Glowing Pathfinder Bugs: A Natural Haptic 3D Interface for Interacting Intuitively with Virtual Environments

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ABSTRACT

***Glowing Pathfinder Bugs* is an interactive art project primarily aimed at children and created by the digital arts group Squidsoup. It uses projection to visualize virtual bugs on a real sandpit. The bugs are aware of their surroundings and respond to its form in their vicinity. By altering the topography of the sand, participants affect the bugs' environment in real time, facilitating direct communication between them and computer-generated creatures.**

This highly malleable and tactile physical environment lets us define and carve out the landscape in which the creatures exist in real time. Thus, virtual creatures and real people coexist and communicate through a shared tactile environment. Participants can use natural modes of play, kinesthetic intelligence, and their sense of tactility to collaboratively interact with creatures inhabiting a hybrid parallel world.

This paper describes the project and analyzes how children in particular respond to the experience; it looks at the types of physical formations that tend to be built and notes how children instinctively anthropomorphize the bugs, treating projected imagery as living creatures – though with a ludic twist.

Introduction

Glowing Pathfinder Bugs builds on Squidsoup's interests in combining informal modes of communication with the individual's sense of space – be that visual, physical, social, or emotional space – to create an arena where meaningful and creative interaction can occur [1]. The piece is an attempt to provide an environment where people, primarily children, can collaboratively engage with (and attempt to control) responsive elements in a highly tactile, multisensory, spatial environment.

Figure 1. *Glowing Pathfinder Bugs*, detail.

The piece is effectively a dynamic, responsive world in miniature. Initial ideas revolved around weather patterns and flooded landscapes, but it became clear that the real interest was not in the landscape itself, but the creatures that live in it. By focusing on the relationships between the environment and its inhabitants, the project developed into a malleable inhabited space, where the virtual creatures are aware of, and respond to, their changing environment. The environment itself can be manipulated and controlled from a God-like perspective by participants.

The initial inspiration for the piece came from the artists' observations of their own children at play, both in traditional sandpits and with animals. The powerful impetus children feel to anthropomorphize and create narratives around living creatures [2] seemed to have a resonance with the landscaping potential of the sandpit.

From an interaction design perspective, the technical interpretation developed out of a search for new modalities for creative interaction, mediating virtual experiences and systems in physical space. This came from a desire, in common with broader efforts within the tangible interactions and physical computing movements, to seamlessly bridge the gap between tactile materials and computerized systems [3]. Natural user interfaces are, and have been for a while, moving more into natural material interfaces, where the properties of a physical material are defined or designed according to the requirements and affordances of the application [4]. In the case of *Glowing Pathfinder Bugs*, the initial motive was to use an engaging physical interface to sculpt the topography of a virtually inhabited environment, with a minimal learning curve.

Figure 2. ***Freq2*****. © 2009 squidsoup.org.**

The project developed in part from a series of projects by the artists that use the human body to control hybrid experiences in real time. *Glowing Pathfinder Bugs* draws in particular on *Freq2* (Figure 2) [5], where participants' silhouettes are used to define the leading edge of an extruding virtual landscape. In *Glowing Pathfinder Bugs*, the physical landscape is mapped directly into virtual space; any changes to the physical topography of the sandpit are immediately mirrored in the virtual environment. However, the themes of communication and collaboration, the sense of and control of real and virtual space are present in nearly all of Squidsoup's work (see, for example, *Driftnet*, *Come Closer*, *Altero*, and *Ocean of Light*). These works are also part of a broader lineage of artworks that merge physical environments with connected virtual layers; examples of this range from David Small's *Stream of Consciousness* to the large-scale projected works of AntiVJ and UrbanScreen.

Sand as Interface

Sand was selected as the interface for a number of reasons. It is a material that most children are very familiar with and play with instinctively; thus it brings the right affordances with it, enticing interaction and engagement. Its physical properties, in particular its malleability, can also be easily controlled. The addition of a little water to the sand makes it sticky and malleable, able to be formed into steep mountains, valleys, tunnels and spires. Its associations with beach holidays and sand castles, suggesting fun and carefree play, are perfect for attracting younger (and older) participants. Additionally, it fulfils a vital role in harnessing kinesthetic intelligence [6], allowing for creative dynamic spatial interaction.

