User Experiences with a Virtual Swimming Interface Exhibit

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Abstract. We created an exhibit based on a new locomotion interface for swimming in a virtual reality ocean environment as part of our *Swimming Across the Pacific* art project. In our exhibit we suspend the swimmer using a hand gliding and leg harness with pulleys and ropes in an 8ft-cubic swimming apparatus. The virtual reality ocean world has sky, sea waves, splashes, ocean floor and an avatar representing the swimmer who wears a tracked head-mounted display so he can watch himself swim. The audience sees the swimmer hanging in the apparatus overlaid on a video projection of his ocean swimming avatar. The avatar mimics the real swimmer's movements sensed by eight magnetic position trackers attached to the swimmer. Over 500 people tried swimming and thousands watched during two exhibitions. We report our observations of swimmers and audiences engaged in and enjoying the experience leading us to identify design strategies for interactive exhibitions.

1. Introduction

Our artwork, *Swimming Across the Pacific*, takes inspiration from the performance art piece "Swimming Across the Atlantic" [15]. It was performed by the artist, Alzek Misheff, who accomplished the artistic endeavour by swimming in the pool of the ocean liner, Queen Elizabeth II, traveling from South Hampton to New York as a comment on contemporary art at the time. In *Swimming Across the Pacific*, we plan to swim across the Pacific Ocean, from Los Angeles to Tokyo, in an airplane to transform it into a "bubble" containing a media arts festival for the same purpose. To do this we developed our virtual swimming locomotion interface as shown in Figure 1 so we can swim virtually rather than in real water as part of the

Figure 1: Swimmer in swimming apparatus.

transformation symbolism. While this swimming device is originally designed for placing in an airplane, anyone can try it to swim and enjoy the virtual water. Thus, as one step in the artwork, we designed and built an interactive installation around the virtual swimming apparatus.

We exhibited our work at the exhibitions of the 2004 International Conference on Special Interest Group on Graphics and Interaction (Siggraph'04, Los Angeles, USA) and Imagina'05 (Monte Carlo, Monaco). These provided us valuable opportunities to observe and evaluate how well our design decisions worked. During the exhibits, hundreds of people enjoyed the experience of swimming. Thousands of audience members also enjoyed watching swimmers in the exhibit. Of particular significance is that, on one hand, the virtual swimming device may be seen technically as a novel computer input device for users to interact through swimming motions with a virtual environment. On the other hand, through careful design of the user experience, we transformed the computer interface into a successful *swimming experience* exhibit.

In designing the actual device, we considered the swimmer as the user. However, in designing the exhibit, we considered three additional user types to make a successful and enjoyable experience for a wider audience. The additional three users types are the swimmer within a group of swimmers, the attendant and the audience. Our main observations during the exhibition validated our design decision to balance the fidelity of all the components. We found that amateur swimmers were more critical than novices or expert swimmers. As well, we realized that the attendants helping people at the exhibit played multiple roles. This required us to build the device and exhibit to allow attendants' full attention to be on the audience and participants rather than the system.

We begin our discussion with related work and the technical design of the novel swimming apparatus that is at the core of the exhibit. Next we describe the exhibit design itself and the workflow of the attendants. Finally, we describe the observations we made during the exhibitions.

2. Related Work on Locomotion Interfaces

"Locomotion interfaces" such as virtual walking, virtual hang-gliding, our swimming apparatus and others, are closely tied to virtual reality (VR). In an artificial reality, where the users have a presence in a 3D space and use their bodies as natural input devices, development of locomotion interfaces is vital for immersive experiences. Christensen et al. say, "Locomotion interfaces are energy-extractive interfaces to virtual environments and fill needs that are not met by conventional position-tracking approaches or whole-body motion platforms." [6] Some VR researchers particularly advocate the development of locomotion interfaces because with their improvement come many more unforeseen applications [7]. Locomotion interfaces have been created for walking and biking. Walking interfaces include the Sarcos Treadport [6, 10], CirculaFloor [11]. TorusTreadmill [12] and GaitMaster [13]. Examples of virtual reality bicycling systems are the Peloton Bicycling Simulator [5] and Trike [1].

