Invigorate a vital part of the digital world: designing play activities with digital animals

Thesis

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Abstract

In video games, interactions with digital animals remains an underdeveloped area, as animals are often portrayed as monsters and food sources—to kill and harvest—without allowing players to behave otherwise. As a response, this thesis investigates how to design play activities with digital animals through the creation of a video game about fish migration, with special focus on player-fish interactions. A game AI technique known as behavioral animation is used to create seemingly intelligent fish that players can play with. The thesis also reviews and analyzes examples of realistic digital animals to showcase them as an important part of virtual game worlds and their capability to make players emotionally invested.

To achieve the goal of designing play activities with digital animals, the thesis project has first created seemingly intelligent fish that autonomously move towards their destination, while sticking together with the group, avoiding obstacles, and running away when detecting predators. On that foundation, the player can play with the fish by leading them to explore the water environment, pushing them upstream against strong currents, and directing them to form the shape of a big fish to swim swiftly away from predators.

Dedication

Dedicated to people who have helped me along the way.

Vita

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Publications

Fields of Study

Major Field: Design

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Chapter 1. Introduction

General Description

Inside the interactive media of video games, players come to expect interaction with the virtual world and its inhabitants. Yet, video games have traditionally limited interaction with animals to killing and resource gathering, effectively representing the animals as monsters and walking resources. The simplification brings two problems. It is morally objectionable (Coghlan & Sparrow, 2020); it wastes the opportunity to build strong attachment and tell compelling stories between the player and the digital animal. Facing the overly simplified interactions, the research purpose of my fish migration video game is to design play activities with digital animals, and in this case, fish, so that the players see them not as prey, but intelligent, friendly co-dwellers of the world, and even become emotionally attached to them.

This thesis also reviews examples of evocative digital animals, with whom players have had memorable experiences and established strong emotional attachment. The memorable examples serve as arguments for animal interactions' importance in creating an overall believable world, specifically for genres like *role-playing games* (RPG) and *virtual reality games* (VR), as such games try to create a whole new world for players to stay in. The review adds a theoretical overview to paint a fuller picture of animals in video games and to justify my effort in designing play activities in my fish migration game.

To design play activities with digital animals, this research combines *player input*, the information the player sends to the computer, with a game AI technique for animal (specifically fish) movement (Millington & Funge, 2009). The game AI technique is known as *behavioral animation* (Reynolds, 1987). Unlike keyframed animation where the animator defines specific position and timing of the animated character, behavioral animation programs each fish to move in a seemingly intelligent way: go to a target position (*Seek* Behavior), avoid obstacles along the way (*Obstacle Avoidance*), and flee from predators (*Flee*) (Reynolds, 1987). In this case, the fish are called *autonomous agents*, since they exhibit autonomous and improvisational movement, without direct player control. The *Wander* behavior (Reynolds, 1999), for example, defines a new target position periodically and applies a force directing the autonomous agents to go there. As a result, the viewer can tell that the agents are wandering around inside a certain region.

The research presented in this thesis involves designing play activities with digital animals by combining autonomous behaviors with player input. As an example, instead of having an agent wander fully autonomously, the player can define a target position for the agent to wander around. Building on the works of computer graphic predecessors, new fish group movement behaviors have been programmed to illustrate the school as a live, flexible formation, with seemingly intelligent fish for the players to interact with. This way, interactions with digital animals is expanded from hunting and killing.

Expertise I am Bringing into the Project

This section covers the expertise I acquired in the MFA program and how it is applied in the thesis project. The expertise is on computer graphics techniques, especially scripting for behavioral animation, using video game development software known as a game engine, fish care and fish behavior, game design theory, and video game accessibility.

I used behavioral animation to create the fish AI, so that the fish appear intelligent and move autonomously. Just as Photoshop has made image manipulation easier, game engines are built to facilitate video game development. My expertise on using a game engine has enabled me to create my game project. As a home aquarium keeper, I developed skills on fish care and got to observe fish behaviors closely. This experience, together with my interest in video games, strongly inspired me to think about digital animals in video games and to make a fish-related game myself. In this project, game design theory has helped me to adapt specific events of salmon migration into my game, with the goal of keeping players engaged. In the past three years, I also learned about video game accessibility, and how specific design choices could enable more players to enjoy a game. Expertise in this area is reflected in designing the accessible input controls for my game.

Foreseeable Challenges

Next, expected challenges will be discussed, followed by a few techniques and concepts that needed to be researched. The first major expected challenge was to extend autonomous movement of my fish with player input. For this challenge, I had to collect more information about behavioral animation and to review the mathematical concepts behind it. The second challenge was to design additional play activities with fish. How to play with fish inside a video game? Afterall, human interaction with fish is very limited. For this challenge, I needed to learn more about fish behavior and collect more information about special animal abilities in video games. The third challenge was to design motion/animation for the fish school. For this challenge, I needed to collect more information about principles of animation and computer graphic techniques for shape transformation.

Extending Autonomous Movement with Player Input

Player input refers to the instructions a player sends to the game, typically using devices such as a mouse, keyboard, joystick, or gamepad—pressing the left or right button causes the on-screen character to move left or right. But in computer graphics, fish schooling behavior is not created by player input, as a player cannot control every single fish all at once. Instead, fish schooling is simulated with behavioral animation, which defines rules for each fish to follow. The rules are to stay close to one's neighbors, go in roughly the same direction as them, and don't run into them (Reynolds, 1987). The combination of these rules results in a schooling effect without player input, hence the name *autonomous* movement. But a game must have player input, which seems to be the antithesis of autonomous movement, hence the challenge.

Designing Additional Play Activities with Fish

Human interactions with fish are often associated with fishing for wild fish and feeding aquarium fish. A lot of aquarium fish learn quickly, associating environmental stimuli with feeding opportunities (Barretoo et al, 2018). Detecting stimuli of human movement, aquarium fish will come to the front of the tank and appear to eagerly await feeding. Another human-fish interaction takes place when scuba divers become immersed in the fish world and have close contact and/or interfere with fish movement. Nevertheless, not many play activities exist between human and fish in the real world, and it seems challenging to design such activities.

Creating Animations for a Big Fish Shape Formation

In my game, the fish have the ability to come together and collectively form the shape of a big fish that has its own behaviors such as fanning its tail and turning to different directions. It is challenging to implement these behaviors, as they require specific animations, made by the movement of each individual fish.

What Each Chapter Contains

The next chapter first examines games that are in the same genre as my fish migration game, and their successful and recuring attributes that are influential to me.

The chapter then discusses salmon migration as it occurs in nature; the natural event serves as the background story of the game. The chapter then covers video game characters' *special abilities* found in existing games, which have influenced me to design special abilities for my fish. The next part is about other peoples' prior works on programming fish behavior and school formation. The chapter ends with a brief discussion of a digital pet keeping game called *Tamagotchi*, because it is full of inspiring play activities with digital animals.

Chapter three summarizes the concept of my project, and how it developed from prior works and research topics in my Design MFA program. I compared my own works with influential works of other scholars to showcase similarities and differences. While the previous chapter covers influential works, the Concept Development chapter talks about how they inspired my project. Specifically, chapter three covers how I developed the idea of creating a game in which the player plays with fish in a migration journey.

Chapter four is about the design process and technical implementation of my fish game. The visual design of individual fish is the first topic. Previous discussions about tradeoffs between realism and feasibility are applied to create a simple fish design capable of showing fish movement and eliciting players' emotional response. The next part discusses the visual design of the big fish formation. Design choices are made to ensure the formation can be recognized as a fish, while minimizing the number of small fish needed to maintain adequate game performance.

The chapter then moves on to the behavioral animations I created, which are used to animate the big fish formation. The animations include forming, tail fanning, and turning to different directions. They are visually pleasing, stressing the big fish as a live, flexible formation. Next, chapter four covers how I designed the specific play activities between the player and the fish, which is the primary goal of the game project. After that, other supporting aspects of my game are presented, such as how I chose the camera angle and how I designed the game's input control with accessibility in mind. Input control refers to how the player uses input devices to communicate with the game.

Chapter five serves as an oral description of my game, for people who do not see or play it. It is written as if I am narrating while playing through the game. Chapter six reviews digital animals in existing games, to showcase the animals as important building blocks to create immersive game worlds. The analysis of successful examples helps justify my effort to design play activities with animals. Chapter seven evaluates my research by listing what I have done to meet my research goals.

Chapter 2. Background

In this chapter, I will be introducing major inspirations to my game project, including other video games and fish activity in nature. This will provide the necessary background knowledge to understand how I designed my game based on fish migration. First, I'm going to talk about particle effects, a recurring theme in this thesis, what the term refers to, and what I mean when I use it. Next, I will talk about video games that are influential and inspirational to me, paving the way for later discussions about what I specifically learned from them. Next, fish stories in nature are presented, because they serve as the background of my game. After that, prior computer graphics work on fish simulation are presented, as it supports the technical implementation of my game. Finally, a pet keeping game is analyzed to learn about interesting interactions between the owner and the pet.

Particle Effects

This thesis uses the term "particle effects" generally to describe the collective movement of objects. Usually for viewers to perceive something as particle effects, they need to see numerous members moving together in a group, where the group's movement overrides that of the individual. For example, this thesis describes fish schooling as particle effects. When people see fish schooling in a tornado-like formation, they typically pay attention to how the formation swirls, while ignoring, for example, how each individual fish moves its tail.

The thesis also uses the term *playable particle effects*, which can be understood as the result of the player actively making, contributing, or influencing the particle effects. For example, the seeds of a dandelion can be used to create playable particle effects, since whoever is blowing onto them can control the blowing intensity, interval, and direction. In my thesis project on fish migration, the movement of the group of fish makes playable particle effects, since the player can influence the movement.

Major Game Influences

Gathering Sky

Birds flocking and fish schooling are wonderous effects to watch. Looking for games that make use of a flocking/schooling effect, I found *Gathering Sky* (Pontoco, 2015), where the player gets to assemble a flock of birds and guide them over various environments, eventually arriving at a spiritual tree that is their ancestral home. *Gathering Sky* uses a top-down camera perspective, through which the player sees the back of the birds as they flap and spread their wings. The ariel view also inspires a sense of grandeur, showing the vast earth down below. The birds fly over green meadows, golden waves of grain, milky forests of stone, and ride winds of rainbow. At one point in the journey, the sky darkens, and an eagle cries, swooping down and breaking the flock into pieces. All the companions fade away behind clouds. When the storm recedes, the birds find their way back together again and reshape the flock, leaving behind them traces of white clouds. With scenic backgrounds, beautiful music, and playable particles that are the birds, *Gathering Sky* is a relaxing, interactive game/visual effects experience. It strengthened my desire to make a game about fish migration.

Journey

In *Journey* (Thatgamecompany, 2012), playing as a character wearing a cape and a scarf, the player goes on a pilgrimage through deserts, deep ocean, and snowy mountains, eventually arriving at the long-desired mountain summit. Notably in the game, the player collects glowing glyphs to extend his or her scarf, which holds energy for the character to fly. The longer the scarf, the more energy it can hold, and the higher or farther the character can fly. When flying, the scarf undulates gracefully, creating yet another beautiful visual effect.

Gathering Sky and *Journey* share three influential themes. One is the journey through different environments while overcoming difficulties. The other is the theme of growth, exhibited in the growing number of birds in the flock and the scarf growing longer. The next chapter, Concept Development, will cover how the two themes are applied in my project.

Influences from Natural Phenomena

Nature is a great teacher. My game project is also inspired by the *Great Salmon Run*, the annual migration of billions of salmon, from the northwestern Pacific Ocean to freshwater streams where they themselves were hatched (Attenborough, 2009). With exceptional navigation ability, they travel up to a thousand miles inland, often back to their exact birthplaces. The salmon are relentless, determined to go home despite the difficulties along the way. Sharks from the ocean, eagles from the sky, and starving bears woken up from hibernation are all eager for the salmons' arrival. The laws of physics also work against the salmon, as they are in an upstream journey, swimming against the currents. Stranding is yet another problem, as the water level in freshwater lakes and streams varies greatly depending on the amount of rain in the area. Stranded salmon must wait in shallow water deprived of oxygen, until the next rainfall comes to raise the water level. When it rains, it pours, creating strong torrents and waterfalls for the salmon to swim against and jump across. On the vantage points of the waterfalls are ravenous bears with their mouths wide open… Salmon migration tells a touching story, strongly influencing my game project.