The Tangible Media Group at MIT has also explored the use of malleable materials like sand as interface [7,8], though both the application and the technical methods used are different from *Glowing Pathfinder Bugs*. *Sandscape*, for example, is aimed primarily at professional architects/

designers and used for rapidly sketching out possible architectural landscapes. Their results suggest that such forms of “Continuous TUIs” (tangible user interfaces) are intuitive to work/play with, and can be used to facilitate collaboration and promote the involvement of lay people [9] – ideal for the more intuitive and playful application discussed here.

Sand has also been used as the interface in other digital art installations. It has been used to symbolize a larger environment, though the modes and effects of interaction have been quite different. *+-now* by Jan Seevinck [10] uses dry sand as a time-based sketching tool and looks at the emergent forms that arise. Dew Harrison’s *Shift-Life* [11], a modelled Darwinian eco-system, also focuses on emergence but through illustrating evolutionary artificially intelligent processes that take account only of predefined meta-interactions (e.g., pouring acid rain onto the ecosystem from a watering can), rather than direct interaction with, and responses from, individual creatures.

Glowing Pathfinder Bugs is unique in using the sand as the primary mode of synchronous communication between participants and virtual creatures. This creates a direct and understandable, yet somewhat unpredictable, form of interaction.

The piece has been exhibited at numerous events: almost a dozen times in various locations in Northern England as part of PortablePixelPlayground, at SOMA/Art Centre Nabi (Seoul, 2009), AbandonNormalDevices (FACT, Liverpool, 2009), iDesign (University of Westminster, London, 2009), Onedotzero (BFI London), and Technofolies (Montréal Science Centre, 2010).

Glowing Pathfinder Bugs – Direct Mapping of the Virtual onto the Physical

In *Glowing Pathfinder Bugs*, the sandpit is visible from a distance but, on approach, visitors notice small bright creatures wandering about on the sand – these are the Glowing Pathfinder Bugs. Each bug is projected onto the sand, and is free to move around the sandpit according to certain predefined rules and behaviors (discussed below). The bugs are therefore visualized in

Figure 3. _Glowing Pathfinder Bugs_, inhabiting both real and physical space. © 2009 squidsoup.org.

their "real" location: they can be seen inhabiting the sandpit, they are aware of their surroundings, and they can navigate around obstacles and along gullies as the landscape is forged (Figure 3).

This means that there is no positional disjunction at play in the installation – the real and virtual worlds are directly mapped onto each other. Each bug is projected onto a specific coordinate in the sand, and is directly aware of, and reacts to, its local physical landscape in real time. If a bug's physical environment is altered, its effect is felt simultaneously in the virtual world. This is in stark contrast to the majority of augmented reality or even general metaphor-based interfaces, where a positional jump is required. In most interfaces, the physical component of the interaction is generally at one location and mapped onto a virtual space that is at another location (e.g., the physical mouse maps to the virtual on-screen cursor), causing the interactor to cope with a location jump that is at odds with our normal relationship with the physical world. Although we are now very familiar with such positional disjuncts, its abnormality means that it detracts from participants' sense of engagement and flow.

Children and adults are generally very quick to understand the processes and rules of engagement in the piece. They appreciate that, by altering the landscape, they directly affect the behavior of the bugs. They can encircle them, trapping them in small areas, they can determine where they go, separate them, or force bugs together. People recognize there is a clear and direct relationship between their actions and those of the virtual bugs.

The idea of creative interaction mentioned above extends to how people play with the bugs – they can be antagonized, terrorized even, but they can also be anthropomorphized, cared for, and husbanded. One of the initial intentions of the piece was to encourage a simple form of animal husbandry; a sense of looking after, controlling, breeding, and caring for these virtual creatures.

Yet the environment in which the bugs live can be regarded as both medium and interface: there are no imposed rules that relate explicitly to the use of an interface or sophisticated instruction set that requires language or experience to use. The intention here is that any hierarchy that forms among the participants is not one of prior knowledge, but is, broadly speaking, an entirely common skillset, a skillset that can be observed even in the youngest children, one which you bring with you or that you develop collaboratively.

A Bug's-Eye View (Technical)

The project's main technical method evolved from experiments using a stereo camera [12] to track body movement and shape in real time. Imagery from calibrated stereo camera pairs can be analyzed in real time to produce acceptable quality depthmaps – images where the color of each pixel denotes its distance from the camera lens (in Figure 4, red is nearest the camera, and blue furthest away).

The setup for *Glowing Pathfinder Bugs* points the camera at the sandpit. It is positioned directly above the pit, next to a projector that is also pointing in the same direction. The two are roughly calibrated, so that the camera image is in alignment with the projected image. Thus, projecting the depthmap image, calculated in real time as described above, would make any peaks appear red, and troughs appear blue.

