Designing an adaptive multimedia interactive to support shared learning experiences

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Abstract

With the aid of new technologies, integrated design approaches are becoming increasingly incorporated into exhibit design in museums, aquaria and science centres. These settings share many similar design constraints that need to be addressed when designing multimedia interactives as exhibits. The use of adaptive systems and techniques can overcome many of the constraints inherent in these environments as well as enhance the educational content they incorporate. Our main design goal was to facilitate a process to create user centric, collaborative and reflective learning spaces around the smart multimedia interactives. We were interested in encouraging deeper exploration of the content than what is typically possible through wall signage, video display or a supplemental web page. We discuss techniques to bring adaptive systems into public informal learning settings, and validate these techniques in a major aquarium with a beluga simulation interactive. The virtual belugas, in a natural pod context, learn and alter their behavior based on contextual visitor interaction. Data from researchers, aquarium staff and visitors was incorporated into the evolving interactive, which uses physically based systems for natural whale locomotion and water, artificial intelligence systems to simulation natural behavior, all of which respond to user input. The interactive allows visitors to engage in educational "what-if" scenarios of wild beluga emergent behavior using a shared tangible interface controlling a large screen display.

Keywords: multimedia interaction, collaborative interfaces, shared learning, exhibit design, intelligent systems

1 Introduction

Informal learning institutions like museums, science centres and aquaria are increasingly using technology to leverage their traditional techniques in order to provide more engaging and informative experiences for their visitors. However, the use of technology in these demanding high traffic environments requires careful design to ensure that the technology enhances the existing visitor experience and effectively promotes the educational content. Several of the more common design constraints in these settings are discussed, followed by suggestions for addressing these issues. We also discuss new adaptive approaches that have only recently become possible because of technology advances. Finally, implementation of these suggestions is contextualized using a recent design process for multimedia interactive developed for an aquarium.

2 Related Work on Multimedia Interactives

The most commonly used technologies in museums, science centres and aquaria include kiosks based around monitors and PCs [Rayle and Reich 2004; Economou 1998], PC's with monitors, using mice for user input [vom Lehn, et al. 2002], touch screens [Gamon 1999] and the use of video through projectors or large screen televisions [Akai and DiPaola 2005].

An emerging area of research has explored incorporating technology to expand on available content for visitors. Far beyond what was available with the headsets with number keypads that are common with 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 et al. 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 technology 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 et al. 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 interactive device consisting of a multicolored cube that is recognized by cameras placed at each exhibit.

3 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 commons issues that must be considered in the design process. Many of their issues stem from the needs of their visitors who have educational and recreational expectations for their visits. An overview of common issues to consider in multimedia interactive exhibit design in these institutions is presented with some suggested solutions.

Effective use of technology

Problem: The use of technology for exhibits can provide tremendous advantages but there are also several limitations to be considered. Using technology in exhibits can be an extremely expensive and time-intensive investment. It often requires a high initial cost as well as ongoing maintenance time and costs. Many institutions have a limited operating budget and do not have the personnel to oversee long-term maintenance issues. Technology can quickly become outdated and may have a relatively short life span. So if technology is to be used in exhibit design, it must provide something that is unavailable using traditional methods like signage or low-tech interactives.

Recommendation: Consider how long the exhibit will be active, how much time and cost will be required for maintenance, and the expected lifespan of the technology. Ensure that the technology will be robust enough to withstand the use it will receive and that it is being used to its full potential. A multimedia interactive should be doing more than is possible with a low-tech alternative. Some of the new possibilities made viable through technology oriented interactives further discussed in this paper include: adaptability at the design, institutional, educational and user levels; combining informational techniques with immersive and experiential qualities; and extending the visitor beyond the physical institution.

Limited contact time

Problem: 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.

