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Human-Scale Systems in Responsive Environments

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Most technologies are human centered, while also operating at a particular scale, from the microscopic (or even nanoscale) to the macroscopic (global scale). Artistic endeavors tend to converge on the human scale—they affect individuals and are valued for their peculiarities, rather than their generalizability for a mass market. Artists' work often involves subverting the original applications of technology (from consumer electronics to medical or military technologies), in order to extend its use beyond the merely functional, into the realm of the social and the aesthetic.

At FoAM, a laboratory dedicated to the entanglement of art and technology, we use and develop technologies at the human scale. At this scale, otherwise opaque technologies can become more comprehensible, meaningful, and capable of directly engaging users' attention and activity.

Our work involves developing responsive environments influenced by technologies such as wearable computing, gestural instruments, sensor networks, permaculture,[1] and tensegrity structures.[2] In these environments, we're exploring a human–computer interaction (HCI) or human–computer–human interaction (HCHI) that discourages stimulus–response metaphors, relying instead on a more subtle negotiation between the human participants and the computational system.

Unlike strict rule-based gaming environments, our environments facilitate conversational interaction models that can assume the shape of free-form playspaces. These environments are composed of media, materials, and architectures that are incorporated into public spaces, creating a tension between the real and imaginary, and between technological and biological systems.

Editor's Note

Every system can become smarter, efficient, and more valuable by factoring in presence information. Society's embrace of instant messaging has shown that a great deal of importance is placed on presence-enabled contact lists and instant connectivity. Even traditional resource management systems such as automated routing use availability and presence to select and connect people to the best available agent in a call center. Multimedia conferencing takes presence information a step further and asks the question of how to connect people based on their disparate communication capabilities. But all these uses of presence information, as exciting as they are now, and as much potential to develop further as they all have, are but a tip of the iceberg of the communication revolution ahead. In the future, the wealth of presence information—and the kinds of information we are able to obtain—will change everything.

We can use new technologies—including sensors, wireless, image analysis, motion detection, and embedded systems—to capture, monitor, and track presence, action, and even intention. In this new era of pervasive presence information, why would my phone simply ring when my entire office could be used to alert me that someone wants to contact me? In this article, we learn of the exciting work done by the group FoAM, in which entire environments are transformed into responsive spaces where people are inextricably part of influencing their environment by their presence, actions, and even intentions. FoAM offers a small window into the future of presence technology—where a person's intentions, as well as their actions, can effect change.

—Dorée Duncan Seligmann

Sensing and the sensory

HCI's history has been punctuated with ideas that challenge existing assumptions about what a computer is and what it can do.[3] The visionary concepts of people like Doug Engelbart and Alan Kay have yet to be fully integrated into systems that are capable of enhancing, but not disrupting, human activity in everyday reality.

When dealing with the physical environment and nonsymbolic aspects of human interaction, many HCI methodologies relevant to screens or object-based systems can often appear misleading. Conventional HCI relies on a thin data

1070-986X/05/$20.00 © 2005 IEEE

Published by the IEEE Computer Society

stream of bits, either as discrete characters or coordinates of a pointer moving over defined regions on a flat surface, for example, which can then be encoded, compressed, and differentiated from noise. Sensor-based input can range from the discrete (switches) to continuous (time-based data streams). Our interest lies closer to the latter end of the sensory spectrum, as we're designing systems that users can experience as components of a physical reality in which action is continuous and unpredictable.

Toward immersive systems

Our senses mediate our interconnection with the world, dominated by sight and skin, tuned by sound, and enhanced by taste and smell. We continuously analyze, modulate, and adjust the synesthetic manifold that seeps into our bodies through our sensory network to such a degree that we perceive ourselves as immersed in the world. Since childhood, we've learned to live and act in this world, and we intuitively grasp the ongoing exchange between the world and our own existence.

With mixed-reality applications, we attempt to take advantage of this inherent knowledge and develop systems that can operate in a similar, continuous, immersive fashion. We're interested in systems that can sense (rather than detect) not just presence or absence, but the range and subtleties of human gestures and interactions.

