Art as a Living System: Interactive Computer Artworks

Christa Sommerer with Laurent Mignonneau

ABSTRACT

The authors design computer installations that integrate artificial life and real life by means of human-computer interaction. While exploring real-time interaction and evolutionary image processes, visitors to their interactive installations become essential parts of the systems by transferring the individual behaviors, emotions and personalities to the works' image processing. Images in these installations are not static, pre-fixed or predictable, but "living systems" themselves, representing minute changes in the viewers' interactions with the installations' evolutionary image processes.

CONCEPTUAL BACKGROUND

During the 6 years of our collaboration, we have worked at the borderline of art and biology and have used biological principles to create interactive artworks. When we met in 1992 at the Frankfurt Städelschule Institut für Neue Medien [1], we came from different backgrounds: Laurent had worked with video, improvisation and performance while my background was in biology and modern sculpture. In our previous individual works, we both had shown strong interests in the structures of nature: Laurent's video work was influenced by the shapes and formations of earth movements, and I had been working for several years on a system called "Phyllologia" [2], which drew upon the leaf classification schemata of Carl Von Linné. These leaf forms were static, and I used them in light boxes and cut-outs. When I joined the Institut für Neue Medien in 1992, I planned to animate these leaf shapes. However, when Laurent saw my animations, he suggested actually growing these forms in real time instead of modeling them by hand—and the idea for our first collaborative work, *Interactive Plant Growing,* was born. Through Laurent's background in improvisation and electronics, we were able to design the system to be interactive, and from my background in botany I knew that plants could be used as living interfaces.

After joining our interests in 1992 we decided to collaborate further and since then have produced several interactive artworks. Our goal was to create works that would become like living systems, addressing the question of life on a biological, as well as artistic and metaphorical, level.

PROCESS-ORIENTED ART VERSUS OBJECT-ORIENTED ART

In 1992 we developed the concept of natural interfaces and evolutionary image processes linked to interaction. We started working with evolutionary biology and became increasingly intrigued by how natural evolution and the processes of nature can function as tools of creation. We adopted evolutionary image processes to create process-oriented art rather than pre-designed, predictable and object-oriented art. In art, much of the production is centered around the art object, the artifact; even in interactive art, many artists still subscribe to the traditional notion of the art object.

When we analyzed the very essence of digital technology, we realized that it is the capability of creating, rendering and displaying processes that distinguishes Turing machines [3] and computers from other media such as photography, film and video. The potential rewards of developing, emerging and evolving processes became a focal interest in our artistic investigations. Instead of presenting the audience with hand-crafted artifacts or art objects, we aim for process-oriented artworks.

MULTI-LAYERED, NON-LINEAR INTERACTION

Based on the insight that interaction per se and the interrelation between entities are the driving forces behind the structures of life, we investigated interaction and the creative process. Creation is no longer solely understood as an expression of the artist's inner creativity, but instead becomes an intrinsically dynamic process. Linking the interaction of human observers (visitors) directly to the dynamic and evolutionary image processes of an artwork allows us to create artworks that are under constant change and development.

Fig. 1. *Interactive Plant Growing,* **interactive computer installation, 1992. Visitor interacting with real plants. (© 1992 Christa Sommerer and Laurent Mignonneau. Permanent collection of the Media Museum at the ZKM Karlsruhe, Germany.)**

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We believe that interaction should not be linear but instead feel like a journey. The more one engages in interaction, the more one learns about it and the more one can explore it. We call this principle non-linear or multi-layered interaction: interaction should be easy to understand at the very beginning but also rich so that the visitor is able to continuously discover different levels of interactive experiences. Existing interactive works can be divided into different groups:

- Pre-designed and pre-programmed paths of interaction. Most CD-ROMs (compact disks-read only memory) and interactive artworks are designed by the authors to give the viewers a variety of different choices and paths to follow, making the discovery of unexpected new paths of interaction rather limited.
- Evolutionary image processes linked to interaction. From our investigations into evolutionary biology, we became interested in how natural evolution can function as a tool in the creation process. By linking evolutionary processes to the visitor's interaction and his/her personal interaction decisions, we pursue an artistically new way of creation. Integral to the design of such an open-ended and unpredictable artwork is the interface, which functions as a direct link between the visitor and the image processes and translates the visitor's interaction parameters directly into the artwork.

