation with Embodied Reference 47

3 Final Animations and Conclusion 50

Final Animations 50

Evaluation 50

Conclusion 51

Future Work 53

REFERENCES 54
LIST OF TABLES

Table 2.1: Research Phase  32
Table 2.2: Animation Phase  33
<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Gertie the Dinosaur Gobbling Down a Tree</td>
<td>10</td>
</tr>
<tr>
<td>1.2</td>
<td>Max Fleischer's Rotoscope</td>
<td>11</td>
</tr>
<tr>
<td>1.3</td>
<td>Dragon's Lair</td>
<td>13</td>
</tr>
<tr>
<td>1.4</td>
<td>The Adventures of André &amp; Wally B.</td>
<td>13</td>
</tr>
<tr>
<td>1.5</td>
<td>Upright Female Merbaby</td>
<td>14</td>
</tr>
<tr>
<td>1.6</td>
<td>Sherri Stoner and The Little Mermaid</td>
<td>15</td>
</tr>
<tr>
<td>1.7</td>
<td>Line of Action and Secondary Motion</td>
<td>16</td>
</tr>
<tr>
<td>1.8</td>
<td>Dory's &quot;I'm Home&quot; Monologue</td>
<td>18</td>
</tr>
<tr>
<td>1.9</td>
<td>Exploring the Scary Side of Mermaids</td>
<td>19</td>
</tr>
<tr>
<td>1.10</td>
<td>CG Integrated Mermaid</td>
<td>20</td>
</tr>
<tr>
<td>1.11</td>
<td>Kingdom Hearts Transition</td>
<td>22</td>
</tr>
<tr>
<td>1.12</td>
<td>Super Mario Galaxy Swimming</td>
<td>23</td>
</tr>
<tr>
<td>1.13</td>
<td>Secondlife Mermaid &quot;Inch-worm&quot;</td>
<td>24</td>
</tr>
<tr>
<td>1.14</td>
<td>Secondlife v. Little Mermaid Comparison</td>
<td>25</td>
</tr>
<tr>
<td>1.15</td>
<td>Endless Ocean Swim / Idle Transition</td>
<td>26</td>
</tr>
<tr>
<td>1.16</td>
<td>AC4: Pushing Off</td>
<td>27</td>
</tr>
<tr>
<td>1.17</td>
<td>AC4: Swimming Turn</td>
<td>28</td>
</tr>
<tr>
<td>1.1</td>
<td>Merbaby Animated with .fbx Motion Capture Data</td>
<td>35</td>
</tr>
<tr>
<td>2.2</td>
<td>Backless Rolly Chair Setup</td>
<td>35</td>
</tr>
<tr>
<td>2.3</td>
<td>Monofin Research</td>
<td>37</td>
</tr>
<tr>
<td>2.4</td>
<td>Jie Tan's Articulated Swimming Motion</td>
<td>38</td>
</tr>
<tr>
<td>2.5</td>
<td>Baby Mermaid Swimming Simulation</td>
<td>38</td>
</tr>
<tr>
<td>2.6</td>
<td>First Adult Mermaid Rig and Animation</td>
<td>40</td>
</tr>
</tbody>
</table>
FIGURE 2.7: First Adult Mermaid Animation + Video Reference 41
FIGURE 2.8: Auto-Swim Fish 42
FIGURE 2.9: Rig with Tail Switch 43
FIGURE 2.10: Olympic Swimmer Mocap Simulation 44
FIGURE 2.11: Swim Motion Reference and Modified Action Lines 46
FIGURE 2.12: Mermaid Rig Iterations 47
FIGURE 2.13: Pose Comparison 48
FIGURE 3.1: Final Animations 50
SUMMARY

The Georgia Tech, Emergent Game Group {egg} is currently developing a multiplayer game that explores the ancient culture of mermaids which is directed by Celia Pearce. This particularly challenging design problem involves the creation of real-time animations for a multiplayer game, which combine human and fish animations to create a mermaid player avatar. The players actively control the motion of the mermaid avatar with expectations of fluid transitions that reinforce the immersion and exploration of the diegetic world. The aim of this project was to develop believable character animations for a player-controlled mermaid avatar in an underwater fantasy environment.

I served as the Art Director for the {egg}’s Mermaids game while investigating real-time mermaid animations for the adult model. I collaborated with Rose Peng, Colin Freeman, and AJ Kolenc. Rose modified the model and texture of adult mermaid avatar, Colin Freeman created the final baby mermaid rig and animations, and AJ Kolenc completed the final Unity integration tasks that control user interaction with the mermaid.

Problem Statement: As part of my thesis project work for the Emergent Game Group, I investigated ways to create believable real-time underwater animations for a non-human, mermaid avatar. Many challenges plagued the creation of believable underwater animation:

- **Underwater Setting:** Animation for an incompressible fluid requires new approaches to achieve the undulating motions appropriate for swimming.

- **3D Space:** Most multiplayer game engines are designed for a 2D platform with some vertical jumps. The Mermaids MMOG requires forethought regarding the
user interface, avatar navigation, and camera placement for mermaid avatars that freely swim in the x, y, and z directions.

- Hybrid-Humanoid Character: The mermaid avatar has no real world counterpart; she is part human and part fish. Consequently, animators must find creative ways to find useful reference material.

- Real-time Motion: Not only does this multiplayer game require believable animations, but they must transition seamlessly according to any combination of keystrokes afforded to the user.

- Technical Specifications: Animations and constraints must be baked out as a fbx file from the Maya software to the Unity game engine and optimized level game play requires models with low polygonal counts.

Needless to say, the challenge of creating believable swimming motion should not be overlooked. Several well-respected studios in the entertainment industry invested millions of dollars specifically in the research and development for their CG underwater films. The Emergent Game Group may not share the same kind of budget or manpower, but it is my hope that the innovative research techniques chosen for this project produce convincing results to create satisfactory immersion within the Mermaid world.

My approach was highly iterative. Each discovery, reference material, or critique resulted in a better animation. Research began by studying the principles of animation, animated films, and games featuring mermaids while simultaneously exploring the best means to study the mermaid swim motion. Upon completion of the research phase I also consulted motion capture, underwater reference, procedural animation, and direct application of animation principles for keyframe animation. Due to my history as a
student athlete and motion capture assistant, my initial hypothesis proposed the implementation of motion capture animation (a form of embodied research) with procedural adjustments to create the sense that these mermaid avatars moved in a watery medium. Instead I discovered:

- Although the motion capture data was never directly implemented in the animations, it served as an integral part in the animation process because it serves as an excellent source of reference material.
- Implementation of the principles of animation is much harder than the mental comprehension of these principles. The best way to improve technique comes through practice and continued feedback from experienced mentors. I attempted keyframe animation several times, but I wasn't successful until I first explored other techniques that solidified my understanding of the animation principles.
- Most of the published research relevant to my research is either too computational & technical or too broad to avoid exposing proprietary material. Of the remaining research, very little of it related to games.
- I achieved better animation results when I consulted reference material that was either stylized or approximated. Ironically, cartoons and monofin swimming footage inspired the finished animations instead of the mathematically or optically accurate sources such as procedural or underwater motion capture simulation videos.
CHAPTER 1
BACKGROUND

Early Animation Study

Before looking at animated films that depict mermaids, it is necessary to look at the history of animation. Walt Disney was not the first animation pioneer in the quest to create believable motion. A man named Winsor McCay gained his first claim to fame through his beautifully inked cartoons strips in the early 20th century. Around this time, animation was still heavily influenced by the "lightning sketch" style, or time-lapse drawing used to show off an artist's drawing ability. One of McCay's most famous animated cartoons, Gertie the Dinosaur, represents one of the first attempts to use realistic drawings to develop a character with personality.