Recommendation: A significant advantage in the use of adaptive systems with high quality graphics is that exhibits can allow for responsive and dynamic interaction that can engage visitors in a very short period of time. Care must be taken to ensure that the interaction is intuitive for first time visitors. It is also important to focus on an engaging design and a brief and easily accessible message. A layered approach, with increasingly sophisticated educational messages at short, medium and prolonged/repeated time periods, can be tied with techniques that lead the user into more substantial levels of content. For institutions with high traffic, adaptive 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 the deeper content more quickly.

High traffic/use

Problem: 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. Most electronics cannot stand up to this type of intense use and abuse, making the robustness of technology one of the key issues to consider in the design process. Technology that is malfunctioning is worse than the most ordinary signage because visitors will be completely unaware of its purpose.

Recommendation: Dealing with this issue requires a thorough understanding of your audience and any precedent for the use that a new exhibit will be expected to get. Understanding your visitors includes knowing visitor demographics, as well as their motivations for visiting and what they expect out of their experience. This information can be obtained from a variety of sources, including surveys, focus groups, interviews, and observations.

Adaptability can include both the nature and physical aspects of the exhibit. Often institutions have a variety of uses, acting as a gallery during the day, and later rented out in the evening for various functions. Having portable or modular exhibits will allow for much more flexibility in a multi-use space. Allowing the exhibit to adaptively change to a variety of uses helps defer the cost of technology and allows the institution to quickly support changing needs. For instance during extreme peak times, staff can switch the display of the interactive to crowd control information or use a high placed display to show real-time video of a current demonstration which would normally be obscured to visitors at the back of the crowd. The same general interactive can be used during the same day for 1) strong educational and hands on use with a staff member leading a school group or summer camp in the morning, 2) standard, full exhibit, unguided educational use during regular hours and 3) more entertainment oriented, non supervised and locked down use during a corporate evening function or camp sleep over.

Visitors travel in groups

Problem:

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.

Recommendation:

Technology has tremendous potential for creating engaging collaborative interfaces that can be used by multiple visitors. Recent research on tabletop displays [e.g. Kakehi et al. 2005] has proven to be effective for collaborative tasks. By designing an interface that allows for collaboration, these learning experiences can become deeper shared tasks. Another technique is to decouple the interface from the display, which can allow a larger crowd to vicariously participate in the interactive learning by watching the large display and discussing options with themselves and those at the interactive controls. Museums, aquaria and science centres already have a propensity for group participation and impromptu "what if" discussions as couples, extended families and vacationers collaboratively view exhibits in a public but comfortable and controlled setting. By understanding the dynamics of that controlled social space, we can design interfaces that can grow, organize and enhance that participatory learning experience.

Need to generate repeat visits

Problem: All institutions share the goal of increasing visitorship. To do this they need their exhibits to allow for extending the experience, or to encourage repeat visits by allowing for various levels of interaction.

Recommendation: To extend the visitor experience beyond the visit a companion website can be developed to extend the content available in the galleries. Multimedia interactives should also be designed to allow for various levels of interaction, so that continued use can provide a deeper exploration of content. This can be accomplished through the use of an intelligent system (e.g. artificially intelligent) for a more dynamic and less predictable visitor experience.

It is also important to ensure that it is possible to update the content of a multimedia interactive so that exhibits can be easily updated and visitors can have a different experience with the same exhibit on a return visit.

Exhibits must work without supervision

Problem: Due to limited staff availability, most exhibits will be expected to operate without supervision and with minimal instruction. This requires that exhibits be very intuitive to understand even for those with little technical experience.

Recommendation: The design of multimedia interactives is an iterative process and thorough evaluations should be done at every stage with considerable visitor input at each. Evaluation may suggest the need for substantial re-design, so extra time should be provided at each stage to allow for this. A variety of visitors should be used for evaluation to ensure that the interactive is usable by those of various ages and abilities. One possible solution to ensure the interactive exhibit is functioning is automatic monitoring of the interactive which proactively alerts busy staff to a problem.

