Art on Graphics

Editors: Bruce Campbell and Francesca Samsel

Endogenous Biologically Inspired Art of Complex Systems

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Artists look to nature for inspiration. Since 2007, we have done so to create a series of "artificial natures," or interactive visualizations of biologically inspired complex systems that can evoke nature-like aesthetic experiences within mixed-reality art installations. A common theme binding the various principles that emerged from this work is the importance of endogenous accounts. Specifically, all perceivable forms have dynamic ontological roles within the world; visitors become part of the ecosystem, both through immersive display and through interactions that induce presence; the simulated world is able to autonomously originate; and as a result, interaction can lead to exploratory discovery. This article describes how we have applied each of these principles in visualization, sonification, and interaction design, with specific examples from exhibited installations. We share our insights gained as we document our techniques.

Endogenous Accounts

A first principle of our work is to "show the system," to direct the visitor's attention toward the substantial qualities of the virtual world, in which both aesthetic form and functionality must go hand in hand. Our goal is to provide insights by communicating the key aspects of the world, and the relationships between its elements, at multiple levels of detail and in intuitive ways.[1] In these regards, our work is closely related to interactive data visualization. (This relationship is explored in detail in our earlier work.[2]) However our working principles diverge by eschewing the integration of textual and statistical indicators, and our works do not serve specific analytic purposes. Because each work realizes a model world, we instead adhere to a principle of *endogenous visualization*, which requires that every perceivable element must have dynamic ontological capacities in the world, playing an active role in multiple world-level processes with other such elements. (We use the term "ontological" with its original philosophical meaning—regarding the nature of existence, being, reality, or ultimate substance—rather than the usage it has taken on in information science, which specifies categories and relationships of entities within a domain of discourse.)

In terms of visualization, this poses some interesting challenges. It implies that "nondiegetic media" should be avoided—that is, no secondary or symbolic notations, almost none of the well-researched statistical graphical devices familiar to data artists, nor the information overlays favored by game designers. (This terminology of "diegesis" is borrowed from film theory: diegetic images and sounds emerge from within the space of the story world, whereas the sources of nondiegetic media, such as the narrator's commentary, appear to come from outside the story world.[3]) Instead, all processes of the world must be conveyed through the sensory displays of components of the world itself. For example, although our development proto-

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Computer Graphics | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

types sometime feature textual annotations, such as property labels spatially attached to agents, we cannot include such nondiegetic elements in an exhibited work because they have no ontological capacities in its processes. Whatever salience such annotations communicate to us must instead be conveyed through intrinsic perceivable features of the agents themselves. So, just as we perceive the wind by how it moves the leaves in nature, in the virtual world we perceive the fluid simulation by how it moves suspended particles. Just as the fallen leaf's color describes its state of decay, a virtual organism's texture imparts information about its internal changes over time.

In addition, since interactive art is deeply concerned with machine-mediated experience, the meaning of a particular work essentially depends on what we can do within it, what we can experience through its responses, and how this reflects critically upon ourselves and our environment. As artists, we are deeply motivated to create computational environments that draw more from nature's sense of open-ended continuation than from rational senses of utilitarian closure. Our challenge is to design interaction such that the visitors may explore an open-ended space, drawing meaningful responses, while indirectly influencing its adaptive conditions, and thus partaking in each other's living time as a fulfilled aesthetic experience. We believe this is made possible by designing interactions such that visitors become fully integrated components within the simulated world, both functionally and experientially.

To support the feeling of becoming part of the system, we focus on display and interaction methods that emphasize immersion, presence, and agency. Presence is generally understood in terms of a subjective sense of "being there," or being engaged such that the artificiality of the situation becomes suppressed. Matthew Lombard and Theresa Ditton describe it as the continuous illusion of nonmediation, with humans behaving as if the mediation was not there.[4] Naturally, immersion is conducive to presence, but it is not the sole factor. Presence also depends on interactivity and, crucially, on how successful actions are supported; experience in general is grounded more in functionality than appearance.[5] Moreover, presence has been found to strongly correlate with agency, which is a subjective property defined as the satisfying power to take meaningful action and that is deeply rooted in bodily experience.[6]

We have used immersive technologies such as surround stereoscopic display, surround spatial audio, and motion-capture sensing to aid this transition, but over-emphasizing immersion can paradoxically lead to disengagement, as the body is reduced to an egocentric viewpoint. To bring the body back into the system, we began exploring the mixed realities of augmented virtuality (bringing the body into the virtual world) and augmented reality (projecting the world back into a body-centric spatiality). We also avoid the direct input of handheld devices, preferring ambient sensing with microphones and RGB plus depth (RGB-D) range cameras capable of a low-latency, natural "transparent UI." Prioritizing indirect modes of interaction that integrate with complex networks of feedback relations in the world leads to interactions for which the consequences of actions are easy to perceive, but ultimately difficult to predict, thus encouraging exploratory behavior.