Fig. 2. *Interactive Plant Growing*, **interactive computer installation, 1992. Virtual plant image. (© 1992 Christa Sommerer and Laurent Mignonneau. Permanent collection of the Media Museum at the ZKM Karlsruhe, Germany.)**

NATURAL INTERFACES

We have been most interested in the invention of "natural interfaces" because they can transport life, variation and personality. Using, for example, living plants as an interface not only provides a new and unusual connection between computers and living beings but also poses the questions of what a plant is, how we perceive it and how we interact with it. Natural interfaces allow humans to project our personalities onto a virtual space. They also circumvent the annoyance of putting on unpleasant devices before entering a virtual space, and they allow unencumbered interaction. Natural interfaces we have used and developed include living plants, water, light and the "3D Video Key" (see below).

INTERACTIVE PLANT GROWING

One of our first interactive computer installations to use a natural interface instead of then-common devices such as joysticks, mouse, trackers or other technical interfaces was *Interactive Plant Growing (*1993) [4]. In this piece, living plants function as the interface between the human visitor and the artwork [5].

Interactive Plant Growing involves interaction between five real plants and five or more human viewers who can, by moving their hands toward the plants, initiate and control three-dimensional (3D) real-time growth of artificial plants. By engaging in interaction with

the real plants, the viewers become part of the installation: they influence how human-plant communication is translated into virtual growth on the computer display. The voltage difference between the viewer's body and the real plants is interpreted as electrical signals that determine how the virtual 3D plants will develop. By touching or merely approaching the real plants in the installations, the viewer engages in a dialogue with the virtual plants (Fig. 1). He or she can stop, start, continue, deform and rotate the growth of the virtual plants, as well as develop new forms of plants in unexpected combinations. As the growing processes are programmed to be very flexible and are not predetermined, the result on the screen is always new and different, depending on the viewer-plant interaction.

Interactive Plant Growing was our first interactive installation that made visitors essential to the development of the piece: without their interaction, the piece could not exist, and images disappeared as soon as the visitors left. It was also unique in the sense that the subtle personality and interaction differences of the visitors could be interpreted in the form of complex scenery that solely depend on each viewer's identity (Fig. 2).

ARTIFICIAL LIFE AND ART: AN APPROACH

After creating *Interactive Plant Growing* we became increasingly inquisitive about the process of creation itself. Artificial Life (A-Life), a research field invented by scientist Christopher Langton at the Santa Fe Institute [6], proved capable of producing processes of nature within a machine (computer environment) and allowed computer programs to evolve over time. This enabled the development of processes and patterns that are no longer predictable or "handmade."

Fascinated by the idea of creation through evolution, not as a scientific simulation or mimicry of nature but as an investigation into the creative process itself, we studied the possibilities of applying A-Life principles to art projects [7].

Natural evolution has brought about a vast variety of forms and structures in nature, so it seemed reasonable to us that artificial evolution could function as a mechanism of the visual creation process. Also inspired by John Cage's use of chance procedures in his musical compositions, we began to introduce a combination of interaction and artificial evolution to our works.
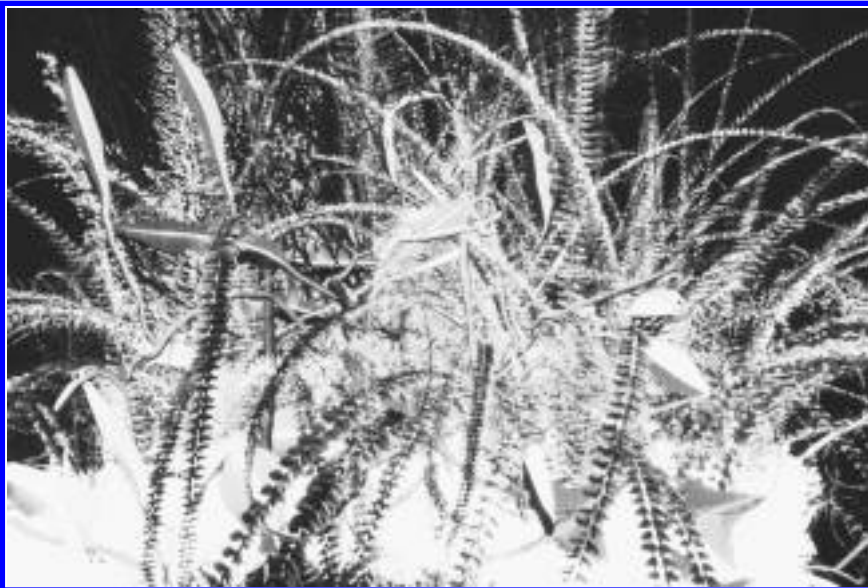
A-VOLVE