By developing systems that behave as entities aware of their own presence and that of the people interacting with them, these systems should begin to enter into a dialogue (polylogue) and thus evolve out of the silent black- or beige-boxed observers that computer systems have become. We are looking to expand the thin data channel of computer-mediated "sense" beyond what humans are currently capable of with the hope that, for example, humans might one day touch over distance, simultaneously see in multiple directions, or have their "ears" distributed through different environments and time frames.

HCI approaches in mixed realities

FoAM's approach to HCI encourages users to engage with computational systems more like they would with a living entity. Such a system should be able to sense an aggregate of stimuli, through which it can form (or appear to have formed) a multimodal image of both the physical environment and its own internal computational state. At the intersection between the physical and the computational, the system should perceive the changes caused by human participants (their movement, social interaction, or even biometric information), as well as more autonomous changes in its own simulated dynamics (such as swarms or particle systems). Furthermore, the system should be able to interpret these changes and formulate meaningful responses—in real time—for an audience that might be overwhelmed with audiovisual stimuli and be trying to make sense of their experience.

In order to test HCHI in mixed reality spaces, we have set up public experiments in a range of locations. During these experiments, we have found HCI usability tests unable to cope with the complexity of a "real life" laboratory. In an attempt to establish a more valid methodology for testing our systems' usability, we turned to research on human-to-human interactions, both with and without technology. We've used both ethnomethodological and phenomenological approaches that have begun to give us an understanding of the variety and range of human responses.[4,5]

Responsive environments

In responsive environments, human participants can manipulate digital media by modulating the physical environment around them, through conscious and unconscious actions (such as bodily movement, physiological responses, speech, and social interaction). As the environment simultaneously senses and responds to these actions, the participants become immersed in media worlds whose shape and behavior react to their presence. The interface between the human participants and the media systems occur through networked sensing technologies that provide data from individuals, groups, and their social dynamics (see Figure 1, next page). As the following example shows, the systems can analyze and use this data to drive media systems ranging from visual to sonic to tangible or even olfactory.

For example, say a person enters an environment and starts exploring the space by moving around and touching its surfaces. She soon realizes that her actions cause simple changes in the projected lights' color. The longer she moves around the space, the more complex the colored patterns become. She then realizes that she can compose changes in the light and that the sounds around her are becoming more obvious and musically interesting.

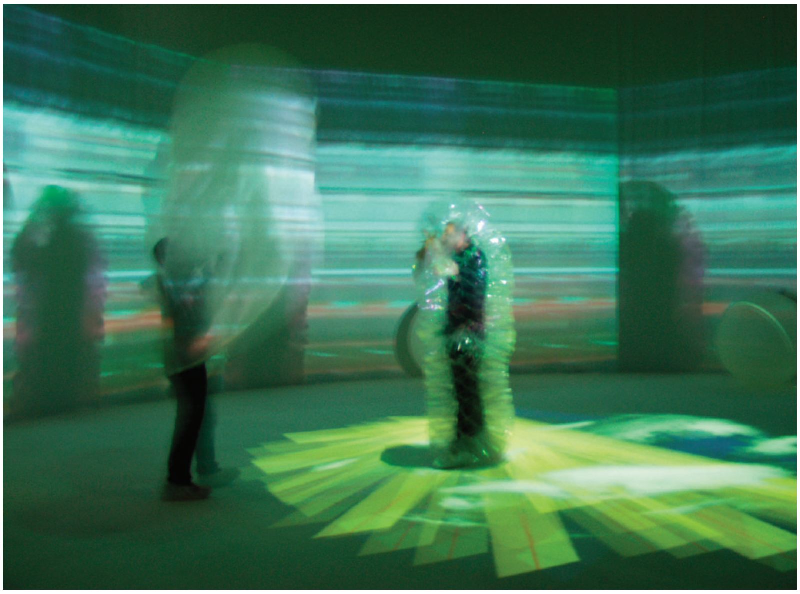

Figure 1. The txOom responsive environment at Italy's BIG Torino Festival (Biennale Internazionale di Arte Giovane).