Overcoming the difficulties, the surviving salmons finally arrive at their birthplaces. Most Pacific salmon (*Oncorhynchus* spp.) are semelparous, meaning that they die after reproducing, making the ultimate sacrifice for the next generation. When salmon eggs hatch, newly spawned salmon known as alevins emerge. Alevins have yolk sac attached to their bellies. The yolk sac serves as the initial source of nutrition. Alevins usually hide in the crevices of gravels. When alevins exhaust their yolk sac and begin to feed on their own, they enter the next developmental stage known as fry. Salmon fries live in freshwater for up to two years until they migrate into the ocean. When salmon are about to enter the sea, they are called smolts, with silvery color on the body as a disguise, to hide from oceanic predators. Salmon spend most of their adult life in the ocean, where they gain most of their body weight. Roughly at age seven, salmon swim again to their birthplaces. Breeding salmon go through yet another transformation, with red color on the body, humps on the back, and hooked nose. (Pacific Salmon Foundation, 2021) When salmon go back home, they carry with them the nutrients, the body mass accumulated from the ocean. The nutrients feed and fertilize the ecosystems along salmons' migration journey (Attenborough, 2009).

Influences from Special Abilities in Video Games

Video game characters' special abilities are like superheroes' superpowers in comics and films. Characters with special abilities are usually powerful and memorable. This section discusses a game that has successfully implemented a special ability for its character, which gives rise to a great number of additional play activities. The example gave me the inspiration to design a special ability for my fish, as a vehicle to introduce more play activities with my fish.

In *Super Mario Odyssey* (Nintendo, 2017), Mario has the special ability to occupy the body of a creature by placing his cap on its head. Occupying the bodies of friends and foes, such as a T-rex, a missile, and a fish, Mario can become a ferocious dinosaur to tear down any obstacles on the way, a missile to fly across canyons, and a fish that can swim swiftly and stay underwater forever.

In total, the game includes 52 creatures that Mario can embody with his cap, which means that the one special ability has enabled at least 52 different play activities that Mario can engage in. This massive amount of play activities not only created a rich gaming experience, but also inspired me to design a special ability to enrich the player's play activities with my fish

Influences on Fish Group Formation

Finding Nemo (Stanton, 2003) makes use of beautiful fish group formation. The film reinforced my idea to create shape formations with my fish. In *Finding Nemo,* the protagonist Marlin, a clownfish, was looking for his missing son Nemo. At one point, he ran into a school of fish that had recently seen Nemo and knew where he was going. The school of fish communicated with Marlin by forming explicit shapes, such as Nemo (Fig. 1) to confirm that the fish they had seen was indeed Nemo. Similarly, they also formed an arrow to point the way Nemo was going, and then the shape of the Sydney Opera House to indicate Nemo was on his way to Australia.

Figure 1: a group of fish forming a fish shape

Rather than *verbally* communicating, the fish school in *Finding Nemo* created morphing shapes that were delightful to watch. Although I did not explicitly acquire this idea from *Finding Nemo*, the film demonstrates a successful implementation of fish school shape formation. The beauty and creativity strengthened my idea to create playable particle formations.

Notably, however, the shape formations in *Finding Nemo* are static—the Nemo formation does not have animated fins or other bodily motions. But to make a playable, *moving* fish formation in the shape of a bigger fish, the formation needs to have moving parts such as fins and tail animated by the movement of each individual fish. Chapter four covers how I accomplished this.

Computer Graphics Precedents of Fish Behavior

Fish Schooling Behavior Based on Craig Reynolds' Autonomous Characters

Computer scientist Craig Reynolds (1987) proposed algorithms to simulate the flocking behavior of birds. Reynolds calls each bird in his simulation a *boid*. A boid is programmed to have a limited sensory region. Other boids inside the region are known as neighbors. Each boid is influenced by its neighbors. Reynolds' *flocking* is a composite behavior emerging from three individual behaviors: *separation*, *cohesion*, and *alignment*. *Separation* keeps each boid away from its neighbors, avoiding collisions. *Cohesion* keeps each boid within a certain distance of its neighbors, so that they stick together. *Alignment* makes each boid turn towards the average direction of its neighbors, so that the group tends to move in the same direction. With each boid detecting its neighbors and following the three rules, flocking behavior emerges.

In addition, Reynolds (1999) also programmed behaviors such as *path following* (boids follow a pre-defined path), *leader following* (boids follow a leader), and *doorway queuing* (boids line up at a doorway and pass through orderly). Following these behavioral rules, characters will move autonomously in a virtual environment, with little input from the animator. Not only do these behaviors create visually engaging particle effects, but they are also AI techniques that represent boids (or fish, or birds) as seemingly intelligent beings. In game programming, "AI" is often used to refer to the rules that control where, how, and when autonomous agents move. I implemented

Reynolds' AI techniques to make my fish into autonomous agents that the player can play with.

Other Notable Works

Amkraut and Girard (1985) demonstrated a behavioral animation of birds flocking. Multiple forces of different directions and strengths were applied to the birds' bodies to achieve ideal orientation, direction, and speed. The same underlying principles can be applied to simulate the schooling behavior of fish. Reynolds (1987) cited Amkraut's flocking as a predecessor and credited it as the first simulation of flocking using behavioral animation.

Tu and Terzopoulos (1994) simulated fish behavior more realistically by implementing physics-based techniques. They modeled their digital fish with pectoral fins, the fins on the side of some fish, to propel the body. Deformation on the fish's body and hydrodynamics are also considered to calculate the fish's movement direction and speed.

Computer graphics works have also been done to simulate the common swimming styles of different fish species (Satoi et al., 2016). For example, salmon belong to a family of fish called *salmonids*. Salmonids move their bodies in S-shape when they swim, with muscle contractions starting mid-body. In comparison, *batoids*, the family of fish commonly known as rays, have a different swimming style. In total, Satoi et al. simulated twelve swimming styles of fish, with differences in the how, when, and which parts of the body move. Since the twelve styles account for most of the behaviors observed in nature, they can be used to simulate the swimming motion for most fish species.

Tamagotchi

The chapter ends with a brief mention to the popular digital pet keeping game *Tamagotchi* (Bandai, 1996), because it is full of inspiring play activities with digital animals. *Tamagotchi* is hosted in an egg-shaped, hand-held, pocketable gaming console. The gaming console can often be seen attached to one's backpack or keychain, because Tamagotchi the pet is designed to be played with regularly.

The life cycle of a Tamagotchi usually starts with him or her hatching from an egg. As the game progresses, the player engages in activities such as feeding, discipling, providing sweet treats, sightseeing, and playing with other pets, all on regular intervals to keep one's Tamagotchi happy and healthy. Each of the activities has depth to it. Feeding too little results in the Tamagotchi being hungry and unhappy, while feeding too much results in the Tamagotchi being sick. The Tamagotchi can be disciplined when it misbehaves, such as asking for food when not hungry and refusing to take medicine when ill. Rich in play activities with the pet, *Tamagotchi* has been successful at eliciting players' emotional attachment. When Tamagotchis pass away, owners mourn their beloved companions. The owners write poems and obituaries and build and visit virtual graveyards to commemorate their time together (Wrye, 2009).

Chapter 3. Concept Development

The concept of my thesis video game project is to lead a school of fish along their migration journey. To control the fish, the game uses both player input and an autonomous AI technique (behavioral animation). This enables the investigation of the research question about how to use behavioral animation to create playable characters/particles in a video game. Since the game makes players play with a group of fish, to journey through different places and overcome various difficulties, it also enables the investigation of the research question about how to design play activities. These activities are different from the traditional killing and hunting digital animals, so that the interaction becomes more representative of the multi-faceted human-animal relationships in the physical world.

How Previous Works Led to This Thesis

This section discusses works I developed during my graduate program and how they led to the research presented in this thesis. During the program, I discovered my interest in particle effects—their wonderous beauty and the intriguing rules responsible for their formation. Be it watching snowflakes illuminated by the streetlights at night or gazing at the fireplace where each flicker of fire looks ever so similar yet different from another, particles effects are often calming and relaxing to look at. To explore particle effects as a relaxing art style, I have made simulations of snowflakes, orbiting stars, and tree leaves floating in the sky. As a fish lover, previously in the graduate program, I created colorful patterns on a koi fish's body (Fig. 2). Later, still using fish as a source of inspiration, I learned about the particle effect of fish schooling in computer graphics and implemented it in a virtual home aquarium (Fig. 3) containing fish swimming and schooling.

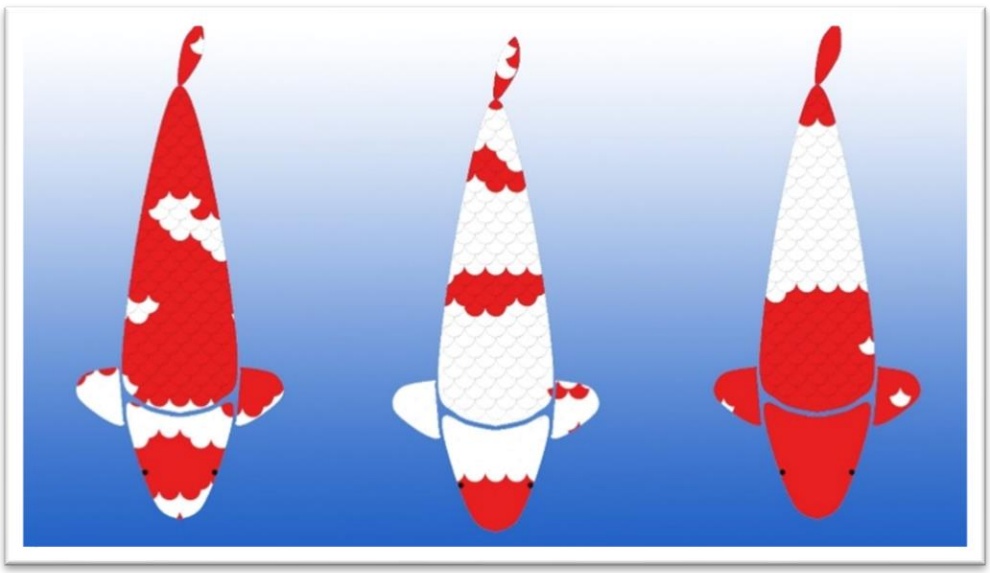

Figure 2: creating color variations for koi fish with computer algorithms

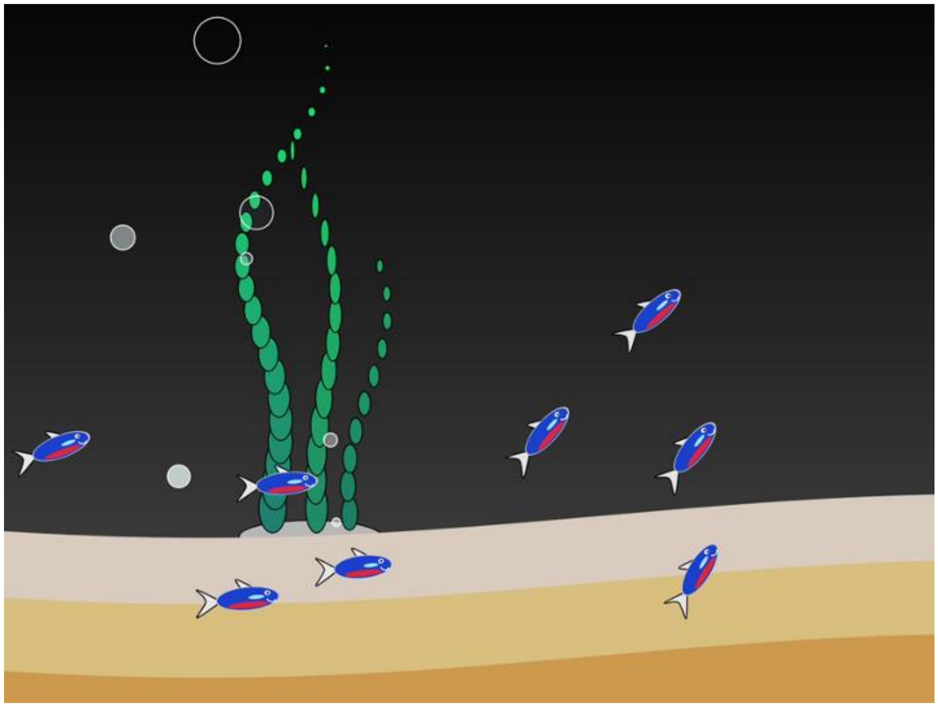

Figure 3: virtual home aquarium

In my virtual aquarium, water bubbles rise periodically, plants undulate, and fish swim leisurely. This scene was created with the goal of making an animated, relaxing environment. Following this thread, I searched for therapeutic values of particle effects—whether viewing the collective, rhythmic movement of objects might bring any health-related benefits. Studies have been done to measure visitors' physiological parameters after aquarium and zoo visits (Sahrmann et al., 2016), as well as the effects of interacting with aquarium fish on human health and well-being (Clements et al., 2019). I also studied other related topics such as *biophilia*, the hypothesis that people have an innate desire to connect with nature, plants, and animals (Wilson, 1984), *palliative care*, the special care to improve quality of life for patients who are likely not able to recover from illness (National Institutes of Health, 2021) and *fireworks*, and why so many people are enamored with them.