In 1994 we started to collaborate with Tom Ray, A-Life scientist and creator of the "Tierra" system [8]. During this collaboration we developed the interactive computer installation *A-Volve* [9], which allowed visitors to create A-Life (in the form of artificial creatures) and to interact with it. Artificial creatures are basically computer-generated forms that display life-like behavior and interact with each other as well as with their environment. *A-Volve* features A-Life principles in the birth, creation, reproduction and evolution of its artificial creatures.

In an interactive real-time environment, *A-Volve* visitors interact with virtual creatures in a water-filled glass pool (Color Plate A No. 1). These virtual creatures are products of evolutionary rules and are influenced by human creation and interaction. Designing any kind of shape and profile with his/her finger on a touch-screen, the visitor creates virtual 3D creatures that are "alive" and swim in the real water of the pool. The movement and behavior of the virtual creature are decided by its form—that is, how the viewer designs it via the touch-screen (Fig. 3).

Behavior in space is, so to speak, an expression of form. Form is an expression of adaptation to the environment. Since form and movement are closely connected, a creature's ability to move will determine its fitness in the pool. The fittest creature will survive longest and will be able to mate and reproduce. The creatures compete by trying to get as much energy as possible; thus, predator creatures hunt for prey creatures and try to kill them.

The creatures also interact with visitors by reacting to their hand movements in the water. If a visitor tries to catch a creature, it will either try to flee or stay still and be caught. The visitor is able to influence the evolution of the community in the tank by, for example, protecting prey from predator. If two strong creatures meet, they may mate and create offspring. The offspring will carry the genetic code of their parents (Fig. 4).

Cross-over between the genetic strings of the parent creatures, as well as the mutation and selection of fitter creatures, provide a simulation of reproduction mechanisms found in nature. Newborn offspring also live in the pool, interacting with visitors and other creatures.

Laurent designed algorithms to ensure smooth and natural movements and "animal-like" behavior of the crea-
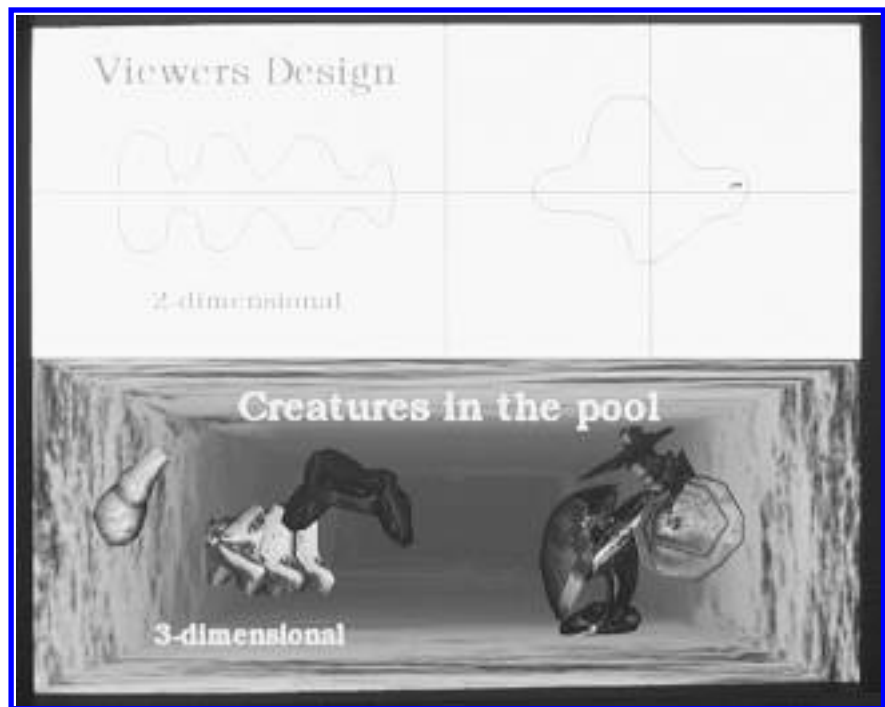