In this silent cartoon, Gertie is a trained circus dinosaur following the bidding of the ringmaster Winsor McCay himself. "When she kneels to drink, the ground sags beneath her enormous mass...The up-and-down rhythm of her breathing can be seen when she lies on her side" (Crafton 113). The fluidity of the motion driven by the narrative of the cartoon allows audiences to assign her anthropomorphic qualities. It took an artist with an obsessive passion for drawing and a photographic memory to expose the detail necessary to breathe life into real and imaginary characters.
Other animators would attempt to follow Winsor McCay’s footsteps, including the Fleischer brothers. Arguably, the most famous Fleischer cartoon characters include Betty Boop, Popeye, and Superman. Brothers Max and Dave attempted to use innovative technological advances to attract an audience to this emerging medium. Their patented Sterioptical Camera allowed them to improve the realism of the 3D space by creating seamlessly flowing environments that "sandwich" the animated cartoon character between the foreground and background layers.

![Figure 1.2: Max Flesicher's Rotoscope.](image)

Another one of their famous inventions is the rotoscope, a device that allows an animator to trace live-action footage frame by frame. The footage was used to choreograph animated characters based on the actions of paid actors interpreting a scene. Despite the Fleischers’ technical inventiveness, the rotoscoped actions in *Superman* did not fit the character, trapping him in a hybridization of hyper-realistic movements assigned to a non-real cartoon character. "Eventually, the rotoscope was to be reserved by Fleischer for the use only in scenes requiring precise movement, and the balance of each cartoon was animated in freehand fashion" (Maltin 85). Successful implementations of rotoscoped cartoons do exist, but often the most novel discovery lies not in the invention, but in the *application* of its use.

Walt Disney would first seek to re-invent animation, but not just from a technological standpoint. Disney quickly discovered how directly tracing photostats of
live footage created animation that "appeared real enough, but the figure lost the illusion of life" (Thomas 323). Walt Disney knew that pencil tracings of live-action reference create stiff and unnatural looking motions. Tracing creates a disconnect between the character and its environment because its motivation, weight, and timing become lost in translation. By utilizing live-action footage merely as a guide, Disney animators studied these motions to establish the 12 principles of animation which include: squash and stretch, anticipation, staging, straight ahead v. pose to pose animation, follow through and overlapping action, slow-out and slow-in, arcs, secondary action, timing, exaggeration, solid drawing, and appeal (Thomas 47). The bolded principles will be highlighted in more detail in subsequent chapters and will serve to evaluate the overall success of the Emergent Game Group mermaid animations. The desire to improve the execution of these principles drove Walt to find ingenious new applications of technologies that revolutionized the quality of animation.

**Disney Mermaids Character Study**

**Why Study Film?**

Walt Disney Pictures pioneered the methodology for producing believable animation and has depicted mermaids for 75 years with cartoons such as Merbabies (1938), and feature films like The Little Mermaid (1989), Finding Nemo (2003) and Pirates of the Caribbean: On Stranger Tides (2011), thereby serving as a perfect basis for this project. Disney animators have not only brought mermaids to life, they have also branched out of the film industry to bring "sumptuous graphics" to the video game industry in the number one arcade game in 1983, Dragon's Lair (Sito 116).
Although no mermaids inhabit this game, *Dragon's Lair* leveraged the storage power of the laser disc to do more than simply move around 8 bit sprites. Despite computer advances, the cross pollination between games and film has seen surprisingly little documentation.

The premiere of *The Adventures of André & Wally B.* at the 1984 SIGGRAPH conference was the first computer graphics animated short to clearly showcase the potential for the computer to convey personality in its characters (Price 55-60); however, technological application for the game industry didn't gain much traction until 2005, nearly 21 years later judging by the dearth of articles within the SIGGRAPH Sandbox. At the very least, any innovation within the game industry remained highly proprietary, unseen by the general public. Rather than reinvent the wheel again and again, I insisted upon analyzing
the principles and technological techniques developed in the film industry which comprises richer history and more extensive documentation. With today's technology, we no longer have the excuse of technological limitations to condone outright neglect of basic animation principles.

*Merbabies (1938)*

*Merbabies* is a Silly Symphony cartoon contracted out by Disney to a studio called Harmon-Ising during the rigorous production of *Snow White and the Seven Dwarves*. The *Merbabies* cartoon depicts baby mermaids who emerge from the rocks in the morning to swim and perform in an underwater circus until they ride back to the surface of the water on a sea of air bubbles. However, the merbaby motions reflect more human than fishlike qualities. For example, the babies forcefully propel themselves with inefficient arm strokes, their fins were only animated as an after-thought or a rudimentary rudder at best. When ascending a seaweed ladder, rather than leveraging the use of their tails to vertically guide them through the water, they pull themselves up one arm at a time as their tails passively undulate from side to side.

![Figure 1.5: Upright Female Merbaby.](image)

Even the merbabies "walking" along the bottom of the ocean floor with their fins confirms the animators' choice to neglect the distinct fishlike anatomy. However, Harmon and Ising did attempt to follow Walt's 12 Principles of Animation. Early animators discovered that most human and animal movements do not follow a linear path. The merbabies move along a parabolic path or **arcs** making the process of drawing the in-betweens more difficult, but it prevents the creation of lifeless or mechanical
characters; notice the parabolic path that the arms follow. Additionally, the animation of the merbaby's hair with the dancing motion adds extra layers of complexity and liveliness. The sole purpose of these secondary actions is to, "add richness to the scene, naturalness to the action, and a fuller dimension to the personality of the character" (Thomas 64). Even the timing of the hair lags behind the arms, head, and torso reflecting another principle called overlapping action. Incorporating some of the principles of animation renders these merbabies "believable enough" despite the inaccurate locomotion. 51 years later audiences had much less difficulty suspending their disbelief for the feature film The Little Mermaid, the most extensive undertaking of 2D mermaid animation.

**The Little Mermaid (1989)**

*The Little Mermaid* is a critically acclaimed film loosely based on the fairy tale written by Hans Christian Anderson about a mermaid, Ariel, who wants to be human. Glen Keane, the co-supervising animator for *The Little Mermaid*, could not have captured the magic of Ariel without live action reference. Although Jodi Benson supplied Ariel's voice, Sherri Stoner brought her character to life. In fact, she acted out scenes both above and below the water and a small tank was constructed at the studio exclusively for her mermaid acting. Below is a side by side comparison of Sherri’s pose and the finished frame that precedes the famous "Part of Your World" song (DisneyPlatinumDVDsTV). Notice how closely the animated image reflects the live action reference.