In almost all iterations of our work, large populations of agents (organisms) interact within a dynamic environment to form an ecosystem.

The richer the resolution, speed, and flexibility of interaction, the more integrated its evolution can be. But to address our goal of creating experiences of nature-like open-endedness, the simulated world must have the capacity to continuously adapt and generate new patterns of behavior and engender broad ranges of possible interactions, such that visitors can discover emergent relationships between elements by interaction and observation, as a child learns by playing in nature. To that end, we turn to biologically inspired complex systems.

In almost all iterations of our work, large populations of agents (organisms) interact within a dynamic environment to form an ecosystem. Evolution in the ecosystemic approach features an endogenous selection criterion, such as maintaining sufficient energy levels to survive and reproduce, which differentiates it from evolutionary systems steered by extrinsic fitness functions defined in advance or actively directed by users. Still, the strength of a particular ecosystemic model derives significantly from the richness of the environment that supports it.[7] The environments used in artificial natures are dynamic, incorporating physically inspired processes that conserve energy, save for some entropic loss, in every transaction. Moreover, the environments are dissipative, subject to

Figure 1. ***Fluid Space*****. This version of the Fluid Space application is distributed over 16 computers and 26 projectors, covering an almost completely spherical screen, with 54 loudspeakers mounted behind it. This wide-angle photograph was taken in 2012 at the University of California, Santa Barbara from the bridge of the AlloSphere.**

the kinds of energetic gradients that keep them away from equilibrium, and the varying rates of diffusion that can lead to naturally occurring self-organized structures.

The ecosystemic approach to evolutionary computational art has been well-established since the mid-1990s.[8] An important observation is that few of these biologically inspired works attempt a realistic representation of life as we know it; instead, abstraction and/or alien surfaces and volumes are dominant. To an extent, this echoes the life-as-it-could-be motto of artificial life research,[9] apparently liberating artists from realism. Nevertheless, as Mitchell Whitelaw previously noted, artificial life art remains representational and still owes a debt to biomorphism in the arts. Although it does not mirror nature's appearance, it nevertheless represents the way life operates: "an aesthetic that is largely focused around visualizations of processes of life."[10] (As Edward Shanken noted, it would be more accurate to describe them as visualizations of current theories of the processes of life.[11])

Installation and Interaction Design

Each of our artificial nature installations invites participants to become part of its ecosystem through responsive environments that utilize immersive or mixed-reality audio-visual displays. Our first installations utilized typical immersive formats, projecting on walls or large screens within darkened rooms. Navigation devices allowed visitors to explore these worlds with six degrees of freedom. This direction has naturally found its best expression in head-mounted displays and deeply immersive facilities such as the AlloSphere (see Figure 1).[12]

Many aspects of the underlying processes of the organisms and their relations to other elements of the world were also made discoverable. For example, in *Fluid Space* it is possible to watch organisms gradually mature from round eggs into fully developed creatures with undulating petal-like appendages. When approached closely, their translucency reveals within them the nutrient particles that are being digested, also gradually changing in color as they are metabolized, until they are ultimately ejected back into the environment.

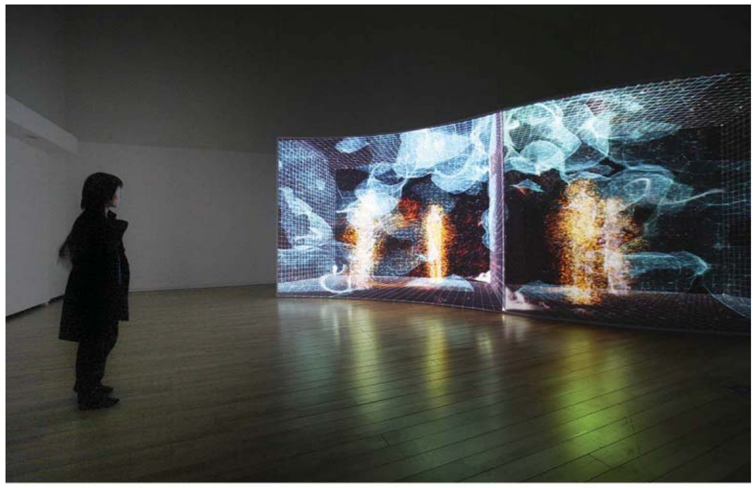
In *Time of Doubles*, we removed navigation and began projecting onto curved, architectural/sculptural objects mounted in the middle of gallery spaces (see Figure 2a), creating a mixed reality emphasizing continuity between the real and virtual spaces. This blending of real and virtual is personified by the projection of the visitors' "doubles" into the ecosystem, detected by means of an array of RGB-D cameras. These doubles are not avatars, but mirror existences that closely reconstruct the shape and movements of participants as volumes of high-density, high-energy particles. The presentation of a recognizably human double induces an immediate psychological link with the otherwise alien virtual world. However, the doubles in the virtual world have distinct appearances and behaviors, extending visitors into alternate roles—of energetic source and kinetic disturbance—within the network of relations of the world. The particles emanating from the visitors' doubles are the primary foodstuff of a species of evolving artificial life agents (see Figure 2b). Participants see, hear, and feel how they are fed to unknown species.