Another group of participants enters the space, making large movements and disrupting the previously composed patterns. The first participant walks across the room. The system recognizes her movement pattern, and resumes the subtler sonic and visual coloring, mixing in the audiovisual patterns generated by the new players. The other participants might see that moving as a group affects the environment differently than playing with it individually. With the environment itself modulating its responses to these situations over time, distinguishing aspects of individual and social play.[6]

In the artistic sphere, responsive environments provide a new trajectory for exploring social interaction, with games and play serving as a means of creative expression for artists, performers, and, most interestingly, the general public. Because their medium is an environment in which people can engage directly with a real-time media system without a defined role, script, or predetermined direction, the artists become more like architects or instrument makers, rather than creators of a finished piece of "art." Working in the interstitial spaces between the physical and digital, responsive environments can bring imaginary worlds to life, letting users encounter them as synesthetic components of a corporeal reality.

Developing such systems requires equal flexibility. At FoAM, the teams developing responsive environments include visual, sonic, and installation artists; material designers; mathematicians; physicists; computer scientists; and electronic and mechanical engineers. After defining a common goal, the team members tend to work autonomously, while remaining open to other approaches. This process enables diverse working methods and outcomes.

Playspaces

The responsive environment projects that FoAM has been involved in aim to move away from the understanding of technologically driven art as a primarily aesthetic and remote discipline. Our goal is to create environments as a basis for compelling, creative situations, where art works can grow into participatory art worlds.

We view these responsive environment projects as phenomenological experiments for nonintentional public spaces.[7] By "nonintentional" we mean that the spaces are designed to evolve without a specific goal and to encourage a multiplicity of interactions and behaviors. Our investigations are guided by questions such as: What kinds of experiences can responsive spaces provide? How can participants benefit from socially shaping their surroundings?

Although these environments tend toward a particular aesthetic, the events within them are unprescribed. We invite participants to play and experiment individually or in groups, as if they were entering into an unknown terrain and were free to carefully explore its dynamics. Such environments let people experience the effects of their individual actions on human temporal and spatial scales (in real time, at room size) through their own senses.

TGarden

TGarden (http://fo.am/tgarden/) was our first public experiment in responsive environments, developed in collaboration with Sponge, a San Francisco artists collective. We designed the TGarden installations to function as calligraphic spaces in which the "play" consisted of players' gestures being transformed into graphic and sound material, leaving marks and traces in much the same way as a calligrapher would with brushes and ink (see Figure 2). We developed several installations over a two-year period, gradually incorporating the public's experiences and feedback.

TGarden took place in a square room with a floor projection and surround sound (in some instances, we included large white balls to distort the projections and encourage playful situations). Participants entered wearing a costume outfitted with basic sensing capabilities (accelerometers for orientation and acceleration, and light-emitting diodes for off-body position tracking). Groups of up to five people then composed an ambience, in which their sonic and visual traces influenced the continuous media output. The system sensed and analyzed player movements, providing the media systems with both raw motion data and a range of "cooked" data. From this, the system could derive such things as one player's compound activity, the players' proximity to each other, and activity over time or average energy levels (by accumulating the total movement of one or more players). The graphics and sound systems could then use this information to modulate the real-time composition of the visual and sonic shapes.

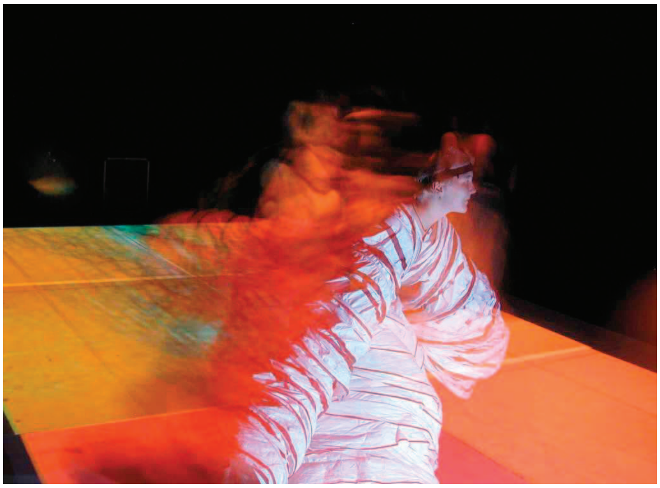

Figure 2. TGarden participant at Las Palmas, the Netherlands, wears a sensor-equipped costume that measured acceleration and orientation of movement.