While not requiring direct human locomotion behaviours, high-end flight simulators have been used in military and pilot training schools for a long time.

Commercial systems using variations of flight simulators include Dreamality's DreamGlider, JetPack, and SkyExplorer, and HumphreyII [3] that includes force-feedback. Much like our swimming apparatus, HumphreyII places the user in a prone position; however, we argue that a flying interface is not a locomotion interface, as people do not normally fly by their own energy.

Virtual swimming offers some unique advantages over other forms of VR and locomotion interfaces. In comparison to flying interfaces such as HumphreyII, most people have experience swimming in water, whereas flying in air is not a common experience. Thus, we expect people to understand and more easily explore our type of interface when moving in a virtual world. Bicycle and treadmill interfaces share this property as well. However, with swimming there are many styles and personal techniques that provide means for people to develop complex behaviours and expertise with the apparatus. This leads to an increase in intimacy with the device [9], providing more satisfaction and enjoyment than may be possible with typical flying, bicycling and walking interfaces.

Examples of other early attempts at aquatic interfaces include Fraunhofer's Aquacave, which allows virtual interaction with cartoon fish characters, and Virtual Diver [4], which is used for artificial reef study. Aquacave used a paragliding harness and pulley system to suspend the diver in a CAVE, wherein a virtual underwater environment is displayed. Virtual Diver explores methods of mapping photographs of artificial reefs onto a 3D reef model, which is then explored using a 3D joystick. Other undersea VR marine navigation and positioning technologies can be found in [14]. In these examples the focus is on the underwater environment itself, rather than on a locomotion interface based on surface swimming that we explore.

One unique aspect of our swimming system is that it occurs at the surface of the water. In addition to our mechanical system, we have implemented dynamic waves and splash action so that the participant experiences a water surface environment while swimming. Though our scenery is intentionally simplistic as shown in Figure 2, it is a relatively straightforward effort to improve realism using caustics, fog effects and textures to achieve a different representation of sea, sky, sun and the swimmer's avatar.

While not a locomotion interface, the Aladdin system [17] is another VR-based exhibit using a magic carpet metaphor for flying around a virtual environment. Observations made during our exhibit shared some of the same ones as in Aladdin such as: the experience is more important than the technology, people like exploring and the importance of quick throughput. However, some of the observations they had contradict ours. Specifically, participants did not need a goal and were content with just swimming, the background story was not so important for participants and users did turn their heads constantly in yaw and pitch. We suspect the
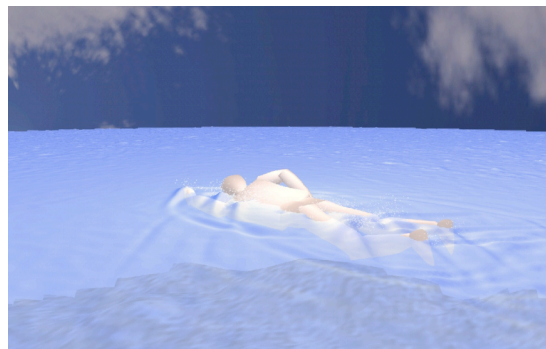

Figure 2: Avatar in virtual Pacific Ocean.

directness and affordances of the locomotion interface for swimming and the attendants interaction with the participants plays a key role in explaining the differences as discussed below.

BUILDING THE VIRTUAL SWIMMING DEVICE

Our current design for the swimmer consists of a combination of mechanical hardware, computer hardware and software [8]. The swimming apparatus (Figure 1) is an 8ft x 8ft x 8ft wooden structure with horizontal beams on top and bottom. The user is supported in a prone position at the shoulders and hips by running static cords through pulleys mounted on the beams and attaching the cords to the harness with carabineers. One major design goal is to give the user a sense of swimming, but not necessarily a sense of being in water. The mechanics allow the user generous freedom of motion coupled with a feeling of resistance and buoyancy. The rope-pulley system for the legs is designed to conform to several frontal swimming styles including: crawl, breaststroke, butterfly and dog paddle. Currently, there are no mechanisms designed for counterbalancing or providing feedback to the arms.