![Figure 1.6: Sherri Stoner and The Little Mermaid.](image-url)
The use of motion analysis not only informed the accurate perspective drawing, the timing, and the overall motion, but it allowed Sherri Stoner the opportunity to add her own personality and flair to Ariel's character. At one point, in-between takes, Sherri Stoner exhaled deeply, blowing up a clump of hair; she had no idea that her motion would be incorporated into Ariel’s mannerisms in the film (DisneyPlatinumDVDsTV). The use of motion analysis as a tool to maintain accuracy and creatively express personality shows a new level of detail that adds to the believability of Ariel's character. Even the secondary action of the hair emotes its own personality. In particular, when she's singing on the ocean floor during "Part of Your World," her hair flattens out against the sand and then "poofs" up to reflect her frustrations with her father.

![Figure 1.7: Line of Action and Secondary Motion.](image)

The "line of action" is a line that describes the character's position and posture; technically a line of action is not a principle of animation but will be treated as such because it creates dynamic or exaggerated shots that craft visually appealing character silhouettes (which is yet another principle of animation). Notice the nice curves that form Ariel’s silhouette as she twirls and pulls her arms in tight then stretches her arms up to the sky as her hair settles back from the upward momentum. Disney mermaids no longer pull themselves through a watery medium; they glide through it with magical adroitness by incorporating more reference material into the animation workflow.

**Finding Nemo (2003)**

As animation trended towards entirely digital film production, Pixar (a Disney subsidiary) engineered new ways to give personality and life to its characters and their
environment. They have "consistently led the animation field into the digital era, while maintaining an important continuity, even a dialogue, with the traditions of conventional 2-D animation" (Telotte 221). By drawing from the classic animation traditions, they too strove to strike a balance between creative license and realism through "hyper-reality."

Pixar's *Finding Nemo* is set in the ocean starring a neurotic clown fish named Marlin who must conquer his fears to save his son. Likewise, the Pixar animators needed to face their fears that come with all the challenges of the rendering underwater worlds never before explored. Animators sought the help of Adam Summers, an ichthyologist who studies fish, to create natural movements for their underwater characters. Summers explained mechanical differences in fish locomotion between Marlin and Dory:

"Clown fish are rowers who tend to propel themselves by moving their pectoral fins in a horizontal motion. Blue tangs, like Dory, are flappers who flap their fins up and down to move and almost never wiggle their entire body. The result was that Father's movements were more fluid and graceful, while Dory tended to flit sharply about" (Arkoff 3).

As the animators consulted experts, they also scrutinized reference material to adjust the **timing** and reflect a fish's ability to quickly dart around at single frame intervals. After further review of Dory's swim cycles, she was only moving her fins to propel her forward, which is mechanically correct. However, the animation didn't "feel" right. In animation there is a saying that "if it looks right it is right." Another notion is that "if you aren't cheating you aren't trying hard enough." In addition to comprehending fish locomotion, these animators still faced the challenge of breathing life into these characters through the acting. First of all, fish float and drift; they are not "grounded"
like normal bipeds, so the equivalent of an angry hand gesture would propel the fish too much across the screen. Secondly, fish do not have muscles in their face to create the desired range of expressions. Therefore creative license or "cheating" was needed to find the right balance between anatomical accuracy and the realistic expression of the characters. Below is a screenshot of Dory's famous monologue at the climax of the film.

Figure 1.8: Dory's "I'm Home" Monologue

Her flexible lips and eyebrows convey her disappointment, unlike a biped which might drop its head or portray a slumping line of action to show dismay. Even though Dory is flapping her fins fairly rapidly, she remains well staged in roughly the center of the composition, so the viewer can focus on her emotion. Her motion contrasts with slow and fast tempos to reinforce the overall performance. Even though recent 3d software allows the ability to create fairly photorealistic renders and replicate accurate swimming biomechanics, creative license takes precedence for the sake of the story.

*Pirates of the Caribbean: On Stranger Tides (2011)*

As the Disney mermaids emerge from the world of 2D animation to 3D live-action, a concerted effort existed to create believable mermaids in our world. *Pirates of the Caribbean: On Stranger Tides (POTC 4)* is a continuation of the POTC saga, but this time a crazed Black Beard is in search of a mermaid's tear to ensure his longevity from
the Fountain of Youth. Ben Snow, the Special Effects Supervisor for POTC 4 expressed his ambition to portray more than just women embellished with an attractive mono-fin. To create a unique look, still rooted in reality, collaborators “studied a variety of marine mammals and fish for the motion of the mermaids. [They] also had synchronized swimmers and professional athletes that [were] filmed on set to help guide the animation” (Mermaids POTC 4). Reference material informed not only the CG animators but also the actresses, swimmers, and even the design concepts of the mermaids' anatomy and movement. In an effort to preserve the mermaids' human qualities, the effects team "used every trick in the book – match-animation, facial motion capture, digital skin and a lot of compositing techniques with splashes and fog to make it all hang together" (Mermaids POTC 4). Despite the many techniques required to complete the artistic vision for the film, one of the most successful, yet terrifying mermaid scenes only required minimal CG adjustments.

![Image](image.jpg)

**Figure 1.9: Exploring the Scary Side of Mermaids.**

The majority of the actress' performance required very little editing in post as the mermaid unsheathed her vampire-like teeth, poised to pounce. Animators and compositors were not afraid to simplify and rely more heavily on pure cinematography so long as the emotion and movement upheld the creative direction on screen. However, the integration of certain shots with live action plates required the use of more techniques and tools of increasing complexity.
The emerging swarm of mermaids above shows a fully integrated CG mermaid. Whether this mermaid is fully CG or composited with a professional swimmer, notice the reverse "C" shaped action line flowing through this mermaid. The slow, serpentine timing of her movements insinuate her ominous nature. Follow through and overlap also contribute to sinister undulations that sell this scene. Her body and tail move through the water at different rates such that it "feels" right. It doesn't matter if this scene was hand painted, keyframe animated, or edited motion capture. The movements and the realistic compositing keep the viewer immersed in believability; one method was not the panacea for solving the animation problem.

Conclusion

As mentioned before, the computational power of the computer has advanced in many ways to bridge the gap between the film and video game industries. Technology serves many purposes in the creation of 3D animation. Not only is it the very means for creation, but it also informs and optimizes the animation process. These films mentioned above succeeded or failed based on their implementation of the principles of animation. Merbabies may have been cute and aesthetically pleasing, but it lacked the realism portrayed in The Little Mermaid. Infinitely more technical challenges arose during the creation of POTC 4, but the basic principles of animation were not abandoned or compromised due to production deadlines. Certain technologies in isolation do not produce the desired results, but can be leveraged to create believability if the application
remains loyal to these fundamentals. With the additional challenge of real-time underwater animation the success or failure of the animations will be determined by my ability to stay true to these animation principles.