However, I soon discovered that, as a distinctive field, therapy does not align with my interests in the artistic and computer graphics aspects of particle effects. Seeking a research topic relevant to personal interests, I came to interactivity—*playable* particle effects. The home aquarium is indeed a place where the owner gets to interact with fish by feeding, changing water, and decorating the space. Therefore, I made my virtual aquarium interactive, by adding player-controlled states to the fish, the player could let the fish roam freely, gather at the water plants, or follow the mouse cursor. I also added the ability for the player to click on the screen to drop food for the fish. These interactions enabled the investigation of the broad research question of how to design playable particle effects.

Essentially, I was making an aquarium *simulator*. Simulators are a popular genre of digital interactive media, for entertainment or training purposes. There are plenty of examples, such as flight simulators, both for aviation enthusiasts and for pilot training. I thought my virtual aquarium could be used for fish care education, to correct common mistakes such as overfeeding and overstocking. Since a home aquarium is a closed space, putting in too much food and having too many fish quickly pollutes the water to a toxic level. It was at this time that I started to connect the dots between particle effects, fish schooling behavior, and caring for fish and animals in general.

But I was not very interested in making an aquarium simulator for fish care education—I wanted to make a video game. Looking for potential research opportunities with this more defined scope, I found that video games had traditionally designed animals as monsters to fight or moving resources to collect. Then, I made considerable efforts to learn about philosophies of animal ethics and to argue that video games' common portrayal of animals is morally objectionable. But to pursue that route, I would need to focus more on writing a philosophy thesis rather than making a video game. Therefore, I refocused to look at the issue from a design perspective. Ranging from the turtle enemy in *Super Mario Bros* (Nintendo, 1983) to the central character in *Tamagotchi,* digital animals serve different purposes in different games. In each case, designing the interaction involves deliberate decisions. I am particularly interested in non-killing, mutual play activities with digital animals. Eventually, I arrived at the project presented in this thesis, a game about fish migration, a fertile ground on which I can design play activities with the fish and create particle effects with their group movement.

Compare the Project Concept in Relation to Existing Works by Other Creators

This section talks about how my project was influenced by *Gathering Sky*, and how I adjusted direction and carried out my project to meet the goal of designing play activities that can be done with the fish. The most influential work to me, *Gathering Sky*, is about controlling a flock of birds across the sky. Influenced by *Gathering Sky*, I made an early prototype of my game controlling a school of fish across a water environment.

To create a novel experience and to fulfill the goal of designing additional play activities with my fish (digital animals), I came up with the idea of making a special ability. The Background chapter introduced the term *special ability*, a unique, outstanding ability that a specific video game character can deploy. This section discusses the special ability in my game and how it is relevant for the research goal.

One significant difference from the birds in *Gathering Sky* is that my fish have a special ability that I call *shape transformation*—each individual fish gathers to form a big fish shape. My big fish shape is especially designed to be a live, flexible formation. After the fish gather to form the big fish shape, they can maintain this formation and move together while holding the shape of a big fish.

This special ability of shape transformation creates an intersection between playable particle effects and play activities with my fish. It creates three particle effects, which I call *Form, Tail Fan, and Turning*. The effects correspond to the movement behaviors of the big fish shape. The special ability creates play activities with my fish by giving them superpowers to overcome various challenges, such as predators and strong currents strengthened by torrential rain. Other possible future usages of the special ability include gathering the fish together to intimidate predators and forming hydrodynamic arrays to reduce water resistance when swimming upstream.

Game Adaptation of Background Stories

Fish stories in nature and in folklore could provide fertile grounds for a video game to flourish. This section discusses the game adaptation of background stories, with special consideration of my research goal and game design theories.

Salmon's Journey Home

Previously I talked about *The Great Salmon Run* as it occurs in nature. This section talks about how I adapted it into my game. Most Pacific salmon are born in freshwater but gain most of their body weight in the ocean. They go to great lengths and overcome great difficulties to return to their birthplace. Along the way, there are cycles of encountering an obstacle, overcoming it, and then enjoying a period of peace and relaxation until the next obstacle. The cycles taken from salmon's journey align with the *flow state* (Csikszentmihalyi, 1975) in psychology and video game design theory. Flow state theory suggests that a video game should neither be too easy and make a player bored, nor too hard and make a player too stressed, but instead have a steady progression from relaxation to tension and back to relaxation. Such cycles supposedly keep the players engaged.

In salmon's journey home, they are going to run into coastal predators, get stranded in shallow waters, and must swim upstream against strong currents when rain elevates the rivers. Salmon even have to jump over waterfalls, where hungry bears wait, with their mouths wide open, ready to feast. But between each difficulty is a time of relative relaxation. Since the flow state occurs naturally in salmons' journey, I decided to take advantage of it and make it into the game (Fig. 4.). My game currently covers the journey until the salmon enter the river, with some prototypes made for later events, such as swimming against torrents and jumping over waterfalls.

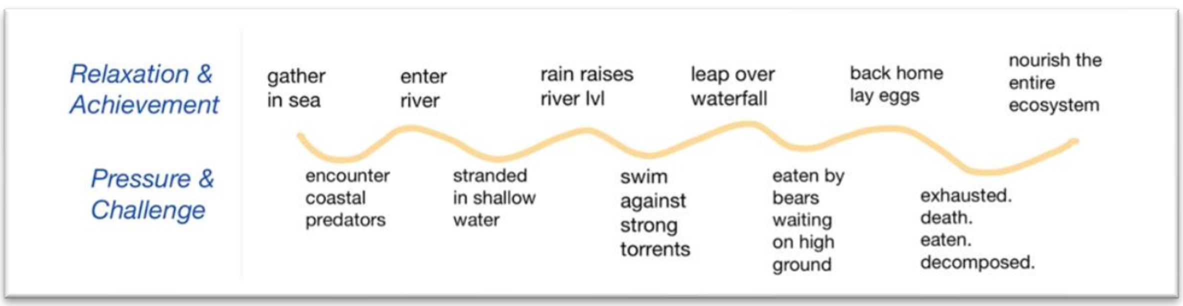

Figure 4: reviewing salmon's story in the context of the flow state theory

Koi Jumping over the Dragon Gate

When choosing the background story of the game, other fish related stories were considered, with illustrations and prototypes made for testing. This section covers this process and talks about how I made final decisions.

Chinese folklore tells a story of koi/carp jumping over the Dragon Gate and becoming dragons. Like the story of the salmon, koi fish must overcome numerous obstacles before reaching the Dragon Gate. Each koi fish tries its best to jump over the gate, but few succeed.

From a marketing standpoint, games with Chinese elements would appeal strongly to the Chinese market. Having played mostly foreign made games for over three decades, gamers in China eagerly support games with Chinese elements. Because such games are relatively rare, Chinese media outlets are always on the lookout to report them, thus providing a potential marketing advantage for my obscure, personal project. Having grown up in China, I would also like to make use of and spread my cultural heritage. I seriously considered this idea and worked with artist Latesha Merkel for fish and environmental sketches imitating a Chinese watercolor painting style (Fig. 5).

Figure 5: attempting to paint with a Chinese watercolor painting style

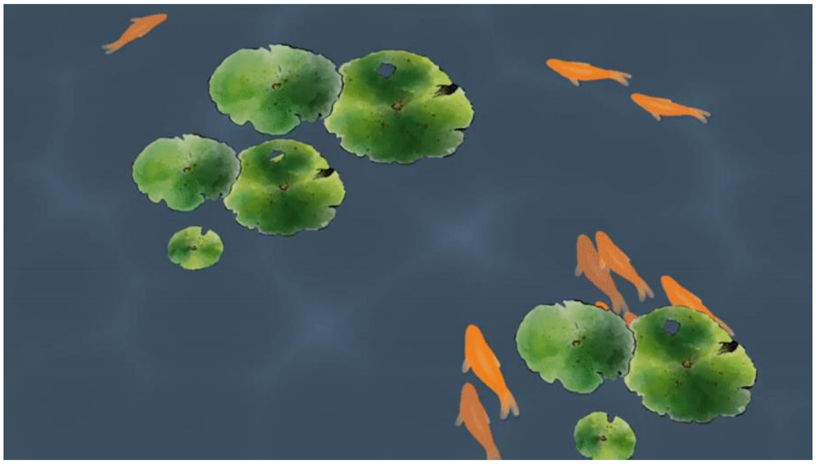

Figure 6: koi pond

I also assembled a game environment with these art assets (Fig. 6). But learning, implementing, and supervising the art style turned out to be not only too time-consuming, but also not relevant to the topic of this research paper. Eventually, I chose salmon migration as my background story, so that I could focus on designing play activities with fish, rather than a particular art style. Like koi in Chinese culture, it is worth noting that salmon play an important role in the culture of some indigenous peoples of North America (Campbell & Butler, 2010). The human-fish connection in a cultural context is a promising background for future video game projects.

Chapter 4. Process

This chapter talks about the design decisions and technical implementation of my fish game. As the entire game revolves around my fish—their migration, their seemingly intelligent behaviors, and their interaction with the player— the chapter begins with my design decisions for the visual appearance of individual fish and the big fish shape, the approaches to animate the big fish shape, and how to illustrate the fish as independent beings that the player can play with. All the decisions were made with strong consideration of my research goals. The chapter then talks about other supporting aspects of my game, such as how I chose the camera perspective, designed the game map to be suitable for the fish behaviors, and how I designed the game's input controls with accessibility in mind.

Designing the Individual Fish Shape

Preliminary Concept

My game on fish migration required designing the visual appearance of the fish. The fish shape started as a simple arrow (Fig. 7). Its simplicity and clear indication of direction enabled me to visualize all the movement behaviors. The simplicity does bring one problem: It fails to indicate viewing perspective. Players cannot tell if they are looking at the arrow fish from above or from the side, as the same shape could indicate either perspective. Also, the arrow shape does not look like an actual fish. Therefore, I

Figure 7: a simple arrow representing a fish

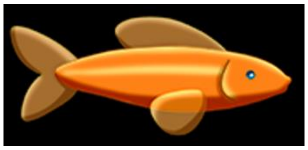

Figure 8: the second, more realistic fish design

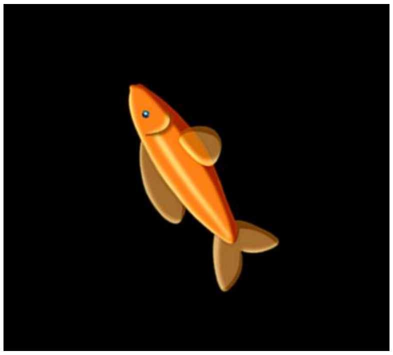

Figure 9: fish upside down

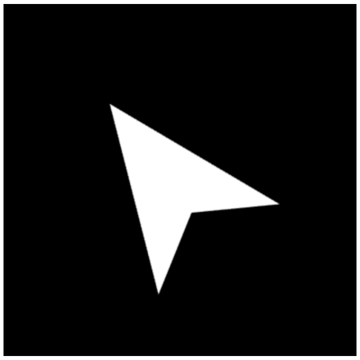

Figure 10: the arrow does not look upside down

proceeded to design a more realistic fish shape that also indicates viewing perspective.

A More Realistic Fish Look

Working with the artist Latesha Merkel, I came up with a design that is easily recognized as a fish (Fig. 8). But a more realistic fish design ends up creating more problems. My existing fish movement algorithm does not prevent the fish from being upside down (Fig. 9), which looks jarring and nonsensical. A more sophisticated rotation algorithm would be needed to define the limits.

Another problem quickly ensues—pathfinding. Previously, if an arrow shape fish was going somewhere above itself on the screen, it could directly rotate towards the destination then move towards its destination. But a fish, like an airplane (which I'll use as an analogy) is under rigid constraints of physics. If an airplane needs to fly to a point above its current location, it cannot just tilt up 90 degrees and fly straight up. Instead, it must take a detour while climbing up. The process is more like driving on a winding road around a mountain, gaining height with each lap. Similarly, for the asymmetrical, more realistic fish design to work, a pathfinding algorithm must be in place to calculate more physically realistic paths.