Fig. 3. *A-Volve*, **interactive computer installation, 1994. Viewers' two-dimensional drawings on a touch-screen become three-dimensional creatures in the pool. (© 1994 Christa Sommerer and Laurent Mignonneau. Supported by ICC-NTT Japan, and NCSA, Urbana IL, U.S.A.)**

Fig. 4. *A-Volve*, **interactive computer installation, 1994. Reproduction of creatures. (© 1994 Christa Sommerer and Laurent Mignonneau. Supported by ICC-NTT Japan and NCSA, Urbana IL, U.S.A.)**

Fig. 5. *Phototropy,* **interactive computer installation, 1994. Visitor interacting with virtual insects. (© 1994 Christa Sommerer and Laurent Mignonneau. Supported by Artifices, Saint-Denis, France.)**

tures. None of the creatures are pre-designed; they are all born exclusively in real time through the interaction of the visitors and the mating processes of the creatures themselves.

A-Volve creatures can be created in one of two different ways: (1) by visitors drawing on the touch-screen or (2) by the mating and genetic exchange of two parent creatures. Thus, an unlimited variety of forms is possible.

A-Volve creatures have a limited life span, within which they should be able to eat, mate and reproduce. The maximum life span is about 1 minute, but the creature can, of course, die sooner.

A-Volve creatures can die in one of three different ways: (1) by starving (not getting enough energy from killing other creatures), (2) by reaching the maximum life span or (3) by being killed by a predator.

Since the genetic code of the offspring is carried from generation to generation and the system emphasizes selection of fitter creatures, the code is able to evolve over time toward fitter creatures. Although evolution can take place by itself without outside influence, the system is designed in such a way that the visitor and his/her interaction and creation of forms will significantly influence the evolutionary process. The visitors act as a kind of external selection mechanism.

Three main internal parameters—fitness, energy and life span—regulate the interaction, reproduction and evolution of the creatures. External parameters include the visitors drawing on the touch-screen as well as their interaction with the creatures [10]. The audience, then, does not interact with objects of the artists' creation—rather, the audience itself creates the non-local and non-physical objects, which by themselves live, develop, evolve or die. All of *A-Volve*'s entities—the images, the forms and the graphical environment—change continuously, as does the audience itself, their imaginations, the ways they conceive and draw forms and how they in-

teract with them. Human-creature interaction itself becomes a creative process.

The social interaction between the viewers and the virtual world is essential to the creation of the work itself. We think of *A-Volve* as a complex system in which, as in quantum physics, the entities transform their states according to probability patterns. This system is like an interconnected, intrinsically dynamic web of movement, interaction and transformation of particles and entities.

PHOTOTROPY

A year later, in 1995, we developed another interactive installation based on A-Life principles, called *Phototropy,* which allows visitors to interact with virtual insects [11]. *Phototropy* is a biological expression that refers to the force that makes organisms—for example, bacteria or plants—follow the light in order to get nutrition and, hence, survive. Light is used in the installation as an interface between the real and the virtual worlds. With its ephemeral and non-physical nature, light acts as the nutrition for A-Life in virtual space.

Phototropy is an interactive computer installation in which visitors interact with virtual insects through the use of a normal flashlight. By shining the light onto parts of a 3-×-4-m screen, the viewer awakens virtual insects that are born in cocoon-like growth forms (Fig. 5). The insects soon start to fly and follow the physical beam of the viewer's flashlight, seeking light as their energy source. If

Fig. 6. *Trans Plant,* **interactive computer installation, 1995. Visitor creating and crossing virtual plants. (© 1995 Christa Sommerer and Laurent Mignonneau. Permanent collection of the Tokyo Metropolitan Museum of Photography, Tokyo, Japan.)**

the insects reach enough light, they live longer and reproduce; if not, they soon die. Since all the insects want to gain as much energy as possible, a big swarm of insects will follow the movement of the visitor's flashlight. However, the visitor must be careful: shining too much light onto the insects will burn them. But, if carefully guided to the light, the insects will mate more frequently and increase their population.