txOom

FoAM continued developing this line of work with txOom (http://fo.am/txoom), a collaboration with four other European organizations and several independent artists. txOom extended the TGarden system with a media environment (and its computational backbone), with the capacity to be attracted or repulsed by particular gestures and grow "moody" or "bored" and modulate its responses accordingly, becoming more like another player. We extended the costumes into architecture, creating more pliable "wearable architecture," such as wearable walls and dresses that served as both large projection screens and trapeze harnesses (see Figure 3). These costumes contained accelerometers and cabling, woven into the materials, enabling the system to sense gesture and movement, as well as the materials' physical characteristics.

The txOom spaces were circular and made of flexible architecture. Visual and sonic media projections surrounded participants as the system projected evocative graphics onto their costumes, the walls, and the floor. We calibrated the media to the particular sensibilities of each costume and its materials, treating each as an independent organism.

Figure 3. txOom responsive environment in Great Yarmouth's Hippodrome. The player's costumes are "wearable architecture": harnessed several meters off the ground, the costumes functioned both as sensing devices and projection screens.

Transient Reality Generators

Currently, FoAM is working on the Transient Reality Generators (TRG; see http://fo.am/trg) project in collaboration with Time's Up and Kibla. In TRG, we explore people's interaction with an environment modeled as an ecosystem or a universe that reshapes itself on a human scale. The space consists of self-contained but interconnected modules that are stretchable and inflatable. The modules' physical properties (stretch, inflation, air density, and so on) can be modulated by the same dynamics that manipulate the visual and sonic media.

The environment is modeled as a "membrane universe" shaped by fictional equivalents of the four fundamental forces: gravity, electromagnetism, and the strong and weak nuclear forces. The participants' movements modulate the effects that the forces have on membranes, which can

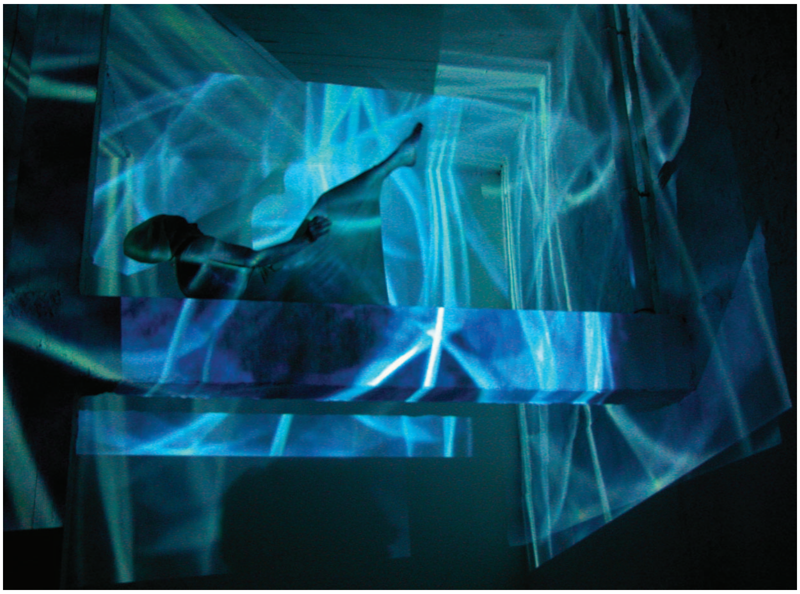

Figure 4. Stills from the performance of **Illumine: Ebb and Flow of Stubborn Matter.** *Experiments in antigravity performance with Camila Valenzuela and Isabel Rocamora (see http://fo.am/illumine/).*

range from compacted and tangled to fully uncurled. The environment discerns participants' movements through a range of sensing technologies, including cameras, stretch sensors, and accelerometers that perceive the sensed activity as a perturbance of the system's internal stasis.

Perceptual technologies

Perception is the crucial link between the environment and any action or response beyond the most basic reflex. Most current sensor systems' bandwidth is made up of many small, comparatively thin channels that provide a more spatially and temporarily distributed viewpoint than the fixed, high-bandwidth human sensory apparatus.