I attempted to implement pathfinding algorithms such as *Bezier curve path planning*, *navigation mesh*, and *A**. But these algorithms can be quite complex, and the endeavor quickly went beyond the scope of this thesis. Therefore, I paused, instead looking for alternative approaches to avoid this issue.

The problems that come with a more realistic fish shape do not end here. According to the hypothesis of *The Uncanny Valley* (Mori, 1970), artificial representations of humans and animals usually gain more appreciation from human observers as they become more realistic; but as they become very close to being indistinguishable from real humans, even minute discrepancies will likely break the façade and make the artificial creature appear disturbing to the human observers. Researchers have found that *The Uncanny Valley* also applies to virtual animals, approaching a higher degree of realism may cause eerie feelings to the human observers

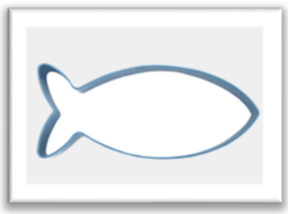

Figure 11: a cookie cutter fish

(Schwind et al, 2018). Such is the case in my second fish design. Although the fish is more "realistic", it looked unintelligent with its static eye. From the perspective of this thesis, infeasibly more effort would be required to animate this fish.

Finding a Balance

Improving upon previous iterations, I selected a "cookie cutter fish" design (Fig. 11), which fulfills the following goals:

1. Simplicity: No extra body parts such as eyes and fins to model and animate.
2. Fish Likeness: It is easily recognized as a fish.

3. Rotationally Agnostic (Fig. 12): Since the fish does not have an upside or downside, it never looks upside down. No rotational constraints or pathfinding is needed to prevent the fish from going upside down.
4. Perspective Indication: The tail shows that the fish is being viewed from the side. This clears the perspective ambiguity of the arrow.

Figure 12: rotationally agnostic

However, this design seems to be the bare minimum of what people would expect from a fish illustration. Is it good enough to fulfill my research goals? Would players be interested in playing with such simple “fish”? Would players develop emotional attachment with these “fish”? Seeking answers to these questions, I searched for animation and video game works with characters made of simple shapes.

Heider and Simmel (1944) studied the human perception processes of other individuals—what stimuli are determinant for our perception of others. Notably, to eliminate factors such as facial expression, body language, and environments, the researchers produced a black and white animation of primitive shapes, namely, a circle, two triangles, and rectangles. Participants were asked to view the 2.5-minute animation and then answer questions about how they interpreted it.

Among the 114 participants, 34 were in the first group and given the general task of "writing down what happened in the picture". Out of the 34 participants, only one described the animation in terms of geometric movement, such as "a large solid triangle is shown entering a rectangle..." Everybody else in the group perceived the animation as a story of live beings—persons, and in some cases, birds. The remaining participants were asked suggestive questions, such as "what kind of a person is the big triangle?" Consistent responses were received again. Participants described the big triangle with words such as *aggressive*, *warlike*, and *belligerent*. It suggests that people can interpret personality from motion of geometric shapes.

Heider and Simmel's animation and my game both use simple shapes to represent intelligent characters. If viewers perceived the shapes in their animation as live beings with their own motives and characteristics, they seem also likely to perceive my simply shaped fish as such. Additional seemingly intelligent behaviors will be implemented, such as pathfinding, to accentuate the fish's sense of direction and strong desire to go home. Emotional attachment between the player and the fish is likely to emerge from their shared experience of going through a migration journey.

Designing the Visual Appearance of the Big Fish Formation

As discussed in the Concept Development chapter, directing the individual fish to gather and form a big fish is the signature move of my game. This section discusses the visual design of the big fish, and how I designed it with the goal of creating a legible aggregation of independent individual fish.

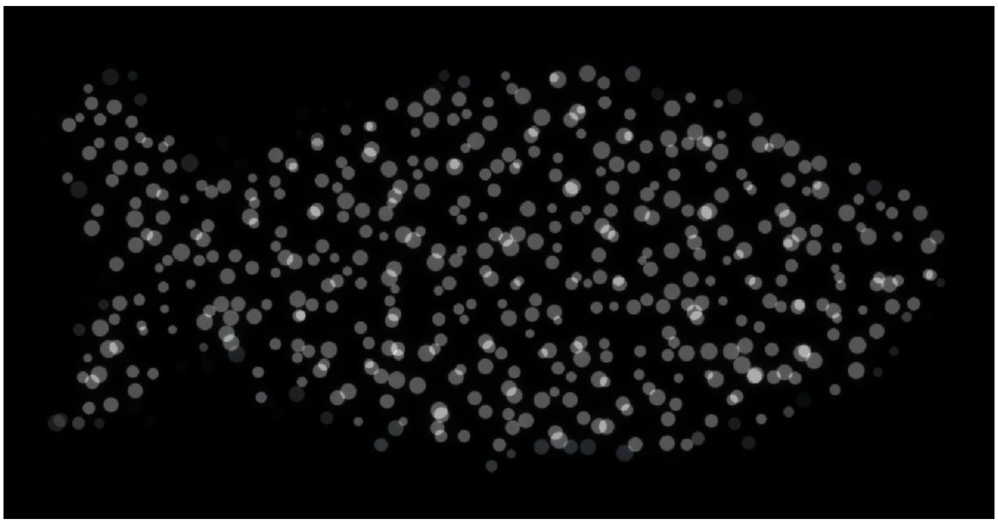

Figure 13: a big fish formation with circles representing individual fish

Shape Legibility

Upon receiving player input to do so, the small fish converge and form the shape of a big fish. To form any shape on a computer monitor, a certain number of pixels are required. Usually, the more pixels, the clearer and more detailed the image. In my fish migration game, more and more fish join the school along the way. With more individual fish acting as pixels, the fish school becomes increasingly capable of forming legible shapes. When a minimum number of fish join the school, they unlock the ability to form the shape of a big fish. Nooks and crannies on the game map are smoothed out, so that the fish do not get stuck and become left behind—they can always come together for shape formation. My first design (Fig. 13) for the big fish's shape was the same as the small fish—the cookie cutter shape. This formation consists of over 500 circles, each representing a small fish. When the game runs, each small fish has their own movement, calculated by the computer. For my game to run smoothly, I needed to keep the total number of fish to less than 200. A formation with less than 200 circles (Fig. 14), however, becomes less legible as a fish. Again, a big fish formation is like pixel art made of individual fish as pixels—it has rough edges. Without the well-defined edge lines on the small fish shape, the big fish in the cookie cutter shape has poor legibility and can hardly be recognized as a fish. Therefore, more defining characteristics must be added to the shape of the big fish formation.

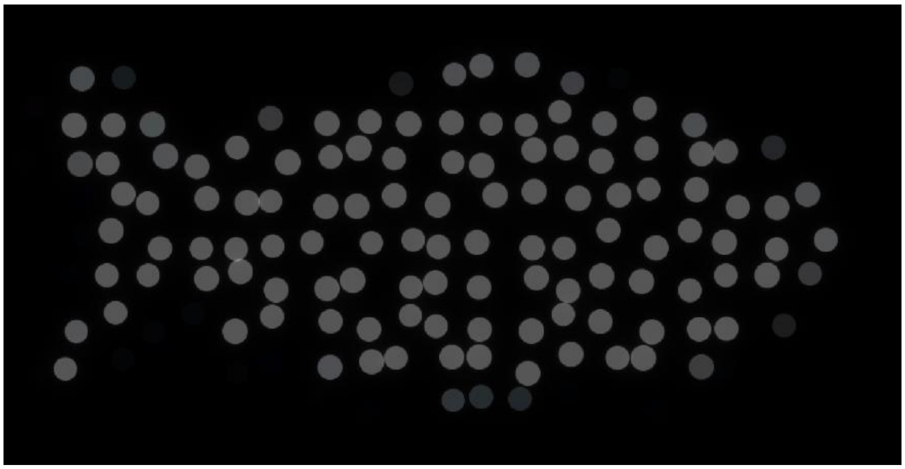

Figure 14: a formation made of fewer circles

Next, I decided to add additional fins, as they are outstanding features on a fish's silhouette. To do so, I re-used the outline of the existing, more "realistic" fish design discussed in the last section. As I expected, including additional fins in the big fish shape indeed made it more recognizable as a fish (Fig. 15).

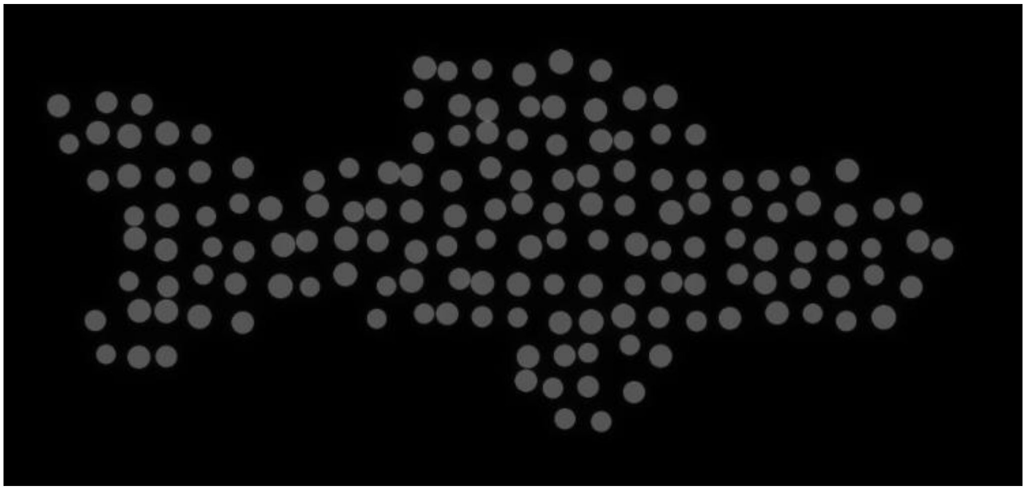

Figure 15: a more recognizable big fish formation

Figure 16: a fish formation with color

Adding Color Variation

With a clearer idea of how the big fish formation should look, I proceeded to add color variation (Fig. 16), because it would give viewers additional visual cues to recognize the formation as a fish. Next, in this iterative process, I designed certain fish in the group to have distinctive colors, such as a darker color for the big fish's eye and on the edges of the body. Emphasizing specific body parts, the color differentiation has made the big fish formation more legible. Then, I put in the actual individual fish shape as I began to finalize the visual design of the big fish formation (Fig. 17). Notice that I also made the dorsal (top) fin bigger, compared to figure 15.

The small fish are designed to have an orangish color because the initial design was inspired by the common goldfish and koi fish, when I and artist Latesha created the koi pond scene (Fig. 6). Later, although I decided to use salmon's migration as the background of my game, I kept this color because it stands in good contrast with the blue water background, making the fish clearly visible. Resembling fish crackers, my small orange fish also bring fond childhood memories. This was an unintended bonus.

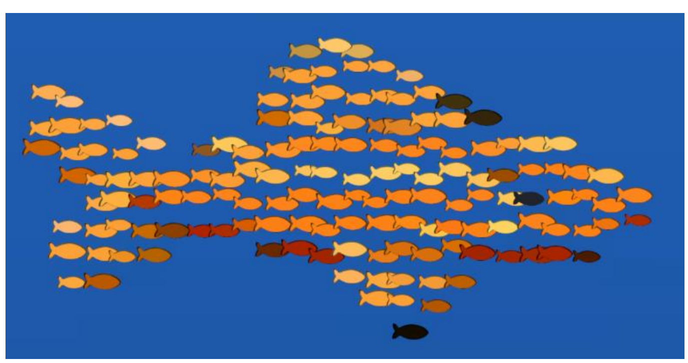

Figure 17: big fish formation made of individual fish, with color

It is worth noting that the sockeye salmon, in their migration journey, go through significant color changes. A sockeye salmon's body is grey/sliver in the ocean, and red when arriving home. I considered imitating this color transition in my game, to make my fish more representative of those in nature. The dramatic change would indicate progression in the game and help players understand the magnitude of salmon's journey, making them emotionally attached to these relentless travelers. In the future, when my game project extends from the current version to covering the entire migration journey, I would like to implement this color change on my fish.

Programming of the Big Fish Shape Transformation and Movement

The school of individual fish transforming into the specific shape of a big fish is the signature move of my game. It makes the game stand out; it is related to the fish school seeking safety together; and it is related to each fish exhibiting a certain degree of intelligence and sensory ability. This section talks about how I designed and programmed individual fish coming together as a big fish and moving together while holding the shape. Specifically, there are three behaviors: *Form*, *Tail Fan*, and *Turning*. The behaviors, detailed in the next section, are intended to show the big fish as a live, flexible formation, rather than rigid points.