The computer hardware components of the installation were: a 1.5 GHz dual-processor Xeon Dell computer system, an NVidia Quadro4 TwinView graphics card, a video projector, two 21" LCD video monitors, a Kaiser Proview XL50 head-mounted display (HMD), two Polhemus Fastraks with 4 sensors each, and an interactive audio system. The control Tcl/tk based GUI runs on either the base computer or a remote laptop. One monitor displays a side view of the avatar for the attendants, and the other shows the swimmer's HMD view that alternates between first- and third-person perspectives. We also use rear video projection onto a screen attached to the wooden structure to show the side view to the audience as shown in Figure 1. Polhemus Fastrak sensors tracked the movement of the swimmer's head, arms, torso and legs and are attached firmly with adjustable Velcro™ straps. All the ropes and sensors cables are routed above and behind the swimmer to minimize interference. An Apple G4 PowerBook controls the interactive audio system. Additional components of the system are a Yamaha EX5R tone generator, a CD player, and a mixing console. The result is output to a pair of powered speakers.

The virtual ocean environment includes visual and audio elements. The computer graphics are implemented in C using OpenGL running on a Debian Linux machine. Typical imagery from the graphic system is shown in Figure 2. The audio system utilizes Pure Data [19] and MIDI. The design considerations for the ocean environment are intended to match with the fidelity of the mechanical system, which is not intended to be entirely realistic. We feel that having any major component of the system being out of balance with others will detract from the user experience.

The main graphical components of the virtual environment are a sky hemisphere, an ocean surface plane, an ocean floor plane, a virtual avatar and various lighting for different times of the day. The sky hemisphere is texture-mapped with moving clouds. The ocean floor is modeled with a rugged plane that is texture-mapped with rocks. Both planes are animated to move past the virtual avatar when the user swims forward; the faster the participant swims the faster the avatar moves. As well, we simulate interactive waves and splashes on the ocean surface. The virtual avatar is a

model of a gender-neutral human figure. We also created the sense of time passage through providing sunrise, daytime, sunset and nighttime by moving the sky and effects of lighting. For both aesthetic and conceptual reasons, we wanted different times of the day in order to alter the sense of reality and timing in the virtual world. Views of the virtual ocean environment are displayed to the swimmer through the HMD and alternate between first- and third-person perspectives.   We provide interactive splashing sounds corresponding to the swimmer's movements for each arm and leg. We also have a continuous seaside ambient sound track that is mixed in from a CD.

The control console GUI, written in tcl/tk, is used for control and automation of the installation. Some parameters that may be manipulated are calibration of sensor data for individual swimmers, control and automation of lighting, and perspectives of the virtual environment as seen by the swimmer and audience.

CREATING THE SWIMMING EXHIBITION

Significant effort was required to shift our design from a stand-alone swimming apparatus to one that we displayed at the ACM Siggraph'04 Emerging Technologies exhibition and Imagina'05. Our major change was to focus not only on the experience of the individual within the apparatus, but also examine the other users that would be in an exhibit setting: the swimmer within a group of swimmers, the attendant and the audience. We will first address our overall constraints for the exhibit, and then we will discuss the more detailed design decision related to the stage, the cumulative experience of all participants, and attendant workflow. Of particular concern was maintaining a balance among all the components of the virtual environment, as well as focus on facilitating the attendants' workflow within the exhibit.

Overall Constraints

We based our design decisions on four main constraints: artistic, computational, robustness, and adaptability.

Artistically, we made a conscious decision not to have the virtual world look too real to match the fidelity of the rest of the system. We also put effort into making the swimmer feel like they were floating and swimming in water-like conditions.   To match the other components, sound and lighting were not 100% realistic. The critical elements were to maintain balance between all the modalities, whether virtual or real. Our artistic constraints motivated implementing dynamic lighting and multiple viewing perspectives for both the swimmer and audience.