The depthmap is not, however, displayed or projected except for initial calibration. It is used instead as the basis for each bug's decision-making process regarding its trajectory. A bug, projected onto a certain location in the sandpit, can easily analyze its matching virtual surround-

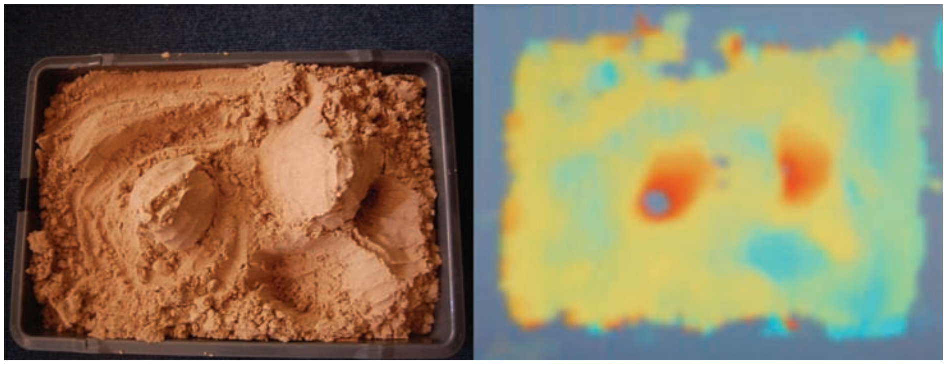

Figure 4. Sample sandpit seen from above, and associated depthmap image. © 2009 squidsoup.org.

ings (from the related depthmap) and use this topographical information to take appropriate decisions as to where to go next (Figure 5). The method is particularly well-suited to recording the topography of sand, as overhangs and tunnels are hard to achieve. This means that topographical surfaces that are occluded and therefore not detectable by the camera are rare, and an accurate virtual model can be read at all times. Speed of movement was used to differentiate sand from faster moving participant limbs.

Now that the bugs were aware of their surroundings, the next step was to develop a decision-making process for the bugs that enabled them to react in a meaningful manner to their changing environment and communicate effectively with their human interactors.

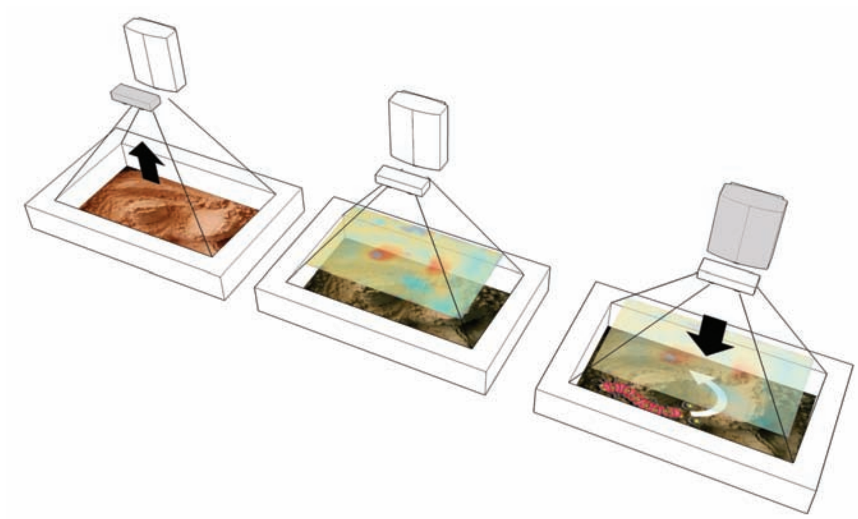

Figure 5. Three stage process involved in Glowing Pathfinder Bugs creature analysis and behavior. Sand topography is scanned in real time and turned into a virtual depthmap layer. The depthmap for the area around each bug is analyzed to determine its new position. The bug is then projected back onto the sand in the new position. © 2009 squidsoup.org.

Bug Behavior and User Trials

Psychologist James Hillman said, “Where imagination reigns, personification happens” [13]. Edith Ackermann points out that this ability to personify and empathize is “a key component of learning and development,” allowing us to appreciate and understand others’ points of view, and then adjust our own. She points to three attributes that maximize engagement with enhanced or animated toys: artificiality (how real does the toy appear to be), believability (consistent and meaningful behavior), and conviviality (apparent ability to empathise and engage directly – in this case associated with anthropomorphic potential). All three attributes are important, but the key here is believability in order for the crucial relationship between changes to the environment and the behavior of the creatures to be apparent and understandable.