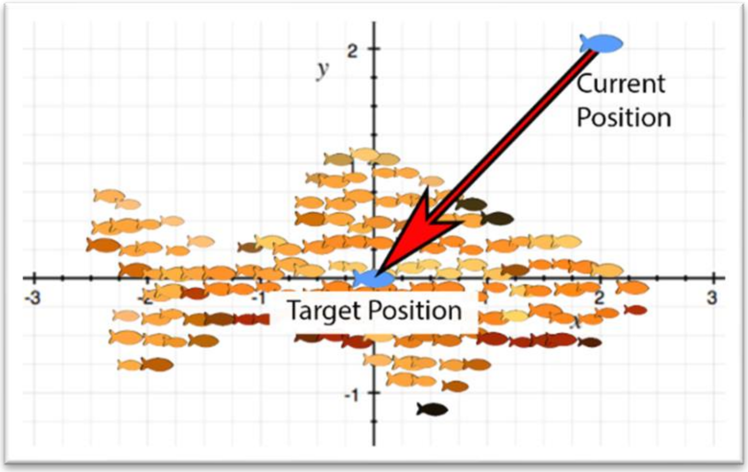

Figure 18: seek force = target position – current position

Review of Behavioral Animation

The computer graphics technique known as behavioral animation is the foundation of how I animated the big fish. Traditional keyframed animation works by specifically defining an object's shape and position at a given time. Behavioral animation works by appling forces that cause the moving objects to move. The moving objects are known as agents. The forces usually either attract the agents to specific target positions, or repluse the agents away from certain positions, such as obstacles. The three big fish behaviors—*form*, *tail fan*, and *turning*—are made by individual fish going to different destinations. Hence, each fish has a destination or a target to go to, which involves Reynolds's *Seek* behavior and *Arrival* behavior. A seek force is determined by the difference between the destination target and the fish's current location. For example, in figure 18, a blue fish (colored for illustration purposes), currently at (2, 2) in the coordinate system, is joining the orange big fish formation by going to its target position at the origin (0, 0). Like number subtraction, to subtract the current position from the target position is to calculate (0, 0) – (2, 2). The result is (-2, -2), which means a seek force that moves the fish two units along the negative direction of the horizontal axis and two units along the negative direction of the vertical axis. Figure 18 shows that to go to its target position, the blue fish should move two units left and two units down. As a fish approaches its target, like a car approaching its destination, a “braking” force is applied to cause the fish to stop when it arrives at the target. My big fish behaviors are achieved by manipulating the position and timing of each fish’s target position.

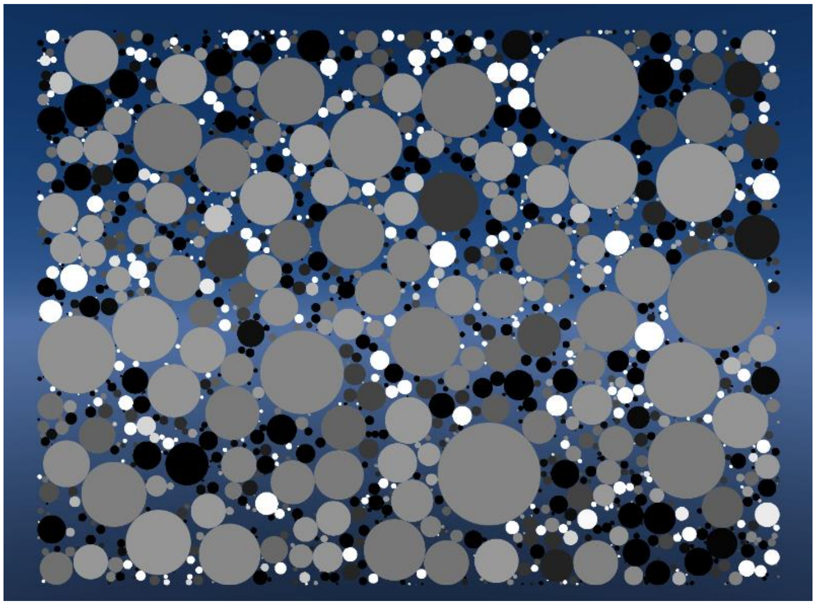

Figure 19: circle packing a rectangular area

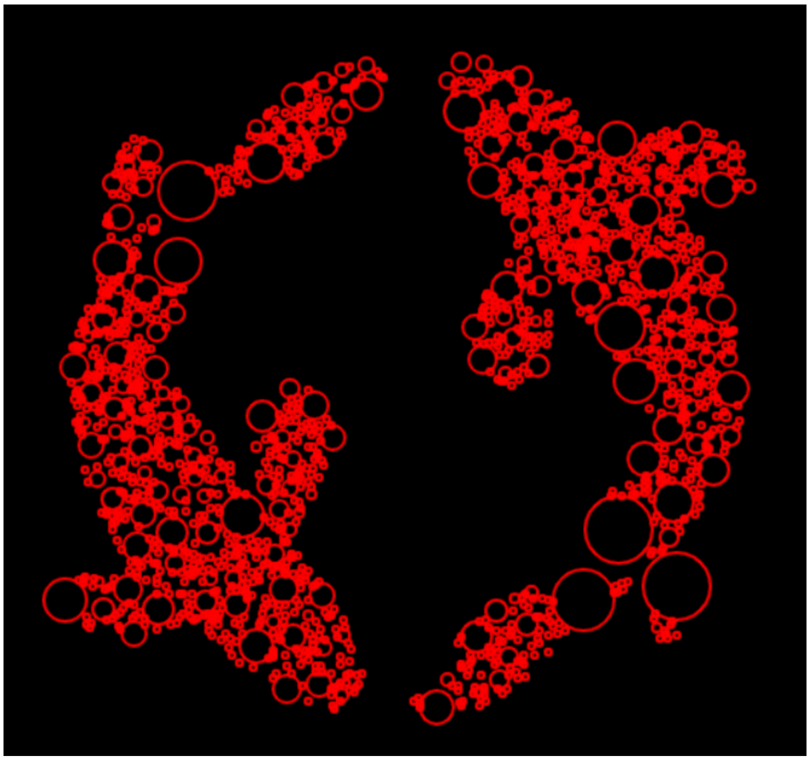

Figure 20: circle packing two koi

Form

Where each fish should be inside the big fish

Previously in the Design MFA program, I learned about a circle packing algorithm—filling a region with lots of non-overlapping circles (Fig. 19). Figure 20 shows a pair of koi fish approximated this way. I defined the filling region in Photoshop beforehand, making them pure black in the reference image (Fig. 21). When the circle packing program runs, it reads the reference image and fills the black region with circles, eventually resulting in figure 20. But having to continuously add new circles and check for overlap, this method is computationally expensive—it causes a noticeable delay at the beginning of the game. To optimize, I could pre-calculate the position and size of each circle, or fish in my case, and then save the results as a file to be read when the game starts. But I chose a more straightforward method. I let the program read the reference image, and inside the filling region, draw a circle, leave a gap, then draw another circle. An analogy would be to use a garden hoe, digging a spot for a plant every 10 inches. The size of the gap is a parameter that changes the plant density.

Figure 21: defining fill and non-fill regions with solid colors.

As mentioned in the previous section, the artist Latesha Merkel made a fish design with a clear silhouette on a black background (Fig. 8). When the game starts, it reads this image, analyzing the color value of each pixel. The game then draws the cookie-cutter-shaped fish at non-black regions. This way, individual fish will fill the colored areas and form the desired shape.

Calculating each fish's formation point as the fish moves

A fish's formation point is the position it should go to form the big fish shape. The previous section talked about how each fish's formation point is calculated when the game starts. Each fish's formation point changes, as the school migrates, no matter if the school moves together in the big fish shape or in the schooling behavior. This can be thought of as a marching band going to different places and form particular shapes at where they currently are. This section discusses the calculation of new formation points, a somewhat complex issue, as the displacement[1] happens on two levels: the individual fish and the group.

[1] Displacement refers to the distance and direction of movement.

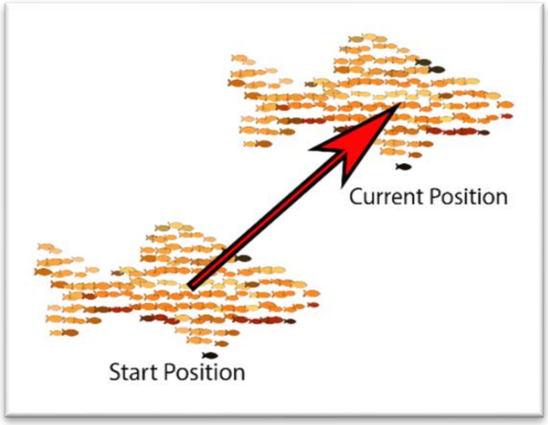

Figure 22: fish group displacement

Think of an airplane inside which everyone has their own assigned seat. When the plane takes off, everybody is sitting in their seat. Sometime later, as the plane is flying smoothly at high elevation, passengers begin to move around, taking a stretch break or walking to the bathroom, like my fish can roam freely—they don't always stay in the big fish formation. The displacement of the plane is at the group level, whereas the displacement of each passenger is at the individual/fish level. Both displacements are needed to calculate each fish's current formation point.

I tackled the fish-level displacement first. When the small fish begin to form the big fish shape, each one goes to its initial formation point. Then, at the group level, the displacement—how far and in what direction the fish group has moved since the beginning—is calculated by the difference between the group's current position and its start position (Fig. 22). Adding the two levels of displacements results in each small fish's current formation point (Fig. 23)—where it should be to form the big fish—so that it can go there from its current position.

```
fish.FormationPoint =
    fish.TargetPosition - fish.CurrentPosition
    + school.CurrentPosition - school.StartPosition;
```

Figure 23: equation for each fish's formation point

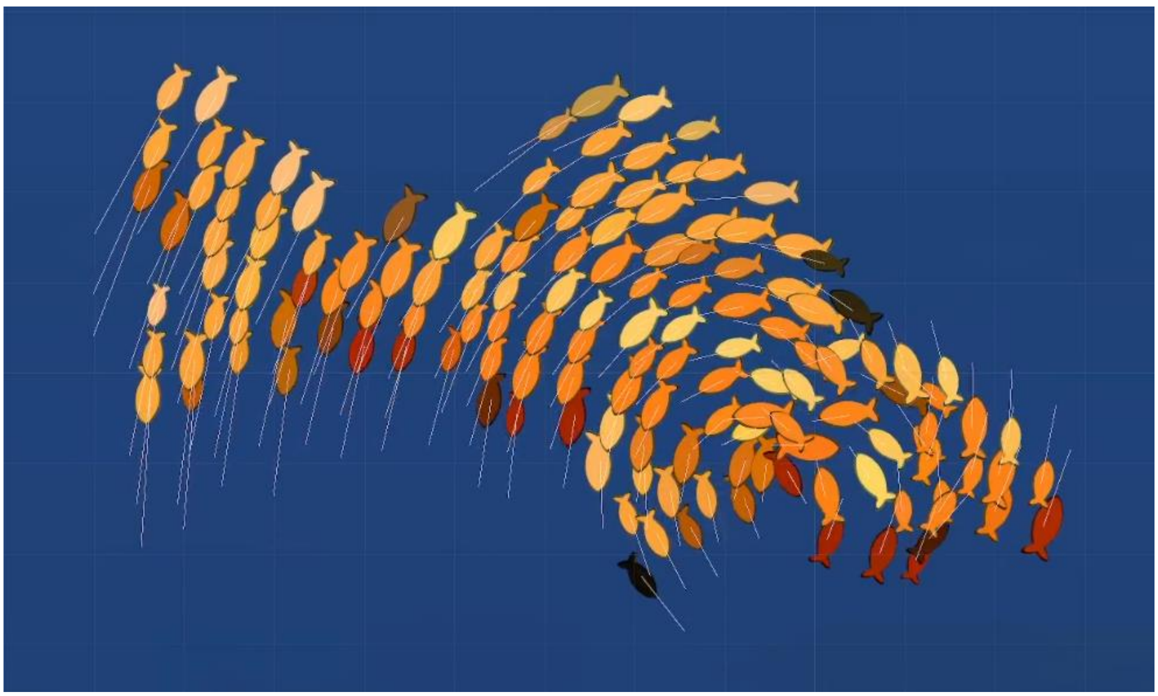

Figure 24: travel distance and direction of each small fish

Tail Fan

I designed the big fish to fan its tail as it moves, to showcase it as a live and flexible formation made of individual fish. The big fish swings its body when it moves forward. On each swing, target positions of small fish on the big fish's tail move by the greatest magnitude, whereas the target positions of fish near the center of big shape move by the smallest magnitude. The difference in each fish's distance to travel results in them arriving at the target point at different times. Figure 24 shows each small fish with a white line indicating its travel distance and direction when performing tail fan. The length of the white line represents the travel distance, and the direction of the line represents the travel direction. Notice that small fish at the tip of tail have the greatest distance to travel. The greater distance to travel, the longer it takes to get there, thus creating the *overlapping action*. Notably, *overlapping action* is one of the principles of animation (Thomas & Johnston, 1981). For example, when an animated character with long hair moves, their hair lags behind. The hair follows a moment later and then does not stop moving immediately when the character stops moving. *Overlapping action* indicates that the moving object consists of different parts, stressing that the big fish is a formation of individual ones.