Similar to the genetic code in *A-Volve,* the genetic code of a single insect in *Phototropy* is passed from parents to children, thus propagating new generations of individual virtual insects, all following and fighting for light. *Phototropy* visitors thus support, develop and enhance the lives of artificially living insect populations.

ENTERING VIRTUAL SPACE

Driven by the wish to enter virtual space and interact with virtual worlds in a more direct way, we developed and patented a new interface, the "3-D Video Key" [12]. This system allows visitors to enter virtual space totally unencumbered and find themselves displayed in three dimensions. Through the 3-D Video Key, visitors are able to cross virtual space freely and in real time, experiencing the virtual environment in a more natural and direct way. We have applied this interfacing technique to three of our interactive installations: *Trans Plant, Intro Act* and *MIC Exploration Space.*

TRANS PLANT

Trans Plant is an interactive computer installation we developed in 1995 for the Tokyo Metropolitan Museum of Photography as part of the museum's collection [13]. *Trans Plant* was realized with the support of Advanced Telecommunications Research (ATR) Laboratories, Japan. In *Trans Plant,* visitors enter a semi-circular room and become part of a virtual jungle that starts to surround them.

As visitors step forward into the installation, they will see themselves projected onto a screen in front of them (Fig. 6). By walking freely and without any devices, they soon see on the screen in front that grass grows wherever they walk, following each step and movement. When a visitor stops and stays still, trees and bushes grow where he or she stands. Changing the speed and frequency of one's movements, one thus creates a biotope full of different plant species.

Fig. 7. *Intro Act,* **interactive computer installation, 1996. Visitors interacting with abstract virtual forms. (© 1996 Christa Sommerer and Laurent Mignonneau. Permanent collection of the Musée d'Art Contemporain, Lyon, France.)**

The size, color and shape of these plants depend only on the size of the person— small children will usually create different plants than will their parents. By holding out one's arms, the size of the plants can be increased; by moving the body slightly backward or forward, the color density can be changed as well. Because each visitor creates different plants, the result on the screen is one's own personal forest that expresses one's personal attention and feeling for the virtual space. As the growth gets more and more dense and the space more and more full of different plant species, the visitor also becomes deeply engulfed in this virtual world.

INTRO ACT

Intro Act is an interactive computer installation we produced in 1996 for the Biennale de Lyon at the Musée d'Art Contemporain in Lyon, France, as part of the museum's collection [14]. In *Intro Act,* visitors enter the installation and immediately find themselves projected onto a virtual space in front of them. As they move their bodies in space, visitors see that the evolution of different 3D abstract organic forms on the video screen in front of them is synchronized and linked to their own movements.

As if exploring a different universe, visitors will try to orient themselves by determining which movement causes

which event. For example, raising one's arm will lead to extensive, wild growth explosions out of one's hand on the screen, while other movements cause expansion and differentiation of the virtual forms.

The visitor's body position is tracked in x, y and z axes through a camera-detection system, and the body movements and behaviors are directly linked to the 3D graphic events. While interacting, the visitor becomes engulfed in the virtual world; the longer one interacts, the more one becomes part of the system. One continuously sees oneself inside the 3D world, defining it, creating it, exploring it and destroying it (Fig. 7).

MIC EXPLORATION SPACE

MIC Exploration Space is an ongoing research project we have been developing since 1996 for the ATR MIC (Media Integration and Communication) Systems Laboratories in Kyoto, Japan. The virtual space in *MIC Exploration Space* is a place of interaction and communication, where human-human communication can be visualized. The set-up displays two identical *Trans Plant* systems at remote locations that are linked together via an Internet link that allows direct data transfer between the remote sites. Advanced camera/gesture tracking software (Pfinder [15]) is used to capture the visitors' movements and ges-

tures in real time, and the 3-D Video Key allows 3D exploration and integration of the visitor's images onto a single, common screen. Visitors at remote locations, therefore, can share the same virtual environment and interact with each other using images, gestures, speech and sound (Fig. 8). The image communication enables visitors at both locations to communicate non-verbally through gestures and movements. As the interaction and image communication is fully in real time, visitors at both locations can interact freely, intuitively and unencumbered.

MIC Exploration Space is a prototype system showing how to enable, enhance and design interaction and communication in the future of virtual communication space [16].