Computers are particularly good at accumulating and processing massive amounts of data (as long as it's Shannon-type information). However, their ability to process human gestures, encode embodied motion, and form associations or act on such data is minimal and often unwieldy. Given this, any computer-based processes operating at the human scale would need to handle degrees of ambiguity, variability, and richness of activity, while also manipulating the acquired data at a much faster rate.

Sensing, analysis, and interpretation

Our sensor analysis is inspired by a geometric approach suggested by Sha Xin Wei[8] and Yon Visell,[9] which was extended and reduced based on our experiences during public tests and performances, along with those of Sponge and Time's Up. This model has gone through two major iterations. The first was a simplical model ("eerm") that mapped sensor data to potential energy in order to determine general and specific characteristics (or moods) of the environment. The second, "gob," was characterized by its use of sensor data to deform a geometric surface that was correlated with the physical space.

One of this method's key abstractions is that it treats direct sensor input and data streams derived from the direct input in the same way. This enables the media systems to receive the raw sensor data and the analyzed and "munged" data (such as "energy levels," "tilt," or "groupness") in the same format. In this way, the media systems can react to simple sensory input, such as acceleration on the *x*, *y*, or *z* axis, while also dealing with more complex, interpreted perceptions, such as interactions between two players with dramatically different activity levels. Our challenge is to design media systems that not only process simple and complex perceptions, but also are capable of meaningfully acting on those perceptions.

The tight coupling between sensory input and environmental feedback shares motivation (and to a degree, methodology) with the "bottom-up" approach found in embodied robotics research. The slower, less direct coupling has more in common with biological or physical simulations. We delineate the regions of our investigation between these extremes.

Experiments in responsiveness

In TGarden, we originally designed a "media choreography" system that could change the states of media responses (much as a choreographer designs dancers' movement through space). However, we could only feasibly implement a preset range of instruments that were directly coupled to the raw sensor data. This limitation resulted in an environment with a fixed range of responses.

With txOom (and especially in the Time's Up installation, "Sensory Circus"), we derived the environmental dynamics from a geometric landscape on which different media states were visualized as surface distortions. The players were modeled as particles moving on this dynamic surface, with their sensor input modulating the particles' trajectories.

The TRG model moves further away from state-based dynamics, constructing a media world shaped by simulated forces that are assigned to particular qualities of the participant's actions. We based the system on a fantastic physics that lets the space grow, decay, compact, or expand on the basis of different actions it perceives. With this approach, we hope to come closer to our ideal responsive environment: a free form, spontaneous space with a consistent aesthetic, yet indeterminate evolution, that people from a range of cultures, ages, and backgrounds can experience.

Decoding presence

FoAM's work in responsive environments focuses on how human movement can influence and shape media environments. In a sense, we "recycle" the residual energy of a body's motion into a resource for media generation and output (see Figure 4). We're particularly interested in participants' untrained, habitual movements such as touching, caressing, grabbing, bending, walking, and jumping, and how responsive media might raise participants' awareness of their effect on the surroundings. Designing environments as semipermeable "skins" has allowed our costumes, architectural elements, and media systems to suggest different movement types, such as heavy, light, restricted, bouncy, and spinning. As participants explored the materials, shapes, and regions that they've found most compelling, the environment's ambience and mood change accordingly.

The responsive environments that we're interested in are places in which people can express themselves through familiar actions and gestures,[10] without needing to learn new interface metaphors. HCI occurs through an intricate network of sensing technologies, perceptual analysis, and evocative real-time media, targeted toward nonverbal and nonsymbolic interaction with the environment and other participants.

Ultimately, we hope to emphasize the importance of human agency in a technologically driven world, by continually testing new and emerging technologies in public contexts and with novel applications. Our experience with different projects has strengthened our belief that the most interesting work can happen when boundary conditions become blurred, bleeding strange edge effects and oozing imaginary realities into the tangible world. Like most technologies, it's most successful when transparent. For full project credits, please see http://fo.am/{tgarden, txoom, trg}/credits.html. **MM**

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