Small fish furthest away from the center of the fanning motion have the greatest distance to travel. The center is known as the *pivot point*, and it does not have to be at the center of the big fish. If the pivot is exactly at the center of the big fish, the big fish's tail and head will both have the fanning motion, with the same magnitude. When swimming, salmon move their tails more than their heads. To mimic this, the *pivot point* is placed towards the big fish's head, so that the fanning movement is manifested more on the tail and less on the head.

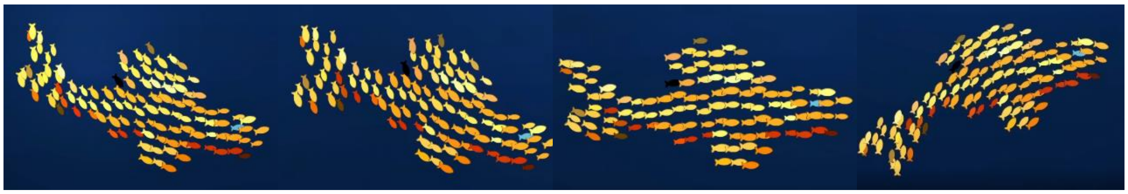

Figure 25: an image sequence of tail fan

When salmon swim, they fan their tails sideways, not up and down. But the tail fan demonstrated here resembles more closely to the tail movement of dolphins. Although unrealistic to salmon's swimming style, I made this aesthetic choice because the up-and-down motion exhibits well in this side-scrolling video game.

Turning

A rotation method is required to turn the big fish to face the opposite horizontal direction, since the big fish shape is no longer rotationally agnostic. Two challenges emerge: how to move all the parts of the big fish 180 degrees to face the opposite horizontal direction, and how to do so incrementally, with *overlapping action*. This section covers how I solved the problem and took the opportunity to create a pleasing animation that once again illustrates the big fish formation as an aggregation of individual parts.

Notice that if I just rotate the big fish shape 180 degrees on the screen, it becomes upside down. What I really need is to mirror the big fish shape. I was able to calculate the mirror positions for each small fish, with a mathematical concept called polar coordinates. To perform the turn, each small fish goes to its mirror position, mirrored around the big fish center. Small fish furthest on the right will become fish furthest on the left. Like the tail fan, since each fish has a different distance travel, they arrive at different times. The big fish moves forward a little bit first to start out the turning behavior. This creates the *overlapping action*.

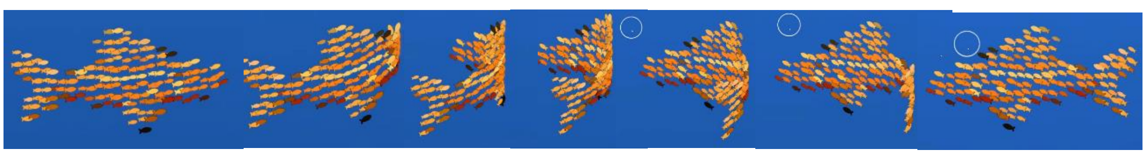

Figure 26: big fish turning process

Pathfinding: Enabling the Fish to Travel by Themselves

This research has the goal of designing play activities with digital animals. The animals must be independent beings and exhibit certain intelligent behaviors, otherwise the player cannot play with them. Pathfinding, making sure that the fish can travel towards their destination without player input, portrays the fish as independent, intelligent beings. Moreover, pathfinding ensures that the fish go forward, with minimum backtracking, to show their strong will to go home. Seeing that the fish are eager to go home despite difficulties on the way, players are likely to become more willing to play with the fish, helping them along their journey.

Unlike pathfinding techniques for steering an agent through complex structures such as mazes, my use case for pathfinding is to send the fish a general direction. Fortunately, one of Reynolds' behaviors, *Flow Field Following*, can be readily used for this purpose. A flow field can be broadly defined as an area in which agents are influenced by external forces. In that sense, the earth is a flow field where everybody is influenced by the force of gravity. I placed flow fields in strategic spots in my game, using their forces to direct my fish. For example, to ensure that the fish go forward, and do not backtrack in a long and winding tunnel, I placed flow fields with forces that match the direction of the tunnel. Once inside, there is always a force to nudge the fish towards the right direction.

However, fully autonomous movement may reduce the impact of the players. If players do not see their actions as impactful, they may not be as interested in playing with the fish. The next section of the chapter covers how I tackled this issue.

Designing Play Activities with the Fish

This research project has the goal of designing play activities with digital animals. This section details this process. Since my game was conceived from the concept of leading a group of fish through their migration journey, the initial play activity is to lead the fish with the mouse cursor. Since the first prototype, I have made it so that pressing and holding the spacebar causes the fish to swim towards the player's mouse cursor. As the project progresses, the simple play activity of attracting the fish with the mouse cursor has acquired more purposes. In addition to being directional, it is also exploratory, and it encourages teamwork with the fish.

As mentioned in the last section, the fish could get to their destination without much player input. Therefore, to encourage player participation, there are hidden treasures scattered across the map. The most important ones are other free roaming fish, waiting to be included in the school. Less important findings include new types of water plants. However big or small, the hidden rewards can only be found if the player purposefully leads the fish to explore the environment.

The act of attracting fish to the mouse cursor also enables teamwork between the player and the fish. When testing to make sure the game works properly from start to end, I often increased the movement speed of the fish, so that I can go through the process quickly. This gave me the idea to slightly increase the fish's movement speed when they are following the player's control. Seeing that the fish swim faster when being attracted makes the player feel that they are facilitating—they are actively contributing a force to the fish in their arduous journey. The extra force can be very helpful in certain situations. For example, when the fish are swimming upstream against strong currents, the fish's forward momentum is nearly entirely lost to the opposing force. When players lead the fish with the mouse cursor, they apply the little extra force that helps the fish overcome the currents. Here, to play with the fish is to overcome difficulties together.

Camera Perspective

The chapter now transitions to other aspects of creating the game, among which is the topic of camera perspective.

Side View

I started with a side camera view, as it is commonly used in 2D games. A side view is good at showing vertical differences. A viewer can get a sense of how tall a building is by looking at it from the side. In my fish game design, the map is planned to cover a wide range of vertical differences, from deep ocean caves to shallow freshwater streams. The change of background water color from deep blue to light blue indicates the progression of the game and that the fish have traveled far and wide. Although not yet implemented, in my plan, one of the climaxes of the fish's journey is to jump over waterfalls. The side view is best suited to show depth and see the vertical movement of the journey, hence the argument for side view.

Top-down View

A top-down camera angle is best for showing the layout of an area. For example, looking at a university quadrangle from a high place is helpful to learn about the area's structure. Such is the case of looking at a koi pond (Fig. 27), which I considered as the starting point of the koi jumping over Dragon Gate story, where the koi are living a tranquil, relaxed life, before embarking on their quest. The term "top-down" here suggests looking downward from a high point. The viewing angle does not have to be ninety degrees, straight down to the objects. Eventually, I did not move along with this camera perspective, since I decided not to pursue this story

Figure 77: koi pond prototype

Designing Game Controls for Accessibility

In the graduate program, I learned about the topic of video game accessibility. The input control design of my game reflects some of my learning. Disability can be categorized as cognitive disability, sensory disability, or motor disability. When playing video games, people with a motor disability may not be able to reach the correct button quickly enough. One-button games address the problem by making the entire game playable with one button. The player can perform different actions by pressing the same one button in different ways, such as press and release, press and hold, and double press.

So far, I’ve mentioned playing my game by pressing and holding the spacebar to lead the fish to the mouse cursor, suggesting the mouse and keyboard as my input devices. Implementing the idea of one-button, I’ve also created control schemes for my game that use just a mouse or a touch screen. Using a mouse, a player plays by moving the mouse and clicking and holding any mouse button. Clicking a mouse button works the same as pressing and holding the spacebar. Similarly, on a touchscreen, the fish are attracted to wherever the player touches on the screen. When the player stops touching, the fish transition to their autonomous state. In all three cases, a double tap, be it on the spacebar, mouse button, or touchscreen, activates the big fish formation. The core idea is to make the game more accessible to players who might have a hard time pressing different buttons (precisely in quick succession).

Chapter 5. Synopses

Short Synopsis

The game shows a group of fish going through an underwater environment, from the sea to the place where the sea meets the river. The game starts in an underwater cave, in which a few fish swim around until the player leads them outside, to start the migration journey. As the game progresses, the player and the fish find more fish to join them, to travel together. With more fish moving together, schooling behavior becomes more obvious. As more and more fish join, the group eventually becomes large enough to enable the special ability to form the shape of a big fish. The player can direct the fish to move either as school or as big fish formation. The big fish formation has its own animations, namely tail fanning and turning to face the opposite direction. Having a greater movement speed than individual fish, the big fish formation allows the player and the fish to escape from a predator.

Long Synopsis

The game starts with a title screen, where circles in orangish color converge to form the word “fish”. Pressing the button “new game” starts the game. In the beginning, a few orangish fish move in an underwater cave. The cave has a circular shape with a boundary wall on the left and an opening to the right. The fish move continuously inside the cave, steering away from the wall and the opening. There is a text prompt telling the player to press the spacebar to attract fish to the mouse cursor. The text fades in and out until the player has performed the action it describes. When the player presses the spacebar, the icon of the mouse cursor, a circle, quickly goes from black to white. The game plays a sound effect, and the fish move towards the mouse cursor. If the game is being played on a touchscreen device like a smartphone or tablet, touching the screen achieves the same results, attracting the fish to where the player is touching. Holding the spacebar keeps the fish attracted to the mouse cursor, while letting go of it causes the game to go back to the initial state, where the fish move autonomously, and the cursor becomes black.

Next, the fish are led to the cave’s opening to the right. The game then shows that the opening of the cave is connected to a tunnel-like structure pointing down and to the right. As the fish move along the tunnel, the background becomes darker and darker, as if the fish are descending to the deep sea. At the end of the tunnel, the environment opens up, showing a larger area. As the player leads the fish to move around and explore the region, the game shows a flat seafloor with plants growing on it. Soon, another group of fish show up. Unlike the existing, orangish fish, the new group of fish are grey, and they are not influenced by the player. The game then shows the player leading the initial group of fish towards the new group of fish. When the two groups come in close proximity, a sound effect plays, followed by the new group of fish transitioning slowly also into an orangish color. The two groups have merged into one, and every fish now responds to the player. With more fish moving together, the schooling behavior, sticking together and moving towards the same direction, becomes more obvious to the player.

The game then shows the school fish moving forward, until an intersection shows up, suggesting that the player and the fish can go either towards the top left, or right. The top left region seems to be brighter, drawing the player's attention, as they move the mouse cursor that way, leading the fish there. The open region narrows down as the fish move further this way. In the end, they find another group of fish and add them to the school. Now that the school has more fish, it becomes more obvious that the fish differ a little a bit in size. While some have a brighter orangish color, a few have a darker color.

Next, the game shows the fish school going back to the previous intersection and proceeding to the right, to another open area. Here the environment becomes darker. As the player and the fish go through the region, they find some additional fish to join them. When new fish join the school, they transition from grey to an orangish color. Eventually, the open area narrows down again, leading to a tunnel pointing to the top right direction. Inside the tunnel are fast moving currents also pointing toward the top right. The currents begin to propel the fish, as they approach. Riding the currents, the fish swim much faster, going through large distances with ease.

At the end of the tunnel, the currents recede, and another large area shows up. The background color of the environment has changed from dark blue to a lighter shade of blue, to indicate that the water has become shallower. Giant kelps appear here, often occluding the fish from the camera. In this open region, the school gets to meet the last free roaming group of fish. With all fish gathered, they have all the individuals needed to form the big fish shape. But the player is not aware of this special ability yet.

The game then shows the open region narrowing down to a small area. Particles show up where the fish are. A text indictor appears on the screen, showing a percentage. The percentage increases as more particles appear, suggesting that there are more particles to be found inside this region. As more particles appear, they can be recognized as a formation of the shape of a bigger fish (Fig. 28). When all the particles are found, the percentage indicator hits 100. A sound effect plays, followed by the individual fish forming a big shape fish for the first time, next to the particles (Fig. 28).