**Swimming Games**

**What's Already Out There?**

Despite the importance of studying animation principles, a multiplayer and real-time swimming project is incomplete without examining why and how legacy 3D swimming games have succeeded and failed in the past. The introduction of a swimming mechanic reveals how typical game engines assume character movements exist along a 2D plane with limited vertical motion, introduces new problems such as pitch and yaw, and creates new challenges for camera placement and avatar interaction. The Emergent Game Group studied several games including: *Kingdom Hearts, Super Mario Galaxy, the Second Life Mermaid Sim, Endless Ocean, and Assassin's Creed IV Black Flag.*

**Kingdom Hearts (2002)**

*Kingdom Hearts* is a game created by the collaboration of Square Enix and Disney Interactive Studios originally for the PlayStation 2 console. This role playing game combines characters from Disney movies and *Final Fantasy.* In the Atlantica level, the player takes on the role of Sora in the form of a merboy avatar. 3D swimming controls include pressing the "circle" button to rise in the vertical z axis, the "square" button to descend vertically, and the traditional joystick controls your general direction. Swimming transitions in the more cinematic tutorial and cut scenes show a concerted effort to choreograph swimming motions for Sora and Ariel. Including details such as
flowing hair with overlap and follow through, drifting in currents, and posing the characters with flowing lines of action enhance the underwater experience. However, during game play swimming, releasing the "O" or the "X" button produces jerky transitions, which is less appealing:

![Image of Kingdom Hearts transition]

Figure 1.11: Kingdom Hearts Transition.

Sora alternates between a horizontal swimming position to an upright resting position in a matter of milliseconds. His rotation around his center of gravity is way too fast and his torso remains too rigid while changing directions, preventing a completely immersive experience for the players due to a lack of realistic drag and fluidity that would be present underwater. Despite these shortcomings, it represents an early attempt to even address navigation in a non-2D platform environment. It merely showcases how much more difficult it is to create animations that transition smoothly according to user input.

*Super Mario Galaxy (2007)*

Another endeavor to create a believable swimming environment is Nintendo's *Super Mario Galaxy* designed for the Wii console, specifically the Beach Bowl Galaxy level. Using the Nunchuk, the player points in the desired direction and the "Z" button
allows diving; and the "A" button on the Wii Remote allows faster swim boosts. The gyroscope in the Wii Remote and Nunchuk creates a new range of freedom in the swimming controls. The player's tilting wrist action easily controls Mario's pitch and yaw in his underwater environment with more fluidity than Sora from *Kingdom Hearts*. The **timing** of the Mario's swim cycle itself adds realism such that he "feels" underwater. With each swim boost, there is a push with a noticeable pause between strokes, creating a nice rhythm to the interaction. Also notice the blue star-shaped cursor that indicates the direction of Mario's navigation as he pauses between strokes. Even the camera does a decent job of keeping Mario **staged** in the center of the screen by matching Mario's pitch and yaw during his dynamic maneuvers.

![Figure 1.12: Super Mario Galaxy Swimming.](image)

These visual cues and smooth transitions add to the immersive experience of the game. However, Mario's navigation seems too "floaty" at times. Fine-tuned motion to reach foreground objects often requires circuitous paths due to an inability to stop momentum when desired. Despite Mario's amazing preservation of inertia, the **weight** and **timing** of his motions and adroit diving motions showcase a satisfactory interaction that doesn't simply emulate flying.
Second Life Mermaid Sim (2006)

Second Life is an online virtual world where players create and control their own content and role play as various characters. Player creators with Second Life adapted the world’s flying mechanism and modified the human avatars to create mermaid avatars that swim underwater. The basic controls include the "page-up" and "page-down" buttons to rise and sink in the water with the typical arrow keys to navigate forward, backward, left, and right. A fun feature exists regarding the z-depth navigation; it is the ability to press "page-up" until the mermaid leaves the water and begins flying beyond and through the sky with distinct freedom. Second Life mermaid avatars are based on modifying bipedal human avatar, so the mermaid avatar literally looks like a human with a monofin attached to the feet. Subsequently, the motions of the mermaid reflect a stiff legged human who can only bend at the knee while simultaneously "inchworming" along. To clarify, the torso and tail contract inward and then straighten out as the mermaid propels forward through the water, not unlike an inchworm pulling itself along the ground.

![Figure 1.13: Second Life Mermaid "Inch-worm".](image)

Although the motion conveys a sense of swimming, the inefficient stroke lacks believability. Similarly to Kingdom Hearts, these mermaid avatars fail to smoothly transition from one pose to the next. When the mermaid stops swimming she instantaneously loses all momentum, her torso rotates upwards, and her arms drop like a
rock. On a positive note, these mermaids do tend to "bob up and down" as they swim idly in place. In this situation the bend knee position works, going through poses not unlike Ariel in *The Little Mermaid*.

![Figure 1.14: Second Life v. Little Mermaid Comparison.](image)

Unlike Ariel's swimming, however, *Second Life* avatars lack the soft **arc-like** motions that create a sense of underwater "softness". Another problem with these animations that is beyond the scope of this paper deals with collision detection. The extra degree of freedom and navigation adds more computational complexity to the problem of preventing a mermaid's tail from penetrating the floor, for example. Despite its flaws, *Second Life* Mermaid Sim warrants scrutiny as it is one of the first 3D environments to even consider creating real-time underwater interactions.

*Endless Ocean (2007)*

*Endless Ocean* is a single player game distributed for the Wii system where the player takes on the role of an underwater explorer. When the player presses the "B" button, the diver character responds to the tilt and orientation of the Wii Remote while propelling forward. A helpful navigation feature occurs when the "B" button is released, the diver spreads out his or her arms, loses momentum, and assumes a slightly more erect
orientation. The interaction feels less "floaty" than *Super Mario Galaxy* (which was designed on the very same console). Of the playtested underwater games for this study, *Endless Ocean* is the first underwater experience to successfully address animation transitions. Unlike previous games, the "idle" transition only lifts the torso slightly as the arms fan out and the legs come down as if the avatar is actually in a watery medium! Not only does the diver smoothly lose swimming speed, as the cursor (indicated by the yellow circle) moves further away from the diver, the torso rotates in the direction of the cursor and corresponding arm motions occur to help propel him or her to the new location. The amount of rotation corresponds to the rate of change caused by the cursor and the camera seamlessly follows the diver's position and orientation while keeping the diver *staged* in the lower third of the screen.

![Endless Ocean Swim / Idle Transition](image)

Figure 1.15: *Endless Ocean* Swim / Idle Transition.

Finally, the avatar no longer looks like a stiff, rotating rod or an "inchworm" (as in Second Life); the player moves through flexible **arcs** with appropriate **weight** and **timing**. *Endless Ocean* creates a tranquil and **appealing** environment that warrants emulation.

