# Blending Science Knowledge and AI Gaming Techniques for Experiential Learning

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## Abstract

This paper addresses the scientific, design and experiential learning issues in creating an extremely realistic 3D interactive of a wild beluga whale pod for a major aquarium that is situated next to a group of real beluga whales in an integrated marine mammal exhibit. The Virtual Beluga Interactive was conceived to better immerse and engage visitors in complicated educational concepts about the life of wild belugas compared to what is typically possible via wall signage or a video display, thereby allowing them to interactively experience wild whale behavior and hopefully have deeper insights into the life of beluga whales. The gaming simulation is specifically informed by research data from live belugas, (e.g. voice recordings tied to mother/calf behavior) and from interviews with marine mammal scientists and education staff at the Vancouver Aquarium. The collaborative user interface allows visitors to engage in educational "what-if" scenarios of wild beluga emergent behavior using techniques from advanced gaming systems, such as physically based animation, real-time photo-realistic rendering, and artificial intelligence algorithms.

## Introduction

Museums, science centres and aquaria, which for our purposes can be referred to as informal learning institutions, are increasingly using interactive technology to leverage their traditional techniques in order to provide more engaging and informative learning experiences for their visitors. Interactive systems that use artificial intelligence (AI) or adaptive systems, and include high quality graphics in the exhibit, can allow for responsive and dynamic interaction that can engage visitors in a very short period of time. For institutions with high visitor traffic, AI gaming based systems can be designed to support a collaborative and participatory space that would allow visitors currently interacting with the system to informally and effortlessly pass on knowledge to new visitors allowing them to experience deeper content more quickly. Content can also be layered to support various learning styles and interest levels (Economou, 1998), which can encourage exploration through the use of 'what-if' scenarios as well as developing problem-solving skills. Increasingly sophisticated educational messages at short, medium and prolonged/repeated time periods can lead the user into more substantial levels of content. AI-based interactive exhibits can also incorporate personalization that allows visitors to work at

their own pace, be in control of their experience and have specific questions answered.  They can also tie directly to curriculum content, which can be easily updated as curricula change. This ease of updating allows institutions to use the same hardware but still change the content on a regular basis, which can encourage repeat visits, since there is always something new to see. This paper will present a case study of an AI gaming-based system developed as a virtual Beluga exhibit for the Vancouver Aquarium. We provide the background of the project, a description of the system, and present lessons learnt throughout the project.

## Related Work

The most commonly used technologies in museums, science centres and aquaria include kiosks based around monitors and PCs (Economou, 1998; Rayle & Reich, 2004), PC's with monitors, using mice for user input (vom Lehn, Heath, & Hindmarsh, 2002), touch screens (Gamon, 1999) and the use of video through projectors or large screen televisions (Akai & DiPaola, 2005). An emerging area of research has explored incorporating technology to expand on available content for visitors.  Far beyond what was available with headsets with number keypads that were common in the museum, today many institutions use handheld devices like Personal Digital Assistants (PDAs) as electronic guides that can provide in-depth information including audio and video for a particular exhibit. (Grinter et al., 2002; Jaen & Canos, 2003). However, more recently, newer forms of context-aware interaction such as headsets with sensors that provide information through wireless technology at each exhibit to each visitor are becoming increasingly popular.  An example of ubiquitous computing includes an exhibit in Italy on the story of Pucini as a set and costume designer (Sparacino, 2004).  For one portion of the exhibit, camera tracking with projection was used to allow the floor to become an interface that let the user to select menu items by physically moving around the space.  Another exhibit used a camera tracked tabletop display that allowed visitors to select a video by moving a physical object on the table.

A unique exhibit called "Re-Tracing the past" at the Hunt Museum in Ireland in 2003 focused on embedding technology seamlessly into the space (Ferris et al., 2004).  Among the technologies used were cards embedded with RFID (Radio Frequency Identification) tags that allowed visitors to explore an object in the collection in more detail at different stations. Experimental interfaces include the ec(h)o (Wakkary, Newby, & Hatala, 2003) project that customizes its audio information based on each visitor's preferences, location and past choices. The system takes advantage of location tracking to provide customized audio around a museum exhibit and provides users with an extremely simple interaction device consisting of a multicolored cube that is recognized by cameras placed at each exhibit.

## Design Issues of Multimedia Interactives in Informal Learning Institutions

Introducing these kinds of adaptive systems into public informal learning settings can allow for some unique learning opportunities, and their use to create multimedia interactives to promote educational content is becoming increasingly common.  Yet inherent in most of these settings are several common issues that must be considered in the design process.  Many of these issues stem from the needs of  visitors who have educational and recreational expectations for their visits.