Present educational content in an engaging and accessible manner

Problem: Because there are many exhibits competing for visitor attention, any educational content presented in exhibits must be engaging and accessible. While this is true of not only multimedia exhibits, it is important to ensure that the technology does not interfere with the accessibility of the educational content. Not all visitors will be familiar with the technology used, so it must be presented in an intuitive manner.

Recommendation: Hennes and Chabay [2001] note the importance of engagement and curiosity to increase learning. Because multimedia exhibits are more dynamic than signage, they can allow for layered content that can 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. [Adams & Moussouri, 2002]. Multimedia interactives 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 be used to tie into curriculum content, which can be easily updated as curriculums change. This ease of updating allows institutions to use the same hardware and change the content on a regular basis, which can ensure dynamic exhibits that encourage repeat visits, since there is always something new to see. Many institutions conduct research in-house. This type of research can be used to create current and dynamic content for exhibits. This allows the knowledge flow to move from the scientist to the staff to exhibit designer, and finally to the visitor through the exhibit. It can also extend content already available in the space.

4 Aquarium Implementation

In the previous section common design issues and suggestions to support the use of technology in exhibits in a way that enhances the visitor experience and promotes the educational content were discussed. The following section will focus on the implementation of these suggestions to the design of our Virtual Beluga Interactive in the context of a public aquarium

The Vancouver Aquarium has over one million visitors annually; 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.

4.1 Visitor Studies

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. Daily visitor counts during high season number in the several thousands, but was much decreased during low season. Therefore it was determined that an interface that encouraged interaction and collaboration was a critical part of the design. Also considered was the fact that part of the local school curricula included a visit to the aquarium and classes of various ages would visit the aquarium almost daily during the school year. Special events were also available including sleepovers and private functions in the underwater beluga gallery. Based on this initial work, a series of guidelines (Table 1) was developed to constrain the design process. These guidelines represent possible solutions to the general design issues of multimedia interactives as well as the specific needs of the aquarium.

1. Robustness	9. Engaging
2. Safety	10. Does allow direct control of belugas
3. Allows for collaboration	11. Intuitive
4. Maintains ambience of gallery	12. Educational
5. Appeals to wide audience	13. Portable
6. Cost-sensitive	14. Crowd-friendly
7. Multi-sensory	15. Fits into existing knowledge flow
8. Has sound component	16. Effective use of technology

Table 1: Guidelines developed after visitor studies work for the Virtual Beluga multimedia interactive.

5 Virtual Beluga Interaction Design

After presentations over several possible prototype projects of our adaptive 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. Digital-Biology is computer animation/simulation software for creating real-time, photo-realistic interactive simulations of biological phenomena [Kraus 2003]. The aquarium was interested in using the system to build an exhibit around belugas. 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 to as the basis for the educational content of the exhibit. The design process for the Virtual Beluga System was based on input from the aquarium staff, researchers and visitor studies.

We worked closely with aquarium staff while designing the beluga model and simulation. In order to ensure that the beluga model was realistic, several iterations were made based on videos and still images of belugas as well as feedback provided by aquarium staff and researchers. One of our design goals was to establish a process flow that allowed knowledge to move from the marine mammal scientists and aquarium educational staff through the interactive and, ultimately, to the visitor. This flow used collaborative techniques to ensure significant and current science knowledge was passed through the system in a way that was not a burden to the scientists. Current research was also incorporated into the design based on a comprehensive ethogram of beluga behavior. .

Figure 1: Beluga at play: Screenshot from the Virtual Beluga Interactive where belugas are interacting with each other and the test object (a floating ball) under physics and collision detection.

5.1 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 chooses at each moment in time, the most appropriate out of a repertoire of possible actions.