**Assassin's Creed IV: Black Flag (2013)**

*Assassin's Creed IV: Black Flag (AC4)* was created by Ubisoft for the Xbox 360, PS3, and Wii U. The fourth installment of the assassin saga takes place both above and
below sea level. These blood-thirsty pirates loot treasure troves and hide from sharks while constantly diving into barrels to maintain healthy oxygen levels. The left stick controls Edward's swim direction, holding down the right trigger propels him faster through the water and periodically the A and B button allow special features like looting treasure and lunging upwards for air. Although Ubisoft developed this game in just 2 years, the animation is not sparse. The avatar assassin, Edward Kenway, swims with an unprecedented fluidity. The normal swimming motion depicts Edward muscling his way through the water with powerful, well-timed strokes as the legs bend and recoil for kicking with varying rapidity. The forward boosting with the right trigger initiates a powerful front stroke swim cycle that transitions seamlessly. Even collision puts a damper on the interaction. If Edward comes too close to an object he sometimes pushes off of the rock structures or lift the arm in the next stroke a little higher.

Another kind of transition occurs with the help of camera cuts. For animations which may require heavy procedural animation blending, a well staged scene and a camera cut hides any jerkiness and ensure that every player sees identical cinematic cut scenes despite unique experiences and exploration paths. The most impressive aspect of the interaction is the handling of navigation turning. The camera follows the orientation of
Edward's torso resulting in no apparent turning relative to the camera. Sometimes the
turns are too tight and rapid camera changing is undesirable. In these circumstances
Edward's torso actually bends or one arm strokes more than the other to create a sense of
movement through the watery medium with realistic weight and timing and attention to
detail.

![Figure 1.17: AC4: Swimming Turn.](image)

AC4 showcases the ability to procedurally combine believable movements that
incorporate the principles of animation and camera motions to create engaging 3
dimensional underwater environments.

**Literature Review**

In addition to the principles of animation previously discussed, these additional
resources informed my extremely iterative process.

**Action Analysis for Animators**

Chris Webster is a former commercial animator who now teaches and researches
animator's creative process as they interpret timing action analysis (Chris Webster-ARG).
His book, *Action Analysis for Animators*, breaks down a number of animation principles,
motion study techniques, and analyzes locomotion and physiology of humans and
animals. Webster explains that the caudal fin, typically referred to as the tail, powers the
locomotion for the swimming. Increased swimming speed results from an "increased
frequency of the tail beats" (Webster 171). As a result, swimming boosts can be controlled procedurally by changing the speed variable. He also explains that fish have a density closer to its environment (unlike a bird flying through the air or a human walking). Consequently, less gravitational pull results in less friction as the fish swim through the incompressible watery medium. This observation affects choices that convey the **timing** and the **weight** of the tail motion for the mermaid avatar. According to Chris Webster,

"[animators] should not depend on any single source of referencing but rather should use a range of resources: textbooks, film (animation and live action), photography (your own and that of others), first-hand animation material (observation and sketchbook work), the first-hand experience of others through mentorship (one of the most useful techniques) and motion capture" (Webster 6-7).

It is in this vain that I explored a hunch that I could use a combination of motion capture and procedural animation to create believable swimming motions. Upon further exploration of these different mediums, I learned how to apply animation principles to a mermaid with an iterative and creative use of reference material that changed over time.

**Articulated Swimming Creatures**

I originally intended to use procedural animation to modify motion capture animation. My friend Jie Jan is a computer science Ph. D. student at Georgia Tech. He also noticed the difficulties creating underwater swimming motions for underwater creatures. In his thesis publication, he describes a complete system for controlling a wide variety of aquatic animals in a simulated fluid environment. Given an aquatic animal that
is represented by an articulated rigid body system, his system can automatically find the optimal locomotion in a hydrodynamically-coupled environment (Tan 1-2). The beauty of this approach is its ability to address realistic motion for fantastical creatures that don't exist or are unavailable for primary reference material. Unlike the animation produced from motion capture data, this simulation exhibits fluid motions resulting from the overlapping action of each segment moving at different rates. The rendering time necessary to calculate the most efficient swim gait for a certain energy allotment of a given 3D model is too extensive. This method allows modifications of certain parameters such as "energy bound, the period of the motion for each degree of freedom, and joint limits" which could be recalculated (Tan 9). Even with these options, the role of the animator becomes diminished. The challenge lies in finding a balance between procedural accuracy and speed with the creative expression an animator can exert to finesse those poses that add the extra pizzazz necessary to avoid lackluster animations.

**Finding the Right CG Water and Fish in 'Nemo**

I knew that I admired the procedural animation of the jellyfish in *Finding Nemo*. An article posted by Karl Cohen for the Animation World Network vaguely relates that procedural controls were used to control the speed, magnitude, and offset of each of the jellyfish pulses (Cohen). These descriptions were given in layman’s terms, but lacked any technical or mathematical details. Proprietary research and animation techniques remained confidential and out of reach from developing animators like myself. Later I will discuss a handy tutorial on the web that explains how to procedurally animate sinusoidal motion appropriate for fish animations.
**Turning to the Masters: Motion Capturing Cartoons**

Despite my initial hunch to use motion capture and / or procedural animation, this article inspired me to take a different approach. Chris Bregler is currently a professor of computer science at NYU, he has worked for Disney Animation Studios and has published several publications on motion capture and commercial projects (Chris Bregler Home Page). In 2002, Chris Bregler released a paper that explored the possibility of motion capturing the extreme poses of cartoons onto other 2D and even 3D characters. The diagrams and concepts he explored inspired me to scrutinize the line of action in Disney cartoons for the sake of bringing the expressive poses to the real-time animation of mermaids. Although I performed keyframe animation for my final product, motion capture still formed an integral part in the creative process.

**Principles of Emergent Design in Online Games**

This article published by the Emergent Game Group sets the stage for my Mermaids animation project. It outlines the decision making process for the creation of the first beta release and gives insight into the design challenges associated with Mermaids. For instance, it underlines that "most game engines are designed with the basic assumption that players will be walking on the ground" and establishes that *The Little Mermaid* is one of the very few established references for mermaid-lore (Pearce and Ashmore 2). Consequently, I investigated ways to create the sense of immersion in a 3 dimensional water world through the animations themselves rather than relying on the 3d engine as well as creative ways to find reference material for a fictitious mermaid creature.
CHAPTER 2
APPROACH & METHODOLOGY

Overview

My process existed in two phases: the research and animation phases; this is nothing new for the production studios that created *The Little Mermaid*, *Finding Nemo*, and *POTC 4*. During the research phase I explored technical and artistic topics that include motion capture, embodied research, procedural animation, and principles of animation. After the research phase concluded, I explored different types of animation approaches in combination with different reference sources. I discontinued the use of motion capture as an animation method and invested more time exploring keyframe and procedural animation. As my research continued I even experimented with the use of motion capture and procedural animation as reference sources. Very few of the techniques listed below served as the final solution for this animation challenge, but each step served as iterative building blocks that improved my understanding and implementation of animation principles. The diagram below describes the process in more detail.

Table 2.1: Research Phase.