We focus on aspects we consider most important to the overall experience as we have limited
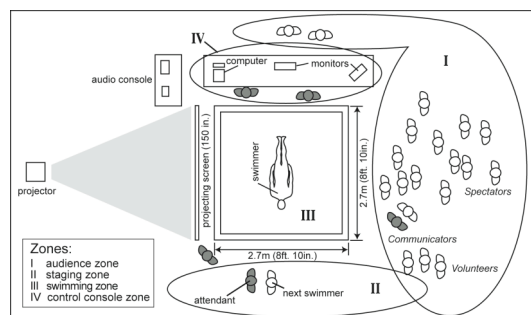

Figure 3: Exhibit layout.

computational resources. We currently are not concerned with providing game-like elements or other extraneous graphics elements such as fish or ships. On the other hand, we wish the swimmer to have an engaging experience at the surface of the water. For this reason, we concentrate on synchronizing the movement of the real swimmer with the virtual avatar and having splashes and waves. We do not support diving under the water.

The Stage Design

The overall visual aspects and staging design of the swimming cage are for the audience. The layout of the swimming space is shown in Figure 3. In an attempt to attract members of the public, we made the design of the environment around the exhibit as pleasing as possible. For example, to enhance the visual aspects of the exhibit the cage is painted blue and white, there are blue spotlights and the uniforms of the attendants are coordinated. To create the feel of an open ocean space, we play a continuous ambient seaside soundtrack. We anticipated that the novel look of our apparatus coupled with the carefully designed spatial character of the exhibit and the visual and audio effect are critical to attracting the audience as noted in [2].

Both the front and sides of the installation are designed to give the audience (Zone I) an unobstructed view of the swimmer in the apparatus (Zone III). The swimmer is positioned such that their physical body is suspended in front of a rear-projected view of the avatar seen from the side pointing in the same direction as the swimmer (Figure 1). In addition, one LCD monitor (Zone IV, right-hand monitor) was placed so that audience members could see the same view as the swimmer's HMD. This allowed the participant and audience to share the swimming experience; also noted by Borchers to be a good design strategy. Posters and brochures are positioned such that they do not occlude the swimmer, but are in areas where audience members are standing.

We decided not to provide a clearly marked area for audience members waiting to try the apparatus in order to avoid making the installation appear like a theme park ride as well as avoid separating these two user groups. Instead, we wanted to create an inviting environment for both these user groups and at the same time not make a strong delineation between the two.

Cumulative Experience Design

We constructed the storyline of the experience so that individual swimmers were actually part of a larger group. Consistent with the theme of *Swimming Across the Pacific,* the overall goal of the installation was to simulate swimming across the ocean over the course of nine hours. Though each swimmer was only in the apparatus a small fraction of this time, their participation, along with all the other swimmers each day, added up to achieve the goal. We portray this by displaying a "flight map" before and after each swimmer in the HMD and projection to show progress of the swimmers flying across the Pacific ocean. In addition, to commemorate their contribution to the overall goal, we give buttons to each swimmer to wear.

Attendant Workflow Design

The layout of the exhibit (Figure 3) has four zones that the attendants navigate: staging, swimming, audience and the control console. The staging area is where

attendants move volunteers in and out of the exhibit (Zone II). Participants swim in the wooden structure in the swimming zone. We located the computers and control GUI in the control console zone (Zone IV). These zones intentionally overlapped to allow attendants to work in multiple areas. The attendants in the staging area or those working at the control console could also easily provide assistance with the swimming apparatus. This helped reduce the number of attendants and allowed them to concentrate on the area that needed the most attention at the time.