To achieve this, various methods of bug-based decision-making were attempted. The requirements of the bugs were:

Natural-looking behavior and sense of purpose

The bugs need to behave as though they are alive; movement is their prime opportunity to encourage anthropomorphism; it can suggest character, optimism, courage, and so on. Early models tended to revert to disconcerting behavior patterns: repetitive movements where a bug would move rapidly between two points was a common problem. Similarly, code that selects the current location as the best available option is undesirable, as the bugs will just stay still, or move within tiny areas. Our bugs needed a sense of purposefulness.

Ability to distinguish between steep and shallow inclines

The aim was to create bugs that could be shepherded, controlled, hemmed in. They therefore needed to see steep inclines as barriers. Shallow inclines, and shallow drops, needed to be acceptable to cope with roughly hewn gulleys. So a relative system was developed that compared the bug's current altitude to the possibilities around it while preferencing the area ahead of it.

Trials with various bug behaviors suggested that those with a preference for modest downward inclination were the most reliable at following rough gulleys, and so this was adopted as the standard behavior.

User trials also highlighted two other requirements for the bugs' behavior, slightly at odds with each other:

Panic

The bugs were freqently attacked in trials. "Let's pop it" and "Kill it" were common instincts among some demographics. It became apparent that the bugs needed an increased instinct for self-preservation. They were therefore programmed to de-materialize if under attack. An attack is detected if there are widescale rapid changes in the local topography (caused by arm and hand movement picked up near the bug by the camera). De-materialization is manifested through a colorful splat (much like that which occurs when two bugs metamorphose, see above), and the threatened bug disappears. It (or another bug, depending on one's interpretation) then crawls out of the ground a few moments later in another location.

Don't panic

The bugs needed to perceive the difference between being attacked and friendly advances. Many children in the trials wanted to pick the bugs up (Figure 6), which could very easily trigger a panic state. The behaviors needed to be adjusted to cope with gentle upward vertical movement, so long as the area all around the bug remained at similar heights as it rose. If only part of the bug is picked up it will, entirely understandably, panic.

Figure 6. Picking up a bug. © 2009 squidsoup.org.

The Narrative Environment

As an introduction to the project, and to explain the behavior of the bugs in an easy to understand way, a playful plotline was built around the piece that imagined the bugs had been captured by Victorian explorers in a distant land (Figure 7):

> Recently discovered by Squidsoup researchers in Faroffistan, the Glowing Pathfinder Bug appears to be a hybrid centipede/caterpillar. It lives in the sandy deserts of Faroffistan, and has the habit of roaming along small trenches, gulleys, and paths. Its usual habitat has been recreated here.
>
> The Glowing Pathfinder is also a very sociable animal – it likes to meet other bugs, and when two Pathfinders meet, VERY strange things happen! [You] may be lucky enough to witness their unique and magnificent instant metamorphosis.

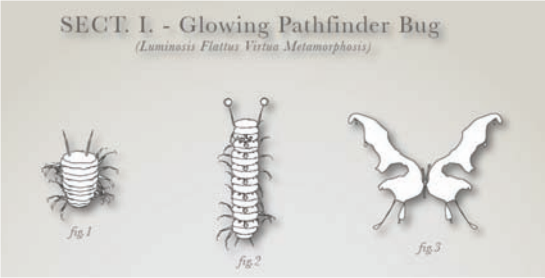

Figure 7. The explanatory narrative was given a Victorian explorer's feel. © 2009 squidsoup.org.

Some form of reward or positive feedback is required when bug shepherding has been mastered, and two creatures meet. A cartoonish interpretation of metamorphosis has been incorporated into the piece for this: when two creatures meet, there is a colorful splat, and the two merge into a single, more advanced, organism. The visualization (the splat) draws on the stains a butterfly leaves behind when it emerges from the chrysalis. Three types of creature were designed: a small, standard bug; a larger, fatter, brighter bug (the product of two small bugs merging); and a butterfly (formed when a large bug merges with another bug).

There are a maximum of six visible bugs at any time. However, each time metamorphosis occurs, two bugs merge into one and this leaves a bug "free" to re-emerge as someone else at another location on the sandpit. This gives the piece an indeterminate feeling, as though bugs magically keep appearing, yet there are never too many to be able to control effectively.