THE BUILDING BLOCKS OF LIFE: *GENMA*

In 1996 we began to study the building blocks of visual creation and investigated how simple structures can result in complex-looking shapes and forms through genetic manipulations. We developed *GENMA* (Genetic Manipulator)—an interactive installation that allows visitors to create, manipulate and explore the genetic design of artificial creatures—for the Ars Electronica Center (AEC) in Linz, Austria, as part of a permanent exhibition [17].

GENMA is a kind of dream machine [18] that enables us to manipulate artificial nature on a micro scale: abstract, amoeboid, artificial 3D forms and shapes. Principles of A-Life and genetic programming are implemented in this project, which allows visitors to manipulate the virtual genes of the creatures in real time. Looking into a mirrored glass box, visitors see the creatures as stereo projections in front of them. By putting their hands into the glass box, they can try to grab the creatures, which are virtually floating in the space of the box.

The genetic code of each creature is schematically displayed on a touch-screen. By using their fingers on the touch-screen, visitors can manipulate a creature's genetic code and thus can change and modify its appearance in the glass box in real time.

By selecting and merging different parts of a creature's genetic string and recombining them, the visitor can engage in intensive experiments and learn how to create complex forms out of seemingly simple structures (Fig. 9). Taking parts of the genetic strings and cutting, pasting or multiplying them—thus adding mutations and variations—the visitor can explore the tools of genetic manipulation.

On a visual level, *GENMA* further explores the concept of "natural" or "open-ended" design—design that is not pre-fixed nor controlled by the artists but that represents the degree of interest and interaction of each visitor. Each visitor creates the forms he/she wants to see, aided by artificial genetics, mutation and manipulation (Fig. 10). One could even say that the audience becomes artists themselves, using the power and possibilities of the installation's tools.

LIFE SPACIES: FROM TEXT TO FORM ON THE WEB

In 1997 we extended the concept of *GENMA* a step further and implemented the principles of open-ended design in an installation called *Life Spacies,* which was developed for the ICC InterCommunication Museum in Tokyo as part of the museum's permanent collection [19]. *Life Spacies* is an interaction and communication environment in which remotely located visitors via the Internet and on-site visitors at the installation in Tokyo can interact with each other through evolutionary forms and images.

Fig. 8. *MIC Exploration Space***, interactive computer installation, 1996. Visitors at remote sites interacting with virtual creatures in the same virtual environment. (© 1996 Christa Sommerer and Laurent Mignonneau. Developed for ATR Media Integration and Communications Research Lab, Kyoto, Japan.)**

Through the *Life Spacies* Web page (Fig. 11), people all over the world interact with the system as well. By simply typing and sending an E-mail message to the *Life Spacies* Web site (http://www.ntticc.or.jp/~lifespacies), one can create one's own artificial creature.

We developed a special text-to-form coding system that allows us to translate text into genetic code. In a way similar to what occurs in nature, letters, syntax and sequencing of the text are used to code certain parameters in a creature's design. Form, shape, color, texture and the number of limbs are influenced by text parameters. As there is great variation in the texts sent by different people, the creatures themselves also vary greatly in their appearance, thus resulting in unique creatures for each participant.

As soon as the message is sent, the produced creature starts to live in the *Life Spacies* environment at the ICC museum, where on-site visitors can interact with it directly through touch (Color Plate A No. 2). The interaction set-up at ICC is the same as that developed for *MIC Exploration Space*: two independent interaction sites are linked together via a data line, allowing visitors at remote locations to be displayed in the same virtual 3D space.

Shortly after sending an E-mail message, the text's author receives a curriculum vitae for his or her creature, as well as an image of how it looks. When the creature dies, a report is sent to its creator, telling him or her how long the creature lived and how many children and clones it produced.

The artificial species can be created in one of two different ways:

- Through incoming E-mail messages. A text-to-form editor creates the genetic code for each creature: one message equals one creature; complex text messages create complex creatures; and different levels of complexity within the text represent different species.
- Through reproduction of the creatures themselves. Reproduction helps the creatures propagate their genotype in the system so they can form groups of different species.