We developed a workflow to facilitate the transition from an audience member to swimmer as shown in Figure 4. The workflow begins by an audience member volunteering to try the apparatus (a). She is then led to the staging area where she is fitted into the harness while the current swimmer is still in the apparatus (b). When the current swimmer completes his swim and returns to the staging area, she would be clipped into the swimming structure (c). With the help of the attendants, she leans over until the ropes hold her in a prone position. An attendant fits the HMD on her. Attendants attach the eight magnetic sensors and strap her feet into the leg pulley system (Figure 3). When she is ready, one attendant changes the flight map in the swimmer view with a GUI button and another provides her some basic instructions. She swims until she is done (d). Once done, one attendant switches the display back to a flight map scene and others help her get out of the swimming apparatus (e). She moves to the staging zone and is helped out of her harness and receives a button (f).

a. volunteering to swim   b. gearing up   c. clipping in

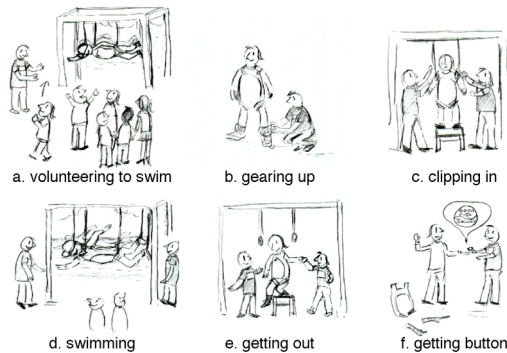d. swimming   e. getting out   f. getting button

Figure 4: Workflow to get in and out of apparatus.

There were several design considerations for getting the swimmer into the cage. The HMD had to be adjustable, to fit the varied head sizes of the participants. In addition, we had to add a chinstrap to hold the HMD in place because the swimmers head would be facing downward. Since the participant was to be suspended horizontally, safety was a major concern. We ensured that the floor around the apparatus was free from obstructions such as cabling and equipment. We also provided a stepstool to aid the swimmer when being clipped into and out of the apparatus. Finally, we had two harnesses to improve throughput.

Users' Perspectives and Observations

Over a five-day period we exhibited the swimming apparatus at ACM SIGGRAPH'04 in the Emerging Technologies exhibit and for four days during Imagina'05. We had four to six attendants helping and observing the experiences of the participants involved while they interacted with the swimmers getting them into and out of the apparatus. We did minimal video recording and did not give participants/audience

members written questionnaires to reflect on the experience during Siggraph. At Imagina'05, we distributed questionnaires and made video recordings.

At Siggraph, approximately 400 people (including about 10 children) tried the swimming device, and there were thousands of people who watched. The people who tried swimming appeared equally distributed across gender with a slight male bias. We did not notice any race bias given the demographics of the event. More often than not, audience members volunteered to swim; however, the attendants would occasionally go into the audience to solicit swimmers. Interestingly, attendants did not have success in predicting who would and who would not try swimming based on appearances.

We had 104 participants fill out questionnaires at Imagina'05 who were predominantly male (86 vs. 20) between 20 and 29 (21 under 20 years, 55 between 20 and 29 years, 23 between 30 and 39 years, 4 between 40 and 49 years and one person over 60 year old). Most were intermediate level swimmers (9 never had been swimming, 21 novices, 68 intermediate and 6 experts). Most had never tried a VR experience (78 vs. 26).

Overall, swimmers had a wonderful, engaging and enjoyable time swimming, and members of the audience had fun watching. The main comment we received is, "It was GREAT!" The main criticism we received is that people would like to have fish in the scene and better graphics. Some people commented that they preferred the third person view and/or would like to have control over the camera angle as seen in the HMD. We also had comments from people who wanted more feedback for the arms.

We consider there to be four different distinct user categories that had unique experiences with the exhibit: individual swimmer, swimmer within a group of swimmers, attendant and audience. Our design had significant impact on the way each type of user interacted and experienced the exhibit.

Individual Swimmer as User

Based on the variety of participants, we are able to group them along two dimensions that appeared to influence their experience: skill level and body size. Two additional factors in the experience were related to the HMD and user control.

We categorize each participant's swimming skill level into three types: novice, amateur, and expert. We assumed that expert swimmers would not enjoy the experience as much as participants in lower skill levels due to the low fidelity of the system. However, based on comments from the participants at Siggraph'04, what we observed was that novice swimmers and expert swimmers appeared to derive a higher amount of pleasure from the experience than amateur swimmers. Quantitatively, from our Imagina'05 questionnaires, almost everyone enjoyed the experience (4.3 score (std. dev 0.8) where 1 = strongly disagree and 5 = strongly agree, to "I enjoyed the experience" and 4.4 score (std. dev 0.8) to "I would recommend other people try it") with no obvious trends based on sex, age, skill or VR experience.