- Effective use of technology - Using technology in exhibits can be an extremely expensive and time-intensive investment, so ensuring that technology is essential to the exhibit is critical.

- Limited contact time - Because each exhibit is just one of many that visitors will experience during their visit, most exhibits will have a very short time to engage visitors and to promote their educational content. However, exhibits also need to allow for deeper exploration of content to encourage repeat visits.

- High traffic/use - During their busy seasons many institutions will have thousands of visitors a day.  This means that multimedia interactives will have near constant use at peak times.

- Visitors travel in groups - Most visitors to museums, aquaria and science centres are looking for both learning and recreation experiences, and more often than not visitors attend in groups. However, many traditional uses of technology in exhibits (e.g. computers with mice) do not adequately support group interaction.

The authors give more detail on common issues and solutions, in a related design-oriented paper (DiPaola & Akai, 2006).

## Aquarium Implementation

The Vancouver Aquarium has over one million visitors annually. It has a significant marine science research center and educational mandate, and is in the midst of a multi-million dollar expansion. As the largest aquarium in Canada, the Vancouver Aquarium is known for its innovative science-based exhibition and gallery design and is interested, as part of its ten-year expansion process, to continue to innovate in this area. Our research group has been working with aquarium staff in the areas of design research and technology based approaches that support their expansion and education mandate. It was also decided to concentrate our collaborative research efforts on one prototype project that incorporates our new design directions. It was believed that this project would have specific and immediate uses on its own, as well as provide a template design process for future exhibit designs.

Prior to the interaction design, many hours of observation work were done in the beluga underwater viewing galleries to understand the average visitor experience and to examine how visitors interacted with the technology that was currently available to them, mainly touch screens, plasma screens and projections.  Technical difficulties with some of the technology suggested that robustness was a key issue to consider in the design.  An examination of available visitor demographics found that 90% of visitors arrived in groups, and that there was a very broad range of visitors. Therefore it was determined that an interface that encouraged interaction and collaboration was a critical part of the design.

## Virtual Beluga Interaction Design

After presentations over several possible prototype projects of our adaptive AI gaming-based design initiatives, the Virtual Beluga project was commissioned by the Vancouver Aquarium based on the artificially-intelligent animal simulation software Digital Biology

developed by Bill Kraus, a NASA researcher in genetic algorithms, and an evolutionary biologist (Kraus, 2003). The aquarium has a number of live belugas as their main attraction and wanted to supplement this with a simulation of a virtual wild beluga pod.  Their goal was to use their recent research on beluga behaviour and vocalization as the basis for the educational content of the exhibit.

Using our design research process, and based on our studies of the aquarium visitors, we worked with the aquarium's education staff to decide on overall and specific learning outcomes, which pointed to a subset of behaviors to implement for the interactive. We then looked at the categorized video clips of the real beluga behaviors and we designed individual behaviors to match the movements of those video clips using our biomechanics research. We created a design iteration loop, where we brought in the simulation work-in-progress to the aquarium and received feedback from scientists, trainers (who spend hours a day with the live belugas) and the education staff.  Once we were satisfied with a set of behaviors, the next step was to determine the context, i.e. what would generate that behavior based on the internal state and the ethogram. For instance, for a given new behavior we would surmise: its internal state, whether it needed some precursor behavior, and what it was likely to do afterward. This second stage went through an aquarium design iteration process as well. Besides the scientific and education staff, we worked with the categorized video, the ethogram and sound samples from the real animals located in the aquarium to build up our simulation system of the virtual wild belugas.
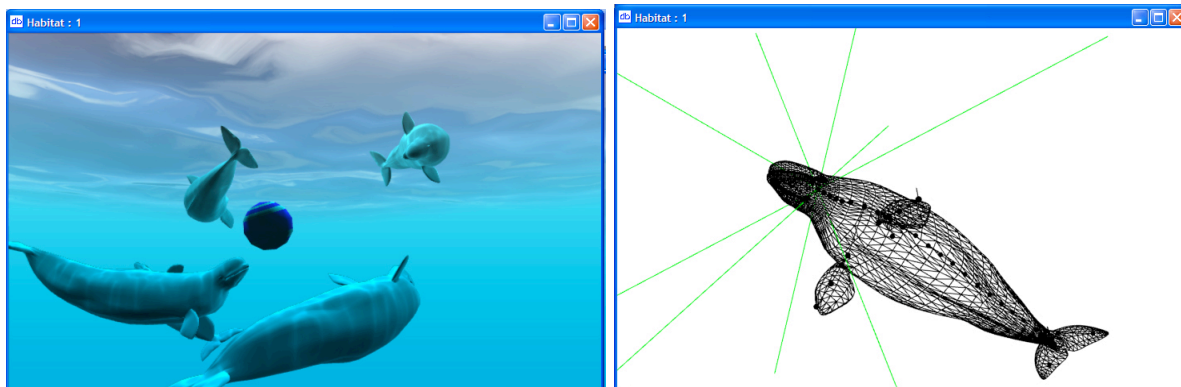


Figures 1 & 2: 1) Screenshot from the Virtual Beluga Interactive where belugas are interacting with each other and the test object (ball) under physics and collision detection. 2) Wire frame shot of a beluga showing physically-based node structure and sensors for perceiving its world.