Evolution in this case acts upon the phenotypic properties and behaviors of agents specified by a program generated uniquely for each agent. Each agent's program is a product of a genotypic process of development implemented via metaprogramming and just-in-time (JIT) compilation. The evolutionary model has no fitness measure, but the viability requirement that organisms must locate and consume food to reproduce imparts an endogenous selection pressure toward the development of effective search strategies. In this regard, the agents form a distributed, adaptive search algorithm within a dataset of nutrient distribution, and each individual organism is an improvised proposal for its solution.

The agents in *Time of Doubles* are sonified using a granular process inspired by cricket chirps, where each sound event consists of a brief train of narrow-band pulses followed by a longer resting interval. These chirps are spatialized with direction and distance cues according to the agent location. The agent's genome is used to parameterize the various properties of the pulses, including pulse frequency, burst rate, burst length, and envelope shape. Many natural organisms have evolved sounds specifically adapted for precise localization and identification, even in noisy environments. In our case, a chirp's bursty envelope aids localization, while the narrow frequency range used allows many individual voices to be concurrently identified. As populations grow and collapse, the soundscape develops from isolated pulses to dense clouds of sound, with timbres that vary with the evolving gene pool, revealing properties of the world at multiple levels of detail. Evolutionary events (such as the discovery of a better search program) cause rapid and readily perceivable changes to the timbre of the clouds.

In *Archipelago* the format is even more sculptural. We project the ecosystem from above onto a landscape of islands constructed of sand (see Figure 3). An array of RGB-D cameras is also mounted above and is used to determine the landscape's topography, shaping the adaptive conditions of the species inhabiting it. The landscape itself is malleable, using a special kind of kinetic sand that does not dry, allowing visitors to reshape the topography and even destroy and create new islands. The choice of an archipelago reflects the necessity of niche conditions to support divergent evolution and echoes the environment in which Darwin's theory of evolution was inspired.

The simulated environment comprises a larger number of fields, including chemical traces left by a variety of different species of organisms and a lichen-like layer of biomass that begins the food chain (see Figure 4a). Pulsating while it grows, the lichen turns white when it reaches its healthiest level, which occurs most rapidly at higher altitudes. Flocks of creatures graze on the lichen, exposing the bare land beneath. When they die, they leave orange-colored blood on the land, which other organisms may feed upon later. A species of social organisms search for the orange-colored blood deposited when creatures die, collecting it and bringing it back to their hives. When leaving the nest, they emit a trail of bright green pheromones for others to follow, and when they carry food, the trail is purple. A scavenger species feeds upon the dead, and at the top of the food chain, predators play at high altitudes but when hungry hunt any other organism they can find. Visitors may wander freely through the island cluster and observe the behaviors of the hundreds of life forms that inhabit it, with alien yet recognizably animal- or plant-like characters, as they busily forage, metabolize, and reproduce. All the life forms are subject to the challenges of a densely populated, unpredictable environment including the topography of the islands themselves.



(a)

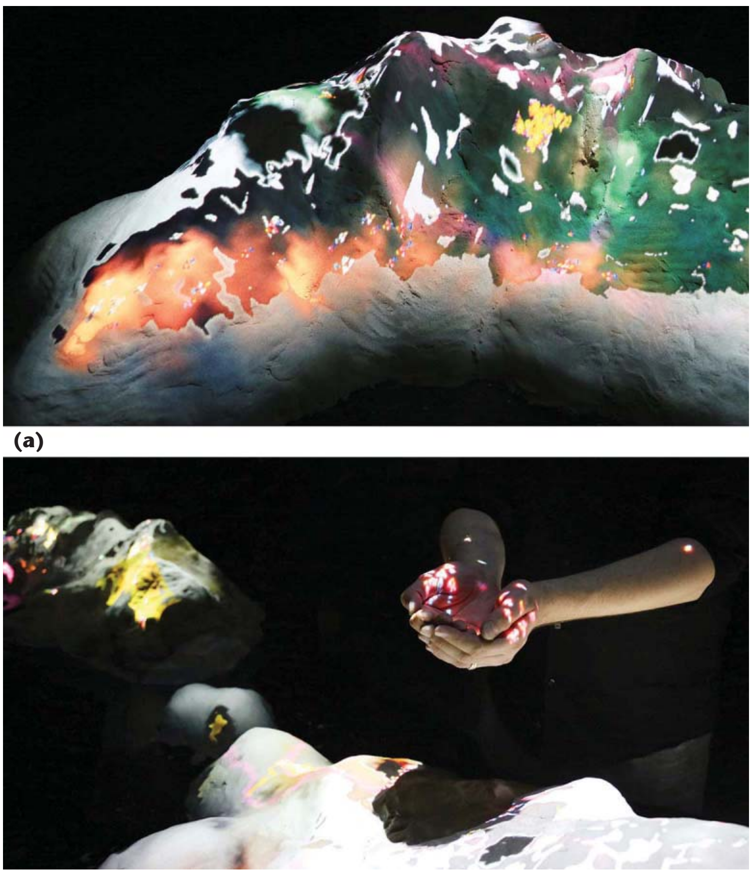
(b)