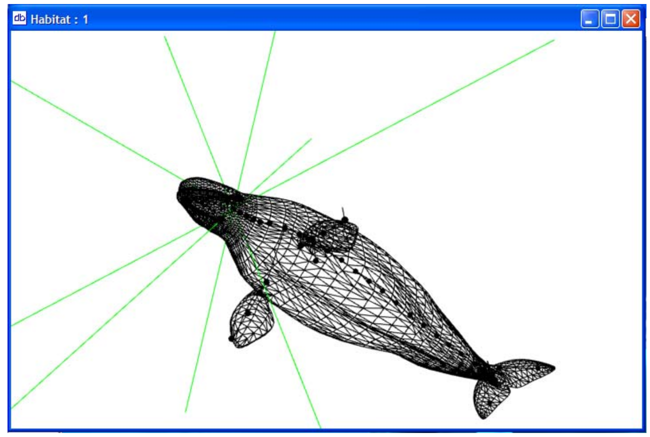

Figure 2: Wire frame screen shot of a virtual beluga showing internal physically-based node structure and autonomous sensors (as lines) for perceiving its world.

Our 'action selection' methodology (Table 2) 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 distant 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 find my mother and nurse). In the Virtual Beluga example our low level actions which allow for natural looking movement are:

- Paddle: Right, Left, Forward, Reverse
- Roll Right, Roll Left
- Body Pitch Up, Body Pitch Down
- Head: Yaw and Pitch
- Jaw Open
- Fluke: Frequency, Amplitude, Magnitude, Phase
- Fin: Yaw, Pitch, Roll, Frequency

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

Table 2: The hierarchical levels of the action selection 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.

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.

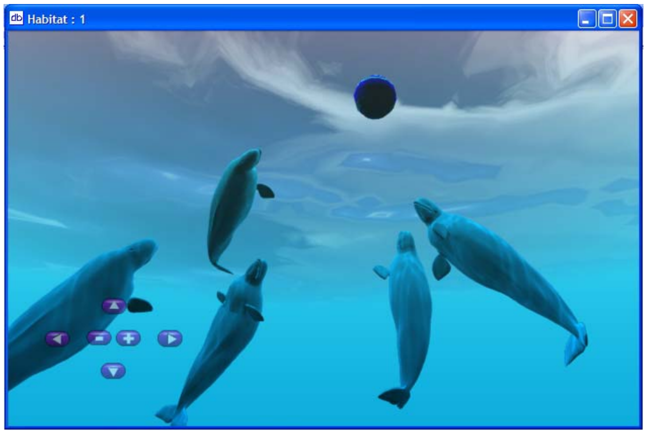

Figure 3: Screenshot of Virtual Beluga Interactive where the belugas are following the test object towards the water surface using their sensors and action-selection behaviors. Camera controls (bottom left) are on in this internal debugging view.

5.2 Learning Objectives

In order to extend the visitor experience beyond what was 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 aquariums 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 impressed 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.

5.3 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. When they had been 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 his 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.

6 Summary and Conclusion

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

Rather than put a system into action for a specific limited purpose, since that assumes the system is ready for the purpose and the purposed if fully known, we believe it is more appropriate to make a system suitable for a purpose, where suitability gives it the ability to adapt. By making the system suitable for a purpose and adaptable within that purpose, adoption can happen where adaptive activity (by designers, staff and visitors) allows the system is made one's own. That making of one's own can happen at the institution level, the educator's level or the learning level.

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.

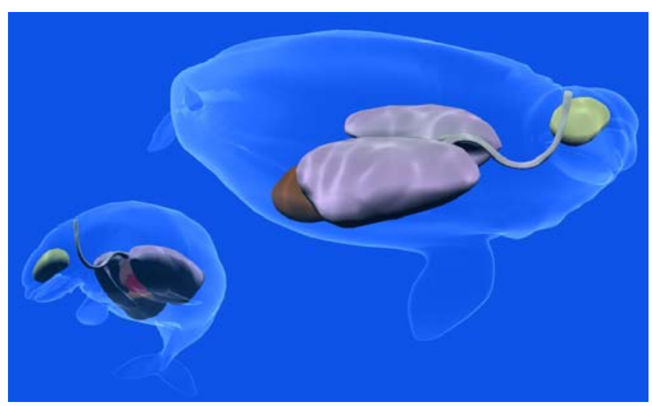

Figure 4: Screenshot of an early design direction of virtual belugas, allowing visitors to interactively toggle on different internal anatomy as the belugas interacts with its environment.