<table>
<thead>
<tr>
<th>Research Phase</th>
<th>Topic</th>
<th>Setup</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Motion Capture</td>
<td>Acted out swimming motion using a monofin and a backless rolling chair</td>
</tr>
<tr>
<td></td>
<td>Embodied Research</td>
<td>Filmed swimming with monofin in Georgia Tech diving well</td>
</tr>
<tr>
<td></td>
<td>Procedural Animation</td>
<td>Collaborated with Jie Tan, fish locomotion calculated according to Navier-Stokes</td>
</tr>
</tbody>
</table>
One of the unique challenges of tackling the real-time underwater animation problem involved exploring technical solutions that are evaluated by artistic or qualitative criteria. There is no quantifiable method to prove my animations are "good enough." If an animation "feels right, it is right," but people perceive animations differently; it’s subjective. As a result, I made sure to consult not only my peers, but professors and industry professionals. Upon completion, I will have also consulted textbooks, film, embodied research material, procedural animation, and motion capture.

**Evaluation Criteria**

Any good animator constantly evaluates and reevaluates his or her work to portray characters in such a way that truly supports the story and the motivations of that character. The feedback from my peers, professors, and industry professionals informed the following criteria that I will use to evaluate my thesis:

<table>
<thead>
<tr>
<th>Animation Phase</th>
<th>Type</th>
<th>Reference Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keyframe Animation</td>
<td>Embodied Research &amp; <em>The Little Mermaid</em></td>
<td></td>
</tr>
<tr>
<td>Procedural Animation in Maya (Tail)</td>
<td>Motion Capture Data</td>
<td></td>
</tr>
<tr>
<td>Keyframe Animation</td>
<td>Procedural Animation provided by Jie Tan</td>
<td></td>
</tr>
<tr>
<td>Procedural Animation in Maya (Tail + Spine)</td>
<td>Embodied Research</td>
<td></td>
</tr>
<tr>
<td>Keyframe Animation</td>
<td>Embodied Research &amp; <em>The Little Mermaid</em></td>
<td></td>
</tr>
</tbody>
</table>
iterative feedback from professors, coworkers, and industry professionals

utilization of these animation principles: follow through and overlap, arcs, secondary motion, timing, line of action, exaggeration, appeal, staging, and weight

smooth swim cycle transitions

mermaid motion "feels" like it is underwater

motion of the human and fishlike anatomy feels integrated

satisfactory movement visible from all perspectives - not just orthographic views

Motion Capture Research

As a developing animator, my initial strategy involved using motion capture as the primary source for the animation with procedural modifications to emulate the sway associated with being underwater. This seemed like the logical choice because of my student athlete and motion capture experience on campus. Part of the research required for this project involved finding the right balance of motion capture data and animation adjustments via keyframing and/or scripting to simulate believable underwater motion. During the initial phase of my thesis development, my committee frequently asked me to justify my rationale for using motion capture. My inability to sufficiently provide an answer forced me to rethink my approach completely.

Several problems arose; Firstly, the data cleanup process using Vicon Blade system was much more time intensive than previously experienced with the Optitrack Capture System. In an attempt to at least transfer the basic motion onto the baby mermaid avatar, I exported the data from Vicon Blade as a .fbx into Maya and roughly scaled down the motion capture data to the approximate size of our baby mermaid. This
process lacked all of the precision that is built into the Motionbuilder software, which allows you to transfer motion capture data from an actor/actress with their own distinct physique to a 3D character with its own distinct physiology.

Figure 2.1: Merbaby Animated with .fbx Motion Capture Data.

Pictured above is a screen shot of my first attempt to complete mermaid motion capture animation. With Kristin Siu's assistance, I performed the role of the mermaid using a backless rolling chair to support my torso as I stroked my arms and kicked my feet together.

Figure 2.2: Backless Rolly Chair Setup.
In addition to seeking feedback from fellow members in the Emergent Game Group, I sought advice from Alex Zemke, an industry animator at Sony Computer Entertainment America, who pointed out,

"[some] popping in the lower back movement, and the lack of any overlap in the tail section. And...there needs to be some up-and-down for the core of the body. In fact, a little surge forward with each stroke, followed by a bit of a settle backward between strokes, would also be nice. This should result in a subtle, bent-figure-eight, arc for the pelvis to follow."

Besides enthusiasm for the helpful feedback from the industry professional, I realized that theoretical comprehension of the Disney's animation principles versus their implementation differ greatly. At the very least, I learned how important follow through and overlap are to creating convincing tail motion. Additionally, I began to realize the minutia involved in motion analysis to breathe magic into CG characters. The deeper I delved, the more reference material I needed because this very stiff-tailed mermaid left something to be desired.

**Embodied Research**

By this point I knew that I needed to examine the movements of this mermaid to an even greater extent. Animators wishing to gain a deeper understanding of their character should physically re-enact themselves those motions as closely as possible. For example, for Toy Story, Pixar admitted their animators tied wooden planks to their feet to understand how to best animate the plastic toy soldiers (Green Army Men). Consequently a small crew of Emergent Game Group members visited the Georgia Tech diving well to experience and document monofin swimming, the closest approximation
available of mermaid swimming. This embodied exploration allowed us to better understand the mechanics that needed to be represented in the animation.

![Figure 2.3: Monofin Research.](image)

We quickly discovered the importance of incorporating sinusoidal motion that propagates throughout the entire body starting with the head and flowing through the rest of the body and finally the tail. Inefficient strokes that originated with the legs or knees led to wasted energy that actually fought against the overly large and stiff monofin (as compared to the tail designed for our multiplayer mermaids). This invaluable experience created "muscle memory" that I could then draw upon when completing mermaid animations. Even months after the experience, the footage from the underwater camera served as a visual tool for further motion analysis from multiple orthographic angles.

**Procedural Animation Research**

In the semester following the motion capture session for the baby mermaid I encountered Jie Tan's thesis presentation at our very own Graphics, Visualization, and Usability (GVU) Center at Georgia Tech.
Pictured above are screen shots of Jie Tan's 3D models that use the Navier-Stokes formula to iteratively approximate the best articulated swimming motion given a 3D model with distinct joint bisections. The algorithm creates physiologically realistic animation, but requires a bisected mesh that prevents this algorithm from being a viable solution because the bisected merbaby does not support the aesthetic choices of the art director and it detracts from the appeal of the Mermaids multiplayer game.

Figure 2.5: Baby Mermaid Swimming Simulation.
Secondly, animation is applied to the geometry, not the joints of the character, which would incur problems in the Unity engine utilized for the Mermaids multiplayer game. Despite the aesthetic, technical, and practical reasons that prevent full implementation into the Mermaids game, the information gathered from these simulations greatly informed the animation of a non-human, underwater dwelling creature. In fact, I took the animation files gathered from Jie Tan's simulation and imported them into Maya with the mermaid baby for reference. Later in the development process, I returned to Jie and asked him to produce a second simulation for the updated adult mermaid model which I will discuss later.