Life Spacies is also based on the idea of evolutionary design—the result is not predetermined by the artist but depends solely on the interaction of the visitors and the evolutionary process. Only the messages E-mailed from people throughout the world and the reproduction and evolution of the creatures
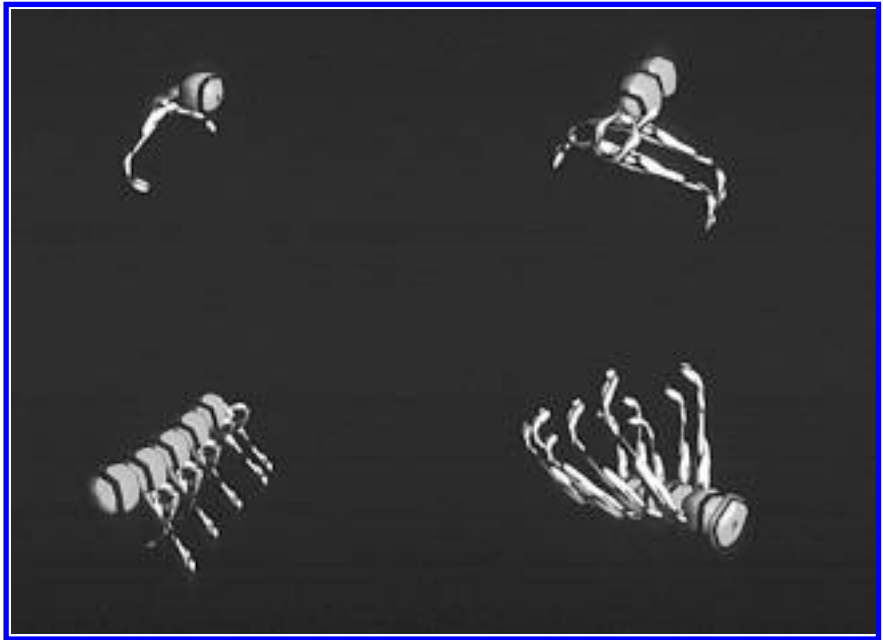

Fig. 9. *GENMA* **(Genetic Manipulator), interactive computer installation, 1996. Example of the development of a creature. (© 1996 Christa Sommerer and Laurent Mignonneau. Developed for the Ars Electronica Center, Linz, Austria.)**
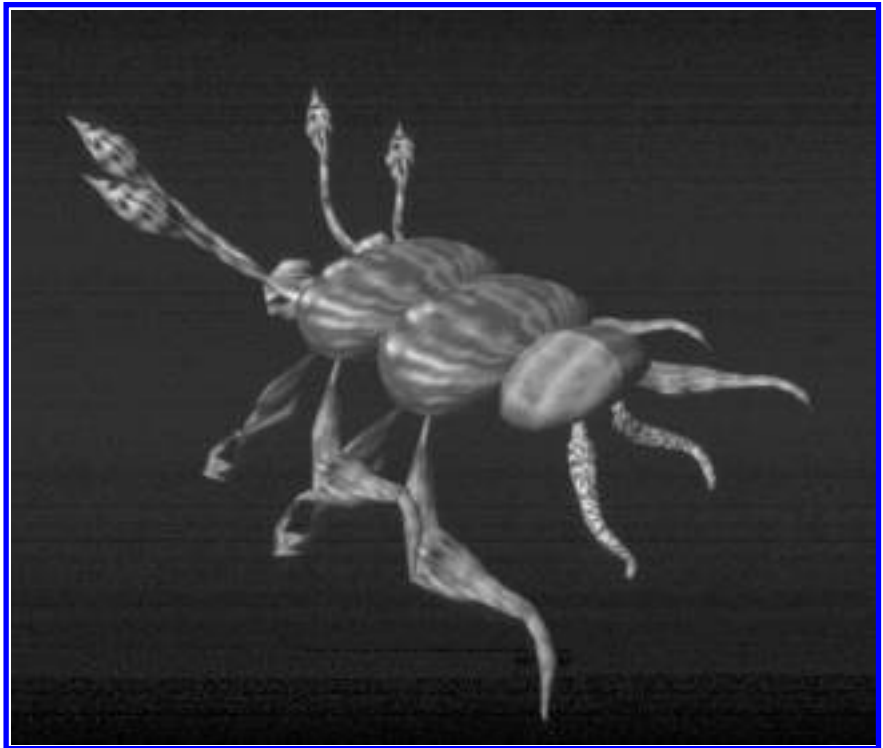