Adaptable systems allow for users (staff and visitors alike) to use the system in various ways allowing for unique opportunities and potential 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 experience 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.

Another adaptive technique that we have employed in our design and software process is to work in layers. The benefits of a layered approach in adaptive design have been well documented [Moran 2002]. Layers allow for slippage between layers. Fast layers explore changes (originality) while slow layers constrain fast layers but provide continuity. A layered approach, be it with the action selection system we are using in the animal behavior software or in the conceptual design of the physical setup where interaction, collaborative discussion space and display of the non-deterministic results are all separate layers, allows us to constantly design in new insights on the science, or user experience level.

The use of adaptive systems for multimedia interactives in museums, science centres and aquaria can overcome many of the constraints inherent in these environments as well as enhance the educational content they incorporate. We have tried to discuss issues and possible solutions to these methods for interactive multimedia designs as well as presenting how these techniques have been used in a specific project for learning about marine mammals.

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References

AKAI, C. and DIPAOLA, S. 2005. Why Technology? Technical Report. Prepared for the Vancouver Aquarium. 13 pp.

ECONOMOU, M. 1998, "The evaluation of museum multimedia applications: Lessons from research", *Museum Management and Curatorship, 17*, 2, 173-187.

FERRIS, K., BANNON, L., CIOLFI, L., GALLAGHER, P., HALL, T., & LENNON, M. 2004, Shaping Experiences in the Hunt Museum: a Design Case Study. In *Proceedings of Designing Interactive Systems (DIS) 2004*, August 1–4, 2004, Cambridge, Massachusetts, USA.

GAMMON, B. 1999, How do visitors use computer exhibits? Findings from 5 grueling years of watching visitors getting it wrong. Accessed from: http://www.big.uk.com/knowledgebase/exhibits/computer_based_exhibits_v1.htm [2005, August 10].

GRINTER, R.E., AOKI, P.M., HURST, A., SZYMANSKI, M.H., THORNTON, J.D. & WOODRUFF, A. 2002, Revisiting the visit: Understanding how technology can shape the museum experience. In *Proceedings from the Computer Supported Cognitive Work Conference*. November 16-20, 2002. New Orleans, LA.

JAEN, J.M. & CANOS, J.H. 2003, A grid architecture for building hybrid museums. *Lecture Notes in Computer Science, 2713*, 312-322.

KAKEHI, Y., IIDA, M., NAEMURA, T., SHIRAI, Y., MATSUSHITA, M., & OHGURO, T. (2005). Lumisight Table: An Interactive View-Dependent Tabletop Display. *IEEE Computer Graphics & Applications, 25*, 1, 48-53.

KRAUS, B. 2003, The Digital Biology Resource and Research Website, http://www.digitalbiology.com

MORAN, T. P. 2002, Everyday adaptive design. Proceedings of the DIS 2002 Conference on Designing Interactive Systems, 13-14. New York, ACM.

RAYLE, R. & REICH, C. 2004, Creating interactive learning experiences for all. In *Proceedings of Designing for the 21st Century, an International Conference on Universal Design*. December 7-12, Rio De Janeiro, Brazil.

SPARACINO, F. 2004, Museum Intelligence: Using interactive technologies for effective communication and storytelling in the "Pucini Set Designer" exhibit. In *Proceedings of the International Cultural Heritage Informatics Meeting* (ICHIM 2004) August 31-September 2, 2004. Berlin

VOM LEHN, D., HEATH, C. & HINDMARSH, J. 2002. Video based field studies in museums and galleries. *Visitor Studies Today!* Fall/Winter, 5-23.

WAKKARY, R., NEWBY, K. & HATALA, M. 2003, Ec(h)o: A model for participation. In *Proceedings of the Creating Communicational Spaces Conference*. May 1-4, 2003, Edmonton, AB.