Figure 2. ***Time of Doubles.*** **(a) This installation incorporated a curved screen, projectors, loudspeakers, and RGB-D cameras. The photograph was taken at the Type:wall exhibition at the Seoul Olympic Museum of Art (SOMA), Korea, in 2011. (b) Participants and their virtual doubles, which are emanations of yellow nutrient particles fed upon by evolving artificial organisms. The photograph was taken at the Microwave International New Media Festival, City Hall, Hong Kong, in 2012.**

The ceiling-mounted sensors also track visitors in the space, with several implications. A common problem in projection-based installations is when a visitor crosses the projector's beam, both casting a shadow on the work and being illuminated themselves. In *Archipelago*, we cannot eliminate the shadows, but we know where they are, so we project black onto the spaces occupied by visitors. We also grant the shadows an ontological role: all life under shadow is destroyed and the

Computer Graphics | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

Figure 3. ***Archipelago*. This overview shows the use of kinetic sand, carved Styrofoam, projectors, loudspeakers, and RGB-D cameras. This photograph was taken at the Capitaine Futur exhibition, La Gaîte Lyrique in Paris that occurred between October 2014 and February 2015.**



(a)

(b)

Figure 4. Close-up detail of *Archipelago*. (a) A flocking group of organisms (red bodies, blue tails) in the lower altitudes have over-consumed the white lichen-like species covering many parts of the landscape and are now dying out, leaving pale carcasses surrounded by a diffusing field of decay (red), which may attract the scavengers visible in the higher altitudes. (b) Visitors can transport virtual organisms by hand from one island to another. Note also the shadow underneath the hand, which is replicated by the black projection. The shadow cast annihilates the white lichen-like species below but also refertilizes the land. These photographs were taken at the Capitaine Futur exhibition, La Gaîte Lyrique in Paris that occurred between October 2014 and February 2015.

land is simultaneously refertilized. The interaction becomes more subtle and sensitive when visitors place their hands upon the land and watch as organisms creep onto their hands. Visitors can then carefully carry these organisms to other islands, tracked by optical flow (see Figure 4b).

Continuations

The development of how each synthesized world works, and how it appears (in software-engineering terms, the model and the view) have evolved hand in hand. There is no separation of concerns here; instead, they become increasingly interdependent, with neither side interchangeable. And as we increasingly make use of runtime code generation, more and more of a world's description may become an actively malleable part of its own ongoing process. In keeping with the theme of endogeny, an important strategy for our future work is to replace statically aggregated systems with genealogical processes that may generate them—that is, working accounts of how every structure and function emerges from simpler initial elements. We hope that this will open a path to a broader diversity of worlds, even though we are attempting to engender nature-like complexity on vastly smaller scales of space, time, and complexity.

As a cultural artifact, each artificial nature reveals "nature as it could be" through endogenous processes at the level of its operation. But despite the whole-world mechanics, each artificial nature remains a work that is oriented to human experience. To liberate this experience, an artificial nature must grant freedom to participants in terms of what they see, observe, feel, and do. By analogy, both a three-year old child and an 80-year-old scientist can enjoy playing in ocean waves—even interacting with the same swell, wash, and breaker at the same time—yet each learns and plays with different values.

In our work, we chose the endogenous components described here—form and function, human as part of the system, design for agency, and open-ended generativity—to intensify primary aesthetic and exploratory experiences. We aim for the growth of both the world and its participants; not only that the more one interacts the more one becomes part of the system, but also that the world is enduringly changed by those who interact with it. Reflecting upon a cultural context that is increasingly immersed in computation, we hope the continued development of artificial natures will grant more transformative experiences and will stimulate more creation and open-ended thinking in terms of nature and artifice.

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