*The Simulation Software*

The Virtual Beluga system (Figure 1) uses techniques from advanced gaming systems, such as physically based animation, real-time photo-realistic rendering, and artificial intelligence algorithms. The system also takes advantage of high end consumer 3D graphics hardware allowing it to be run on affordable desktop computers without the need for expensive, specialized hardware or costly IT maintenance procedures and expertise. It allows for:

- Real-time interaction among organisms as well as between organisms and the viewer.

- Lifelike organic movement through the use of actuators ('virtual bones and muscles') and a virtual physics model (Figure 2).

- Intelligent behavior, in which some animals have the ability to learn from experience.

- A true 3D environment with collision detection; realistic objects, lighting and shadows as well as directional sound.

   The system through its modular structure and intelligent object design has several benefits that fit our design goals including:

- Variable content is supported - individual organisms can grow and change over time, and new organisms can be added and removed.

- The simulation can be easily updated to reflect changes in current scientific thinking.

- The non-deterministic nature of the simulations means that no two simulations are alike.

- The interactivity of the simulations provides an opportunity to perform 'what-if' experiments by the viewer.

- The system is fully scalable - the number and complexity of organisms is limited only by the speed and memory of the computer on which it runs.

   The artificial intelligence subsystem, which uses a modified neural net approach, is built to allow for new behaviors with an 'action selection' mechanism that chooses which behavior is appropriate depending on the internal state of the animal. The 'action selection' method (from both ethology and artificial intelligence) is used to deal with realistic, animal-like situations; that is, how an animal makes the most appropriate decisions out of a repertoire of possible actions. Our 'action selection' methodology (Table 1) uses a hierarchical approach where low level actions such as individual body movements (e.g. fluke position) are built up as a vocabulary for mid level sub-systems (e.g. move naturally from point A to B or keep a reasonable distance from others while staying comfortably in the pod). These mid level sub-systems are algorithmically combined into high level behaviors (e.g. I am hungry and need to find my mother and nurse).

*Table 1*: *The levels of the AI system, use external and internal data (top - what I see, who I am) and choose a longer term high level behaviors (bottom) as well as continuous natural actions to achieve those behaviors.*

| sensors | internal state | memory |
|---------|----------------|--------|
| ACTION SELECTION | | |
| avoid obstacles | flee danger | pursue food |

Each animal has sensors (Figure 2) to detect other animals, objects in the environment, or user interaction (Figure 3). Information from these sensors, combined with the animal's internal state (e.g. level of hunger, fear, current position, family status) and memory of previous events, is used by the animal's virtual 'brain' or action-selection mechanism to choose an appropriate

behavior. These animals are independent thinking entities, so when combined with stimuli and each other, they create non-deterministic and natural group scenarios.
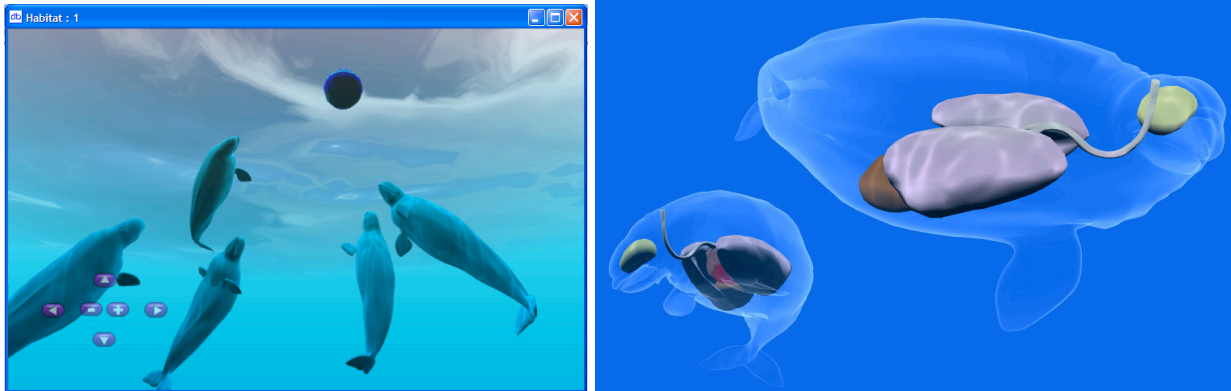


Figures 3 & 4: 3) Screenshot of Interactive where the belugas are following the test "ball" towards the water surface using their sensors and behaviors. 4) Screenshot of an early design, allowing visitors to interactively show internal anatomy as the belugas swim and interact.