We hypothesize that novice swimmers seemed to enjoy the experience as it gave them the sensation of swimming but they were not hampered by an inability or fear of swimming. They were able to swim using simple strokes, or simply float and enjoy the environment. Expert swimmers were originally expected to be overly critical of

the environment since it does not present a realistic physical or visual swimming environment. What we observed, however, was that these swimmers quickly moved past the fidelity issues and concentrated heavily on their body. It appeared that the expert swimmers were using the device to explore the way their body moves through space. In some cases, trying movements typical of swimming, while other times they appeared to be trying different motions, ones that might not be possible in water, to feel and see the results. Most expert swimmers, however, did comment that the lack of resistance on the arms is one factor that they thought detracted from the experience. The lack of feeling liquid on skin was not reported as detracting from the experience from any of the swimmers. We suspect that amateur swimmers concentrated on the visual environment and indicated verbally as well as on the questionnaires. Though many enjoyed the experience, this category of swimmers seemed to be most critical of the fact that the installation did not provide a realistic environment.

One aspect that was common to all swimmers dealt with the coupling between the movements of the swimmer and the avatar. We had two main observations: first, that the movements must look the same, and second, the approximately 100msec of latency between movements was not a significant issue. Swimmers rarely mentioned the lag in the system. We believe that the fluid nature of the environment and the fact that the swimmer only had relative position cues to gauge where they were, mitigated the effect of lag.

People with smaller bodies appeared to have a different experience than those with larger bodies, probably due to using a one-size-fits-all harness.

Head-Mounted Display Issues

Many swimmers commented that they enjoyed the third-person view in the HMD. Since the swimming apparatus affords full-body motion, it is thought that full-body perspectives helped the user maintain a stronger connection between their physical movements and those of the avatar within the virtual environment; seeing the avatar's arms, legs, head and torso moving synchronously with theirs. This connection enhances intimacy with the device [9]. One difficulty, though, was that the HMD sometimes slipped during swimming. Some users suggested substituting a wrap-around display or simply a monitor placed in front of the swimmer rather than the HMD. Pierce et al. discuss other strategies to deal with HMD problems [18].

Swimmer Control

Perspective changes in the HMD were automated by means of the control GUI. Thus, the attendant did not have to concentrate on changing it; however, the view changes seemed to confuse some swimmers. The participant was unclear who was controlling the views. Some swimmers originally thought they were able to change it even though it was just coincidence that the view changed. This suggests a user difficulty in both execution and evaluation of the interface [16]. Similarly, the swimmer did not directly control when the experience started or stopped. Rather, it required an attendant (out of the swimmer's view) to switch between the view of the flight map and the virtual ocean environment. It was observed that participants were also confused by this ambiguity.

Swimmer in a Group of Swimmers as User

The swimmer was also part of a second user group, that of a group of swimmers collectively swimming across the Pacific Ocean. Our hope was to provide swimmers with a broader experience in the exhibit than just using a virtual reality device. However, we observed that participants were confused by the concept of collectively swimming across the Pacific Ocean. Our use of a "flight map over the ocean", to convey the idea was confusing. In addition, many users were disappointed to find that they were not swimming across the Pacific Ocean themselves, in compressed time. Quantitatively, during Imagina'05, participants judged with a score of 3.5 (std. dev = 1.0) suggestion they are between neutral and agree with being part of the team enhanced the experience. Thus, our solution to have the attendant provide the swimmer with additional instructions during the exhibit was not so effective.

Attendant as User

The primary job of the attendants is to help volunteers get into and out of the swimming apparatus according to the workflow as described in the *Attendant Workflow* section. Essentially, they were a main part of the interface between the system and the participants and audience. As such, they played three main roles during the exhibit: *system user*, *performer* and *mediator*. The attendants scored 4.8 out of 5 (std. dev. 0.66) by Imagina'05 participants when asked if they thought the attendants were helpful.