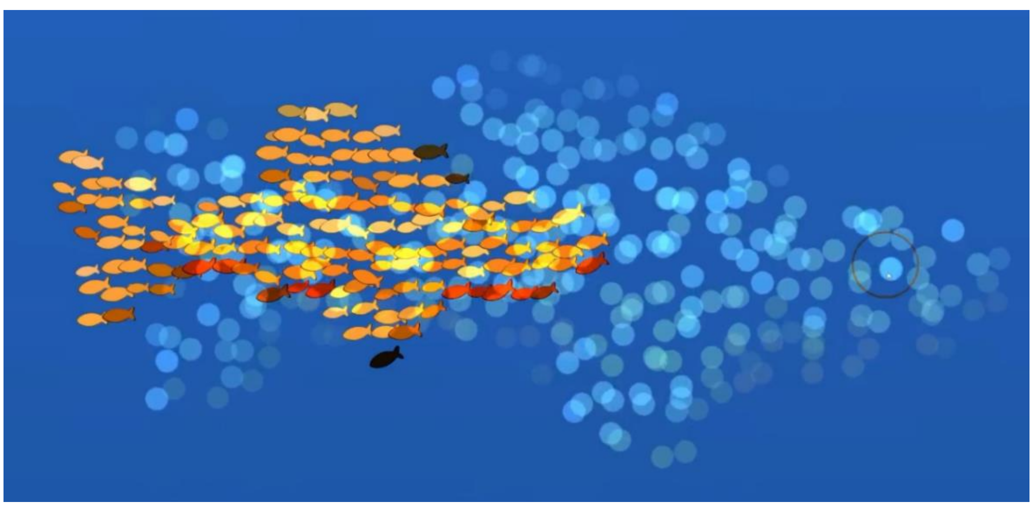

Figure 28: big fish formations made of individual fish and individual particle

The fish hold the position, and a text prompt shows up, telling the player to double tap or double click to activate the big fish shape formation. After the player double taps the spacebar, the big fish formation begins to move. The fish is still attracted to the mouse cursor when the spacebar is held. Double tapping activates and deactivates the big fish formation.

As the player plays with the formation in the next open area, they notice the tail fan animation as the school moves forward while holding the formation. If the player directs the formation to turn to the opposite direction by moving the mouse cursor behind the formation, the formation will turn, showing the turning animation. A large open area is prepared for players to test out the new ability and new animations. I have attempted to program obstacle avoidance behavior for the big fish formation (Fig. 16), but there are still situations when the fish run into and get stuck inside obstacles. So, I made the area big and open to avoid this issue.

In the big open area, players get to enjoy a period of relaxation and test the newfound ability, until the next challenge emerges. The next challenge is to run away from a predator fish. The player needs to activate the big fish shape for each fish to swim fast enough to flee from the predator. But still, the predator inches ever closer. Just when our fish are about to be caught, they squeeze into a narrow tunnel. Once inside, they proceed in an orderly fashion, not moving until the next fish has first advanced and cleared out enough space. To accomplish this, I used Reynolds' *queuing* behavior—every fish waits for the fish in front of it to move first, to portray our fish as intelligent beings.

Too big to enter the tunnel, the predator fish gives up and leaves. And our fish proceed safely forward, at the end of the tunnel is another open area. Here, the seafloor begins to rise, eventually leading the fish to a freshwater river. My thesis project covers the first part of the fish migration journey, from the sea to the river. It is here that the first part of the migration journey is concluded.

Chapter 6: Examples of Evocative Digital Animals

This chapter analyzes evocative digital animals in existing games, in order to provide theoretical support of how such animals are created and how they contribute to the overall digital world.

So far, this thesis has addressed the research question of how to use behavioral animation to create playable particles and also the research question about how to design play activities with digital animals. While they are standalone questions deserving dedicated effort, they are intermediaries that ultimately serve the goal of creating a realistic, *immersive* digital world. The Oxford Dictionary (2022) defines immersive as "a computer display or system generating a three-dimensional image which appears to surround the user". A movie theater with a big screen and dark environment is immersive. A *virtual reality headset*, a pair of goggles that display images right to the user's eyes while occluding vision of the physical environment, is immersive. Beyond its literal meaning, the word immersive also connotes the viewers feeling as if they are really inside the world presented by the display. Watching an immersive film about orcs, elves, and fire-breathing dragons makes the audience feel that they are a part of that medieval fantasy. Playing an immersive video game about the wild west lets players become explorers in that bygone era.

Video game makers, especially those working on *role-playing games* and virtual reality games, strive to create immersive experiences, to make the players feel as if they are a part of a virtual world. The term *immersive video games* often first calls to mind graphical realism. Indeed, graphical realism is one of the frontiers where game makers have been making progress to create ever more immersive worlds. Although game developers have already been able to create digital humans indistinguishable from physical ones, graphical realism is only part of the equation.

In addition, I have listed other aspects, namely interactive, behavioral, and narrative realism, that are essential to building a realistic virtual world. In the context of digital animals, *graphical* realism would be to render the fur on a dog as it is tumbling in a pond. *Interactive* realism would be to be able to pat the dog, feed the dog, or to play a fetching game with the dog—do things people would normally do with a dog. *Behavioral* realism would be to make the dog respond properly to players' actions. *Narrative* realism would be about how the player and the dog got to meet and the stories between them.

Human relationships with animals are multifaceted. To us, animals can be food sources, monsters, friends, lovely pets, destructive pests, and awe-inspiring co-dwellers of the planet. Interaction with digital animals should expand from the traditional catching or killing to reflect the nuanced human-animal relationships. This demands expanding interactivity from only catching or killing animals, as video games have traditionally allowed the players to do. Granted, games do not have to have realistic animals to be fun. The turtles in *Super Mario* that Mario jumps on and kicks are not realistic. Games that aim to immerse players in another world, such as role-playing games and virtual reality games, need *interactively* realistic animals the most. Specific examples are presented in this chapter.

Although video games often portray animals as fighting targets and moving resources, the medium has also created plenty of memorable, bonding experiences between players and animals. This chapter serves two purposes. First, it shows digital animals' capability to elicit emotional responses, which provides arguments for digital animals being an important part in the virtual game worlds. Second, it analyzes successful examples that reveal characteristics that make players invested in animals, so that these techniques can be applied in future endeavors, both for myself and for other game makers.

What is Considered a Video Game Animal in This Thesis?

Before the discussion about the realism of video game animals, this section briefly talks about what I mean when I refer to a video game animal. Video games are fantasized experiences, where turtles fly with wings on their shells, spectral horses materialize out of thin air, and animal-like characters talk and run on two feet. Since creative imagination has blurred the line between what is considered as an animal and what is not, this section serves to discuss the issue, from the perspective from this thesis. I am considering a video game character an animal if it assumes the physical appearance of an animal, in both facial and bodily feature, and appears to have similar intelligence to a real-world animal. Please note that these are general guidelines, not concrete definitions. The classification is often not strictly binary, with cases lying in between that can be argued either way or outliers that do not seem to fit in the discussion.

Humanoid Characters

In this thesis's context of playing with digital animals, I do not consider humanoid characters that can communicate by spoken words as animals. A notable example is Sonic the Hedgehog (Sega, 1991). While bearing some resemblance to a hedgehog, Sonic can talk and is not considered an animal in this thesis, because of his humanlike intelligence. There are many characters with animal face and human body, such as Micky Mouse and Ninja Turtles. These characters can be argued either as animals or human beings with animal faces. Whatever the case may be, I do not include them as a part of the discussion in this thesis. Similarly, this thesis does not consider most humanoid zombies, aliens, and robots as animals.

"Non-living" Characters

I consider non-living characters such as zombies, specters, and robots as animals and relevant to this thesis, if they have seemingly intelligent behaviors and assume the physical appearance of animals. As shown in Heider and Simmel's animation, viewers overwhelmingly considered the animated geometric shapes as humans or other living entities such as birds. Wrye (2009) has also argued that a digital animal is often a social and psychological construct.

In most cases, this thesis considers a seemingly intelligent being with the physical appearance of an animal an animal. But the intelligence of such characters must be kept below a certain level to stay representative of real-world animals. If a robotic dog is so intelligent that it can talk, drive a car, or play chess, it is considered a robot, not an animal. An ambiguous case is when a game shows what an “animal” is thinking or trying to communicate by showing subtitles on the screen. The “animal” does not speak words out loud but exhibits cognitive abilities higher than that of real-world animals.

Mythical Creatures

Mythical creatures with animal-like intelligence and appearance such as unicorns and phoenixes are considered animals in this thesis. But exceptions exist. If a mythical creature can talk, I do not consider it an animal because this thesis is about playing with digital animals with animal-like intelligence and appearance. Likewise, if a mythical creature is humanoid, it is most likely not considered as an animal. An example in this regard is golems, humanoid creatures made of stone. There are other outliers in this category. Vampires are considered animals if they assume the form of a bat but are usually considered humans if they assume the form of a human. Some hybrid creatures, such as centaurs, mixtures of humans and horses, and mermaids/sirens, mixtures of humans and fish, blur the line between animal and human. These situations likely require their own case studies.

Interactive Realism with Animals: Horse Riding in Video games

Although interaction with digital animals is often limited, horse riding is an exception. In the history of video games, some of the most acclaimed titles feature the play activity of horse riding. Such games provide valuable insight on how to create a strong relationship between the player and the horse. Moreover, each game implements horse riding in its uniquely realistic or unrealistic way, thus offering a valuable scope to analyze how different games implement the same activity with various degree of realism, for their specific goals.

Shadow of the Colossus

In real life, when riding a horse, the rider gives instructions to the horse. But in video games, there can be two different approaches. The first is the player controlling the character to control the horse. The second is the player controlling the horse directly, making the process much easier, as it removes a layer of communication. *Shadow of the Colossus* (Team Ico, 2005) features the first type of control. In this game, players play as the main character named *Wander*, and rides *Agro* the horse by spurring and pulling the reins. These are delicate and precise actions, as Agro is often hard to control and does not obey the orders from Wander. Agro cannot make big turns when she is running fast. She won’t run on rocky terrains or when near cliffs, despite being spurred. When enemies are present, she tends to flee and comes to Wander hesitantly when being called. The limitations, while often frustrating to the players, portray Agro as a realistic horse.

Shadow of the Colossus features a desolate open world with few inhabitants. The game world would have been too lonely without Agro's companionship. I hypothesize that riding Argo is designed to be realistically difficult to accentuate Agro being its own entity. Despite being harder to control at times, Agro with her own will and personality, feels like a live being that many players have grown fond of in the lonely game world. In this way, players become emotionally invested in Argo, their only friend and a source of solace.

Red Dead Redemption 2

Red Dead Redemption 2 (RDR2), a game set in the late nineteenth century in the western United States, introduces a bonding system—the better the player and the horse is bonded, the easier it is to control the horse. A newly purchased horse turns unwillingly. The player needs to pull the rein repeatedly for the horse to change direction, and the horse must move forward to perform a turn—it does not turn while standing on the same place. RDR2 provides many different interactions with the horse, such as riding, feeding, patting, and brushing. As the player engages in these activities, the horse becomes more bonded with the player. Eventually, the horse will be able to turn without having to move forward. The horse gets more stamina and is less likely to be startled. Horse riding is indispensable to the wild west fantasy. RDR2's bonding system not only instills realism, but also gives players a sense of progression.

The Legend of Zelda: Breath of the Wild

The Legend of Zelda: Breath of the Wild (BotW) (Nintendo, 2017) also demands skillful horse riding from the player. When the mechanic is first introduced, the player is tasked with riding through all the obstacles in a range. Spurring the horse to the maximum speed makes it hard to make sharp turns that exist between the obstacles. The player is specifically instructed to ride at a moderate speed, to pay attention to skill, rather than speed. Riding a horse skillfully, rather than through brute force, is consistent with BotW's overall design, as it is a game full of creative problem solving. If the character does not have enough stamina to climb up a cliff, he can instead chop down a nearby tree and use it a bridge. To deal with a formidable enemy camp, the player can shoot at a nearby beehive and have the bees attack the enemy.