*Learning Objectives*

In order to extend the visitor experience beyond what is available by looking at the live but captive belugas on display, the aquarium wanted to present their current research on beluga behaviour and vocalizations in a way that was not possible with the live belugas. A considerable amount of data was made available to us in the form of a beluga ethogram (a comprehensive outline of beluga behaviour), recordings of beluga vocalizations, and video footage of beluga behaviour. There were three main learning objectives for the exhibit:

1. Belugas live in an acoustic world.

2. Human activities affect how belugas use sound to communicate and navigate.

3. Our knowledge of wild beluga behaviour is very limited.

In order to emphasize that belugas live in an acoustic world, sound was an essential component of the exhibit design. Vocalization data on wild belugas is difficult to come by, therefore it is only through the study of the aquarium's captive belugas that we have been able to learn as much as we have about beluga vocalization. However, it is understood that the behavior and vocalizations of captive belugas are not necessarily predictive of that of wild belugas, and the exhibit will be presented so that visitors are aware that we are presenting our 'best educated guess' of what beluga interaction might look like in the wild. To explore how human activities might impact beluga behavior, the aquarium stressed the importance of not letting visitors directly manipulate the virtual belugas. As part of their mandate, they strive to promote a respectful and appropriate relationship between the animals (even virtual ones) and the visitors.

*Interface Design*

Based on the visitor studies, learning objectives, guidelines and client recommendations, it was determined that the interaction design would use a tabletop interface to allow for

collaboration and to remove any expensive electronics from direct user contact. The concept was to use a round table that would be camera-tracked. Visitors would have access to pieces representing either belugas or other environmental variables such as ice, food, or ships that they could place on the table. Once placed on the table, they are tracked by the camera and introduced into the virtual scene that is projected on a large screen in front of the table. Because the system is intelligent, the belugas will react to different environmental variables in different ways. For example, if an aggressive beluga is introduced into the scene, the other belugas will react to its aggressive behaviour. Visitors will be able to try different combinations of variables to try 'what-if' scenarios to find out how the belugas will react. As the belugas react they will show various behaviours and make vocalizations based on those behaviours.

## Summary and Conclusion

Much of our research work has been to build a system and design process that had to be flexible enough for working directly with researchers and research data in an iterative way. There appears to be the potential to take this system and feed it back to researchers to allow them to test hypotheses on how these behaviors work. However, the main goal is to use adaptive design techniques mixed with adaptive AI gaming-based software techniques to allow a knowledge flow from scientist to exhibit interactive to visitor that allows informal learners to engage more deeply in complex content.

Our main design goal was to facilitate a process to create user-centric, shared, collaborative and reflective learning spaces around smart multimedia interactives. New adaptive approaches, that have only recently become possible due to technological advances, were used with the goal of enhancing user experience. These adaptive approaches included adaptive design techniques, AI behavioral software to drive artificially intelligent animals, modular software and adaptive educational techniques.

At the institutional level, our first rapid working prototype was of a swimming beluga where it was possible to interactively see internal anatomy -- an interactive, animated scientific illustration of sorts (Figure 4). The software allowed us to brainstorm with aquarium scientists and education staff using this working prototype (as virtual systems were new to them). As they adapted to and then adopted the idea of interacting with virtual marine mammals (a somewhat controversial idea in an aquarium) they were more able to express what they felt was the best use of the technology - that of teaching visitors about wild group behavior and that belugas live in a world of sound. At the educational level, aquarium staff can play with open ended scenarios using the interactive, coming up with a sequence of events or serial narratives with different educational directions. At the visitor level, the interactive can be used differently for a group, both intellectually and given the specific social setting. Adaptive systems allow for users (staff and visitors alike) to use the system in various ways allowing for unique opportunities and potentials to emerge. This can occur when a system is made modular, allowing for repurposed or recombined use because the system is inherently open. Therefore, the same basic modular system can be used on a simple computer/mouse setup in the summer camp, be under full control by an experienced volunteer member on a plasma screen in the interpretive center room, and be used on the main exhibit floor with a fully collaborative tabletop and projection system.

## Acknowledgements

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