**Basic Animation Technique Research & Implementation**

At the conclusion of the first year, my understanding of the swimming movement exceeded my current skill set. Consequently, I sought additional resources at Savannah College of Art and Design to rectify this discrepancy. It is in my Animation 504 class where I learned how to take the principles of animation and put them into practice through 2D and 3D animation. The first two exercises consisted of animating a bouncing ball and waving flag. Principles like squash and stretch, timing, solid drawing, follow through and overlap became necessary to achieve a successful hand-drawn animation. The squash of the ball when it hits the ground and the stretch before and after it hits implies the weight and deformation of its impact. The number of drawings necessary to create the proper pacing determines how much energy the ball has going into and out of the bounce. Inaccurate drawings that accidentally grow in size, for example, destroy the illusion. The waving flag requires proper motion of the fabric moving at different rates to create that sinusoidal motion. I didn't know it at the time, but these exercises were
exactly what I needed to apply to the mermaid animation. Outside of class we sketched people, paying attention to the **line of action**. In conjunction with these exercises, I applied the same principle to mermaids, but instead I referenced the underwater footage from our monofin excursion and *The Little Mermaid*. In addition to animation principles and practices, I gained knowledge of Maya's graph editor and the importance of removing unnecessary keyframes on individual transform channels (translateX verses rotateY) and matching the tangents of the first and last frame of looping animations. In Animation 505, I worked through Maya from a very low level "node" based theoretical understanding to building complex rigs for 3D characters, a skill necessary for the mermaid avatar.

![Figure 2.6: First Adult Mermaid Rig and Animation.](image)

For this rig, I simply adapted a basic biped rig; instead of two legs branching off below the root node, I only created one chain down the rest of the tail. Everything else was the same for all intents and purposes with exception to a couple additional helper joints in the tail.
Pictured above is a screenshot of the adult mermaid in front of the underwater footage. Notice how the mermaid's poses are similar, but not an exact duplicate or rotoscoped version. On the plus side, this animation incorporated more follow through and overlap than previous iterations. The mermaid's motions followed parabolic paths or arcs, the timing of the tail flick felt like it was resisting and pushing through the water, and the animation cycled smoothly with matching tangents. However, the hair didn't "feel" underwater because it was stiff and motionless, unlike Ariel's hair which takes on its own personality. The hair offered no secondary or overlapping motion. To avoid this problem in the future, I gave the new mermaid a stylized "cornrow" hairstyle which looks more realistic when motionless. Other problems existed with the original adult mermaid model. The skin weights were not smoothed out to prevent linear "jaggies" on the tail. Proper skin weights can average out the values for each vertex, creating nice smooth curves with deformation. For the time being, I received positive feedback as it did
represent a significant step forward in my progress. In an attempt to retexture this rig, I failed to key the mermaid in a neutral "T-Pose" before performing modifications. This setback combined with additional rigging assignments in Animation 505 inspired me to rethink the initial rig setup.

**Procedural Animation Implementation**

For the next portion of the mermaid process I delved deeper into Maya and discovered MEL expressions and MEL script. I discovered an online tutorial which walks you through the process of creating those procedural sin waves that create very convincing **follow through** and **overlap** in the tail. Although these expressions allowed greater control than the articulated swim motion simulation algorithm, I still wanted more options than simply adjusting the speed, amplitude, and offset of each joint.

![Figure 2.8: Auto-Swim Fish.](https://vimeo.com/27444091)

My last exercise in Animation 505 involved building a basic biped rig with a forward kinematic / inverse kinematic switch built into the arm such that a character could use inverse kinematics to pick up objects and switch back to forward kinematics without breaking the rig or requiring "counter-animating" to wrestle the rig and try to make it work. It is this course that inspired me to re-build a mermaid rig with a tail that can
switch between two modes: one being procedurally created by the sin wave function and the other keyframe animation of an IK spline tool. With the ability to use one or both of these at the same time I hoped to strike a balance between procedural speed and accuracy (seen in Jie Tan's simulation) with the ability to fine-tune the animation as needed.

Figure 2.9: Rig with Tail Switch.

The top tail rig shows the tail under the influence of the sin wave function and the bottom tail rig shows the joints influenced by the yellow handles above. These handles drive the clusters that control the IK Spline tool which calculates the rotations of joints in a chain such that a handle can "pull up" a joint while the relative distances of the joint chain remains intact. The middle tail receives partial influence from each tail rig to create the resulting motion seen on the mermaid mesh. Notice how many joints there are in the tail. Normal keyframe animation would shy away from rigs with too many joints because of the additional animation curves. With this rig, the additional joints can be managed with the procedural motion and the IK Spline Handles.
The reference material for this animation actually came from the motion capture data published by Chris Bregler and associates in the Manhattan Mocap group. They extensively analyzed the swimming technique of Olympic swimmer Dana Vollmer, gold medal and world record holder in the 100m butterfly stroke.

![Figure 2.10: Olympic Swimmer Mocap Simulation.](https://www.youtube.com/watch?v=lDG2_K9N2ac)

Of the reference material I looked at, this was both the most informative, but also the most confusing material to study because of the complexity of the motion. Consequently, I do not feel like the arm motion in my mermaid animation truly represents the butterfly stroke as it pertains to human swim motion. Although this new rig achieved smooth tail motion and I created another tail rig to allow for modifications, I still struggled to create a convincing result that appears to *drag* within the watery medium. I even wrote a MEL script which uses the "setKeyframe" function to write that same sin wave behavior onto the animation curves of the tail joints. This allowed me the freedom to further manipulate the motion in the graph editor. However, the extra emphasis on the tail setup failed to maintain a uniform movement of upper and lower body working together as one unit. The entire motion as a whole seems to rotate on a pendulum and the overall motion fails to start from the head and continue down the rest of the body through the tail. On
the whole, although the new hair style no longer detracts from the underwater animation, it still fails to be believable.

**Keyframe Animation with Procedural Reference**

Exploring the inner workings of Maya with MEL scripts and expressions, rig switches, and motion capture data continued to expand my knowledge of the subject matter. Frustrations with the complex rig forced me to think about simplifying and accounting for future animators understanding how to create future animations with this rig. The third iteration of this adult mermaid excluded an FK / IK arm switch, eventually required fewer joints in the tail (with smoother skin weights), and I enlisted the help of Rose Peng, the art director who designed the original Mermaid, to completely redo the texture to create more appeal. In an interest to avoid workflow problems experienced from the first mermaid, I first made sure to zero out all of the controls in the T-pose at the 0th frame and learned how to export skin weight maps from {egg} member and fellow master’s student Colin Freeman. Basically, once the joint placement and skin weights were set, this allowed us to simultaneously work on animation and retexturing (rather than a more linear workflow which leaves little room for adjustments when mistakes are discovered). For reference material, I again sought the help of Jie Tan to create a simulation, but this time I bisected the adult mermaid model and requested renderings of the front, side and top views. The most recent calculated swim gait, created convincing undulations, but the timing of the follow through and overlap were too even and did not achieve the nice tail flick motion requested by my adviser and seen throughout *The Little Mermaid*. My solution was to take this simulation into Adobe After Effects, and draw new lines of action for the mermaid to follow that better reflect the drag of the tail
moving upwards before it snaps back down to propel forward through the water. The new poses that I keyed morphed from pose to pose rather than reflecting the proper weight and timing of the tail flick.

Figure 2.11: Swim Motion Reference and Modified Action Lines.