Elden Ring

Elden Ring (FromSoftware, 2022) provides an example where realism yields to convenience in a calculated way. Here, a player rides a spectral steed that is summoned out of thin air. Upon summoning, the horse materializes right under the player. As the horse emerges, the player jumps up quickly to transition into a sitting pose. Although unrealistic, the process is quick. It takes the player about two seconds to summon the horse and sit on it. In all the other aforementioned games, the player has to call the horse, wait for him or her to arrive, and then climb up, eventually spending much more time than in *Elden Ring*. Again, in *Elden Ring*, when the horse is defeated by enemies or released by the player, it vanishes back into thin air. In addition to making mounting and dismounting speedy, by making the horse a spectral one, *Elden Ring* got to save development resources on horse death modeling and animation—they are not needed because the horse just vanishes. As a game that features formidable enemies and brutal combat, the spectral horse circumvents yet another problem, which is the narrative of death. The spectral steed does not die like a corporeal horse. It can always be in reincarnated.

Narrative Realism: Background Story of Human-Animal Companionship

Narrative Realism refers to telling a convincing and memorable story between the player and the animal. It is one of the factors that support an immersive game experience. This section details such an example.

Dark Souls (FromSoftware, 2011) tells a story of a knight called Artorias and his companion wolf Sif who once fought against the spread of the Abyss. Sadly, Artorias and Sif failed in their mission. During his last moments, knowing his imminent death, Artorias cast a magic shield around Sif, saving his life, and leaving himself swallowed by the Abyss. At the present time, the player is once again determined to cleanse the evil forces of the Abyss. To enter the Abyss requires specific equipment—the old ring of Artorias. When the player enters the grave of Artorias to seek the ring, they run into the wolf Sif who resides at and guards its former master's site of burial.

As the player enters the grave, a cutscene plays, showing Sif pouncing on the player. Due to *Dark Souls's* non-linear quest design, depending on what the player had done previously in the game, a specific version of the cutscene will play. There is a side quest to travel through a time tunnel to the past to witness the heroic knight Artorias and young Sif combatting the Abyss. Had the player done the side quest and made acquaintance with Sif in the past, the present-day Sif, in the cutscene, closely looks at, sniffs, and recognizes the player. It is a heart-wrenching reunion, because Sif is determined to fight against his friend of yore—to prevent the player from getting the ring and getting swallowed by the Abyss. Frowning and with a grimace, Sif lets out a howl of anguish towards the night sky, and then proceeds to slowly pick up the sword of Artorias...

However, if the player had not done the side quest to meet Sif in the past, the present-day Sif does not recognize the player and behaves like a hostile guard towards a thief trying the defile the grave of its former master. The cutscene shows that Sif then quickly jumps towards and picks up the sword, ready to fight the player.

Dark Souls tells a strong story about Sif. The fight with Sif is not just another fight with a heartless, ferocious beast, but a loyal companion trying to protect its former master and the player. It is heartbreaking to fight and kill Sif. The sentiment is prevalent in all online forums, with players leaving comments such as “Rated M for Mental Breakdown” and “This boss fight is extremely depressing”.

Having to kill Sif has made Sif’s story all the more powerful, which seems to be contradictory to my argument that killing animals is often unrealistic. Indeed, *Dark Souls* did not give players a choice not to kill Sif, which can be considered as interactively unrealistic. But what the game is lacking in interactive realism, it compensates with narrative realism. This chapter aims to analyze why some animal characters are memorable. Sif's story supports this goal by showing that narrative realism can contribute strongly to the overall realism of the digital animal. It is because of the strong narrative that Sif is no longer perceived as a heatless beast, but a loyal guardian sacrificing his life for his loved ones.

Behavioral Realism: Animal Vulnerability

This chapter supplements the topic of realistic digital animal behavior. It is worth noting that behavioral realism is closely related to interactive realism. Behavioral realism has been covered earlier in the chapter, when I talked about how different games make horses react differently to player input.

A well-written background story is not the only reason that Sif is evocative—Sif also exhibits some realistic behaviors. Notably, unlike many enemies and bosses that either show no change, or become more aggressive with lower health, Sif becomes weakened, starting to lose his aim, panting, and limping as his hit points get chopped away by the player. Sif is like a real wolf, a living entity that can be and will be injured and weakened—not a fictional monster oblivious to pain and fighting with full strength until death.

Realistic injury and weakened state can be applied to many different video game animals. This is an example of the broader idea that digital animals or AIs should have their limitations—a wolf's power decreases when it is injured, and a horse drains its stamina when running full speed ahead.

Personal Example: Player's Choice to Kill or Not Kill the Animal

Having talked about different aspects of realistic digital animal in video games, in this chapter, I analyze a typical video game scenario, a quest to hunt a bear. The idea is for game designers to consider and create not only savage beasts, but also intelligent, sentient beings that players can relate to and empathize with.

Treasure hunting quests are frequently seen in video games. Typically, the main character enters a village and then either learns from the notice board or hears from someone that rumor has it a mysterious beast is residing in the mountain nearby. There could be a bounty placed on the man-devouring beast or the beast's pelt is a highly sought-after material to craft a legendary armor. Hunting the beast usually rewards the player with money, crafting material, and unlocks progression in the game.

What typically happens next is the player goes to the rumored location, finds a grizzly bear prowling around, then prepares his or her weapon of choice, starts a fight, kills the bear, skins it, goes back to the village, and receives the bounty. Such scenarios often have limited interaction between the player and the animal—the player must kill the animal. Instead, imagine in the big game hunting quest, during reconnaissance, the player sees the target, a gigantic bear mother, leading her cubs to a river, drinking water, and digging around for clams to eat. In this case, behavioral realism is enhanced because the game describes a scene that can often be observed in nature. The realistic behavior of the bear mother caring for her children will increase interactive realism, because it gives the player a context to see, not ferocious beasts, but a heartwarming family. Then interactively, players can make their own decision to either give up on the best animal hide around or to hunt down the bear.

The story can certainly be more nuanced; and maybe it is a cliché to exploit people's sympathy for young offspring. However, the point still stands, which is to consider painting a well-rounded picture of animals and to let players make their own choice. Some may not mind hunting down the mother bear, while others may let her go. Interactive and behavioral realism with digital animals is impactful because it allows players to play according to their own will, to put their own hearts into the virtual game world—to be immersed.

Chapter 7. Evaluation of the Creative Research and Project Results

This chapter serves to reiterate the four research goals and how they are achieved: creating perceivably intelligent fish that the player can play with; designing play activities with the fish; making players emotionally attached to the fish; and reviewing realistic digital animals in existing games.

Playing with Digital Animals

Playing with digital animals suggests that the animals are their own entities. It demands the animal to exhibit somewhat intelligent and predicable behaviors. This section reviews how my fish are programmed to behave seemingly intelligently, as they can swim both by themselves and in response to player input.

Inspired by the natural phenomena of salmon migration and the simulation of fish schooling in computer graphics, I made a game about fish's journey home. To illustrate the fish as intelligent beings that the player can play with, I used a computer graphics and game AI technique called behavioral animation. Driven by Reynolds' behaviors such as *Seek*, *Obstacle Avoidance*, *Flow Field Following*, and *Flee*, the fish gradually move towards their destination, while also steering away from obstacles and running away from predators. With the autonomous movement of fish as the foundation, the player can play with the fish by leading them to explore the environment and find more fish to join the school. More activities are covered in the next section.

Designing play activities with digital animals

To play with digital animals, it is also necessary that the animals are "willing" to play—intelligent behaviors would not matter if the animals do not respond to the player. Therefore, this section reviews different ways the fish respond to the player.

Leading the Fish

The first play activity is to lead the fish with the mouse cursor. Whenever the spacebar is held, the fish swim towards the player-controlled mouse cursor. This seemingly simple play activity serves multiple purposes. It is directional, exploratory, and it enables teamwork.

The directional purpose is straightforward, to lead the fish in a certain direction. Although under the influence of the pathfinding algorithm and obstacle avoidance, some of the fish can eventually get to the destination (the beginning of the river) by themselves, there are many discoveries that can only be made if the player leads them there, hence the exploratory purpose of the interaction. The discoveries could be as small as finding a new type of plant or as significant as finding more fish to join the school. The player is rewarded for exploring the environment with the fish.

The activity of leading fish enables teamwork between the fish and the player, through the simple design of the fish's movement speed being slightly increased when they are following the player's control. This also gives the player a clearer sense of being in charge, as if he or she is contributing a force, working together with the fish to a specific direction. The sense of participation accentuates the idea of playing with the fish and lending them a hand in the arduous migration journey. For example, when the fish swim upstream against torrential rain that flush them backwards, they struggle, sometimes barely moving forward, and sometimes are pushed back. The player's intervention at this moment is monumental, giving the fish just the extra little force needed to overcome the currents. This scene did not make it into the current version of the game project, as it happens later in the migration journey when the fish are inside freshwater river. But as a prototype, it serves as an important example of the player playing with the fish and leading them through difficult situations. The extra force and speed enable collaboration between the player and the fish.

Shape Formation

In my game, the fish have the special ability of shape formation. This section reviews how it helps to fulfill the goal of designing play activities with digital animals. Directing the fish to come together to form another shape and move together while holding the shape is a play activity with the fish by itself. Moreover, as a special ability, it also adds a new way to deal with certain tough situations. For example, the big fish formation moves a little faster, giving the player and the fish an edge to flee from predators.

I overcame significant challenges in the process of creating the shape formation, animating it, and making the fish move while holding the shape. The big fish formation, as it currently stands, is a foundation upon which additional play activities with my fish are waiting for be built. Possible future uses include scaring predators away by forming a shape bigger than the predators or jumping together to overcome a waterfall that is too tall for individual fish to cross.

The shape formation ability also serves the goal of stressing the perceived intelligence and independent identity of each fish. Everyone has a position in the shape, everyone will go to their positions upon player input, and every individual movement comes together to form the big fish movement.

Eliciting Emotional Attachment

Digital animals are capable of eliciting emotional attachment from the player. This section reviews the characteristics of my game that can lead to this effect.

Psychologists have found that collaboratively solving difficult problems creates close relationships, even between people and groups that were previously hostile towards each other (Fine, 2004). The fish migration game, focusing on playing with fish, creates numerous collaborative opportunities between the fish and the player. By leading the fish, giving them extra helpful force, and directing them form into the big fish shape to tackle special problems, the player could not only relate to the fish's struggles, but also actively facilitate their progress. The fish, on the other hand, through their seemingly intelligent behaviors, appear to exhibit a strong will to go home, despite the difficulties. This perseverance again encourages the player to participate, creating a virtuous cycle that strengthens collaboration, understanding, and reciprocity, all of which can elicit and strengthen a player's emotional attachment (Wrye, 2009).

The fish school creates an environment where individual fish are likely to becomes less noticeable to the player. Emotional attachment could be undermined if the player does not recognize specific fish—if every fish is alike and personal identity is lost in the group. To deal with this potential issue, I designed the fish to have different colors and sizes. For example, the fish at the eye of the big fish shape is colored blue, while other fish on the edge have a darker color. The variations make the big fish shape more legible and accentuate the unique characteristics of each fish.

Discussions on Realistic Animals in Video Games and How They Could Support an Overall Immersive Game World

Since my game project could not match the scope of games made with large teams of people and large budgets, I reviewed existing digital animals in those games to showcase animals' potential as threads to weave immersive game worlds. To dissect and answer the question about what makes digital animals realistic, I examined graphical, interactive, behavioral, and narrative aspects of realistic digital animals and provided examples for each one. Granted, not all video games need realistic animals, and all games made for entertainment are a mixture of realism and fantasy. Therefore, analyzing the common play activity of horse riding, I investigated how different games adjust the degree of realism differently, for their unique goals and situations.

I made special efforts to give a broad overview of digital animals in video games, how interactive realism could contribute to player immersion, and of the intentional decisions designers have made to make animals more realistic or less realistic. As society interacts with digital content more and more, I think the study of digital animals is a burgeoning field for myself and other researchers to work in.

Creating Particle Effects with Behavioral Animation

While simulating particle effects and using behavioral animations were not among the initial goals of this research—they are techniques I needed to learn—I ended up creating new behavioral animations inspired by fish behavior. To reiterate, the behaviors in behavioral animation define target positions for agents to go to. The *Form* behavior defines each fish's target position in the big shape formation. *Tail Fan* changes each fish's target position rhythmically. *Turning* moves each fish's target position in the big fish formation gradually towards its mirrored position. My new behavioral animations provide an approach to animate group behavior while the group is holding a specific shape.

Computer graphics draws inspiration from math, physics, and hand-drawn animation techniques. I am glad to have applied one of the principles of animation, *overlapping action*, to *Tail Fan* and *Turning*. *Form* sometimes also exhibits *overlapping action*. When some fish are father out/behind, it takes longer for them to arrive at their formation point. In our Department of Design’s annual open house exhibition, a video showing these animations was well received by viewers. As a student and a practitioner, I am also glad to have first learned a technique from other scholars, and then implemented it with personal adjustments.

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