Created Environments

The relatively simple behaviors of the bugs are not complex enough to encourage the production of a wide range of forms in the sand. Additionally, the focus of the piece is not on the aesthetics but the function of forms created. Nevertheless, the forms are of interest and act as a record of the interactions of participants and the communication between kids and bugs.

The forms created by participants are surprisingly consistent and homogenous, and can be categorized as follows:

Mounds

These are usually the first form to be built. Part rudimentary sandcastle, part test to see the effect on the bugs, mounds are often the first attempt on the part of users to affect or communicate with the bugs. A mound is then frequently elongated to form a barrier.

Barriers

At its simplest, a barrier is a wall that divides bugs, stopping them from traversing between zones (Figure 8). However, the idea is often expanded, and the wall may subsequently not be perceived by the builder as a barrier at all, but more of a challenge to test the behavior of the bug: will the bug cross over, how high does the barrier need to be, and so on. Sometimes the building process results in a focus on form for its own sake.

Dishes

These attempt to bring together; to corral the bugs into specific areas. Rather than leaping fences, the bugs can be huddled together, surrounded by the edge of the dish. Dishes are generally produced when small groups of participants (2-4) are actively engaged in the development of sand forms. Several participants referred to such structures as amphitheatres or arenas for combative sport.

Figure 8. Building barriers. © 2009 squidsoup.org.

Gullies

Gullies are complex forms that imply leading and direction: children are not simply herding or dividing, but are sending the bugs on a journey and so may be creating a narrative for the bugs or inventing more complex games from the simple interface. Gullies usually occur either as a second barrier (i.e., making a long, narrow zone bounded by two barriers), which then evolves into its own form, or through the encouragement of an adult. However, in both cases, the gullies can develop into complex branching structures.

The motive of the participant is also worthy of note. The behavior of the bugs elicits the building of forms that control them. This control can be used to separate and isolate, or to bring together – to kill or to help procreate – and this relationship between cause and effect is well understood and ruthlessly exploited (by children in particular). Thus the forms that emerge on the surface of the sandpit may look similar but emerge from very different intentions. Similarly, the collaborative aspects of construction are very complex, and may be competitive or collaborative, and geared towards the full range of ends discussed above.

Findings and Conclusions

Glowing Pathfinder Bugs was conceived as a small but immersive space where people can communicate directly, and interact physically, with responsive virtual creatures. It uses sand as a physical interface that doubles as the environment in which virtual creatures live.

Ackermann suggests that to optimize engagement and quality of user experience, the creatures need to respond in a believable way, simultaneously responding meaningfully to changes in their environment, and in a convivial way to engender empathy and relationships, while retaining an appropriate level of artificiality.

It seems that the design decisions taken have managed to fulfill these criteria. Several public trials and exhibitions of the piece have shown that it is effective and attracts a large and engaged audience, particularly among younger participants. Attendance time is very variable, but some children have stayed for well in excess of an hour, and have frequently returned. High levels of flow and immersion in the piece, and affinity with the virtual bugs, were exhibited by many participants. These properties are helped by the very direct and physical nature of the interface, coupled with the lack of positional disjunction. Bug behavior also, being clearly responsive and quite animal-like, assists in building relationships between bug and user, causing in some instances a real sense of loss when a bug "pops" or is "killed" (this is captured on video – see

[14]). The bug behavior, design, and the use of a sandpit, with all its inherent associations, also ensure a strong ludic element to the piece, putting people in a mental space where play is clearly the point, and is likely to be rewarded.

The paper undertakes some rudimentary user analysis of the forms created in the sand by participants. These are fairly homogenous, but occur for a range of reasons defined by complex and conflicting forces (controlling bugs, the will to sculpt form directly, differing perceptions of the processes at play). The forms created are very different from those generally sculpted in sand. Further research on this aspect of the project would require analysis of the forms created under different circumstances – for example, by altering the bugs' behavior and appeal (e.g., making more realistic bugs, spiders, or snakes).

At a broader level, it is clear that this kind of approach to physical interface design has huge potential. The use of 3D cameras in computer interfaces (whether using an infrared camera or stereo comparisons as used here) is an expanding area, though the usage generally focuses on the tracking and analysis of body movement and gesture. The potential for using similar technologies and techniques for analyzing topography/surface shape is pregnant with possibilities and potential uses. Work so far on this project, and others mentioned in this text, point the way for exciting future projects and research.

Acknowledgements

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