For the attendant as *system user*, we provided a robust and flexible design of our system for attendants to use. The control GUI enabled the attendants to adjust the system's parameters as needed. Initial parameters were set with only occasional adjustments afterwards, such as when an audience member or swimmer requested it. The simplicity of this interaction allowed the attendants to spend minimal time attending to the system and maximum time attending to the people.

By being a *performer* for the audience the attendants provide a theatrical and entertaining context to the audience to entice them to try it. Once an audience member agrees to become a participant, the theatrical context provides the mechanism to establish the attendant as a *mediator* that can be trusted. Trust is important since the *mediator* and participant need to have intimate interactions, so that the participant can fully enjoy the experience and feel safe. Some design elements support the role of *performer* such as a special bright T-shirt with a logo that all attendants wear. The T-shirts functioned as a uniform and costume to maintain the attendant's role as *performer*.

We observed the attendants, as *mediators,* bridged the gaps in understanding between the complex layers of the system such as the swimming gear, the VR environment, the different perspectives, and the artistic context. The mediation allows smooth human-computer interaction for the participants. *Mediators* give life to the installation beyond the technical aspects and make it accessible to the participants. As *mediators*, the attendants contextualized system deficiencies in cases where we encountered minor problems during the exhibit. Our design decision to use two harnesses influenced how the participant and the attendant related to each other. While waiting for the current swimmer, the attendant helped the participant get their

gear on and continued to talk while waiting. The act of working together initiated contact that facilitated a bond that continued to grow while they waited together.

Mediators interact with participants at two levels: verbal and tactile. *Mediators* talk to the participants to help them putting on gear, explaining what he is seeing or offering support to make him feel safe when he had to place his trust in the equipment to hold him up. They also communicate and entertain participants to make them feel comfortable in swimming experience. We anticipated this aspect in our design.

We observed another important aspect of the *mediator's* interaction*:* **touch**. Attendants had to touch participants regularly in the staging zone and the swimming zone (Figure 3). Touching made participants feel safe and complemented the verbal instructions. We found participants responded very positively to the direct physical experience of being touched by the attendants, allowing them to enjoy the experience of being in the swimming apparatus. We believe that the theatrical context of the exhibit allowed attendants to touch people in potentially sensitive areas that could have had quite negative consequences in other contexts. However, since the response was positive, our observations suggest that touch is effective in mediating the experience in interactive installations that have complex layers of interaction. We may only hypothesize in other mediated activities such as bungee jumping and skydiving that touch plays a similar role.

Audience as User

We observed several different roles audience members played: volunteers, communicators, and spectators. *Volunteers* are audience members who wish to participant in the exhibit and try the swimming apparatus. They often interact with the current swimmer verbally as well as ask the attendant detailed questions while waiting. *Communicators*, though not interested in swimming, are the audience members who are interested in understanding the contents of the installation. They ask questions and interact with the attendants and even the swimmer. We observed that *communicators* are particularly interested in what the swimmer is seeing in the HMD. They like to follow the swimmer's experience and they often interact with swimmer verbally; encouraging them, cheering them and joking with them. *Communicators* navigate the swimmer zone and audience zone spontaneously. *Spectators*, typically stand around the swimming apparatus watching and taking photos of the swimmer but generally do not talk to the attendants. For them, the poster and brochure are useful sources of information. Our design accommodates all the types of audience members, providing information, amusement and enjoyment for everyone.

Summary

We were very pleased that so many people enjoyed the *Swimming Across the Pacific* exhibit at ACM SIGGRAPH'04 and Imagina'05. This result validates that our main design directions for this novel virtual swimming exhibit were correct. We made three contributions: first, we created a successful swimming experience exhibit based on a VR swimming apparatus that was enjoyed by participants and audience members; second, we identified multiple roles of the attendant to engage and enhance the participant and audience experience; and third, we developed an exhibit-oriented

artistic context for the swimming apparatus. Thus, we believe that the approaches we use led to an enjoyable experience for all users informing the design of similar exhibitions that have complex interaction with technology.

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