At this point, I knew that I liked the tail flick motion inspired by The Little Mermaid and the underwater monofin footage used as a reference for the first iteration. In this case, artistic or embodied approximations felt more realistic than the mathematically accurate procedural simulations. Therefore, I made efforts to optimize this rig by modifying the shoulder placement, minimizing the number of tail joints and tail helper joints, and adjusting the skin weights all took place for the final rig revisions. Once new skin weights were created and exported, Rose and I confirmed that our workflow could still be maintained before continuing further.

**Procedural Animation with Embodied Reference**

Before confirming my decision to revert to the older monofin footage and The Little Mermaid footage, I briefly experimented with the procedural animation for the entire rig (not just the tail), but quickly disliked my inability to account for nice "S" curve
shapes that begin at the head, invert at the torso, and continue down the rest of the tail.
The closest approximations I created were two separate waves (one for the torso and another for the tail). At this point, I still needed more control.

**Keyframe Animation with Embodied Reference**

I once again referred to the original underwater footage for reference and performed keyframe animation. This time I completed a normal swim cycle, an additional "power boost" swim cycle where the mermaid pulls herself forward a little more, an idle animation where the mermaid simply wades in the water, and transitions into and out of the swimming and idle positions. In search of more constructive criticism, I approached Greg Azzopardi, the professor for my Animation 504 course at SCAD. Overall his feedback was positive with a few suggestions; he liked the overlap of the fingers and the tail, found a keyframe where the helper tail joints fell off their nice arc paths, suggested allowing the head to lead the body a bit more and to add some asynchronicity in arms and torso to avoid "twinning" which happens when parts on the opposite sides of a character follow the same motion with the exact timing. After applying these corrections, I also sought the advice of my adviser, Celia Pearce.

![Figure 2.12: Mermaid Rig Iterations.](image-url)
I knew that this last iteration finally succeeded because my project advisor Celia Pearce conceded that the mermaid's tail "had just the right amount of resistance in the water." These animations also smoothly transitioned due to precise starting and ending poses with matching tangents. Several animation principles were upheld to ensure that this mermaid avatar seemed to exist within an underwater environment. The timing of the tail and the secondary motion of the fingers exhibited nice follow through and overlap. The latest mermaid texture added to her overall appeal thanks to Rose Peng's creative help. And the avatar follows realistic arc-like motion after adjusting the tail helper joints. I attempted to be mindful of the action lines flowing through the mermaid's body such that they create nice "S curves." Comparatively speaking, I do think the poses in The Little Mermaid are more exaggerated, but the swim cycles I created serve as a believable mechanism for the avatar to interact with its environment.

According to Scott McCloud, the more abstract a cartoon, the more the viewer sees his or her self in that cartoon (McCloud 36). Seeing as the Mermaids game seeks to promote
emergent multiplayer behavior, the cartoon aesthetic and the generic, yet believable motions, seem to suit the goals of this project.
CHAPTER 3

FINAL ANIMATIONS AND CONCLUSION

Final Animations

![Rig 3 Animations](image)

Figure 3.1: Final Animations.

https://vimeo.com/92002028

https://vimeo.com/92004289

Evaluation

The iteration for these mermaid animations is evident by the evolution of the quality of the model itself and increasing precision of the movements. Feedback from friends, advisers, and industry professionals initially focused on very broad suggestions to better implement principles of animation such as overlap, following arcs, and avoiding unappealing poses. As the quality of the animations improved, critique focused more on the finer details such as lowering the arms slightly or deleting a keyframe here or
there to perfect the **timing**. After addressing these tips, the overall consensus from friends and colleagues is that these animation do “feel” like they exist in a watery medium, the timing of the keyframes create movement of a fantastical creature rather than highlighting its hybrid-human nature, and they transition very smoothly from one motion to another because of the precise treatment of the tangents in the graph editor.

Unlike feature film production, the final mermaid animations must look **appealing** from multiple angles instead of the specific shots planned out ahead of time. This is why the embodied research proved to be so helpful because we were able to take swimming footage from multiple vantage points and import it into Maya.

Due to the subjective nature of animation, I did receive critique suggesting implementation of even more exaggerated undulations for the swim motion from Alex Zemke at Sony Computer Entertainment America. This is just another style of mermaid swimming that a fellow egg member, Colin Freeman already implemented for the baby mermaid. I justified my decision to refrain from further modifications because the final adult mermaid animations still effectively achieved all of the evaluation criteria defined above and modifications would require extreme modifications of joint placements and skin weights to achieve the new motions. However, the skin weights we did achieve greatly improved the appearance of the low poly model necessary for optimizing gameplay time.

**Conclusion**

Again I emphasize the highly iterative nature of this design process. I set out to discover a way of accomplishing believable swim motions which takes place in a medium that behaves differently than gravity for a fantastical creature that doesn’t exist.
Even the “most accurate” reference material that informed the animation process was an approximation of how a hybrid-human character would move. Procedural animation incorporates mathematics to predict the optimum swim pattern of almost any creature (fantastical or not) and both embodied research and motion capture relied on a human imitating a fish-like swim motion with the additional help of a monofin. The backless rolling chair setup for the motion capture created the least realistic movements, but even the underwater monofin swimming failed to replicate the exact fluidity of our mermaid avatar’s tail. The size and thickness of the monofin and mermaid tails varied drastically. The challenge lay in the ability to learn as much as possible from each of these sources and piece them together in one final application of the animation principles that creates believability. The Little Mermaid and the embodied research proved to be the most useful reference material because both involved physical reenactment either directly or indirectly. Even animators like Glen Keane looked at live action reference to inform Ariel’s movements. The procedural simulations and the optical data provided by Chris Bregler’s Olympic swimming motion capture produced uniform movements that differed too much from the desired swim timing of our cartoon avatar. But even these sources created yet another opportunity for motion analysis and improved animating skills.

Ultimately underwater motion capture of humans wearing monofins under the creative direction of the animators could create even better results in the future (just like the production of POTC 4), but budgetary and skill level limitations of the Emergent Game Lab required a much more creative approach instead. My exploratory process provided a low-cost alternative for smaller, independent research labs to create believable animations of fantastical underwater creatures.
**Future Work**

In the future, the creation of even more animations such as gestures for spell casting, collision avoidance, and body rolls would enhance the Mermaids game mechanics. I would also enjoy collaborating with the game developers to fine tune the mermaid interaction and navigation. Since game engines failed to anticipate features necessary for 3 dimensional movement, I would enjoy testing out new ways to handle collision detection, camera interaction, and interaction controls. Unlike bipedal collision detection, the lowest point of contact changes with each tail flick. A potential solution includes dynamically changing the bounding box depending on the current animation state. Calculations for collisions will be different for the idle verses the swim animation. Camera placement is another tricky element for 3d games. If the camera stages the avatar at the center of the screen, depending on the angle and the distance, the player’s view of objects behind the mermaid could be blocked by their own avatar. Additionally, game design often tries to keep other avatars, enemies, or points of interest centered in the view as well which adds another competing layer of complexity. Further playtesting to fine tune animation speeds for transitions and controls would improve the Mermaids experience to an even greater extent.
REFERENCES