Fig. 10. *GENMA* **(Genetic Manipulator), interactive computer installation, 1996. Example of a creature. (© 1996 Christa Sommerer and Laurent Mignonneau. Developed for the Ars Electronica Center, Linz, Austria.)**
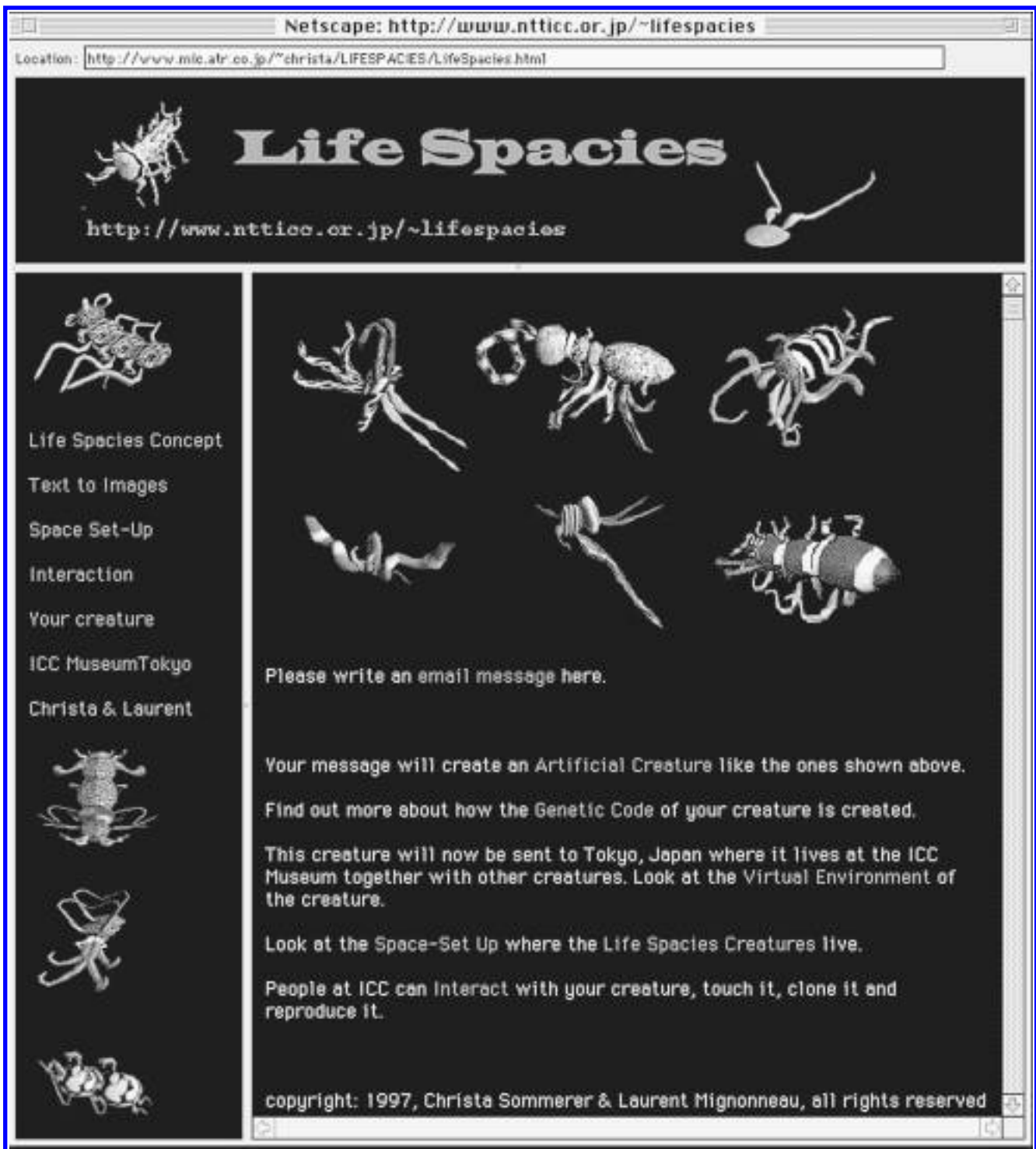
Fig. 11. *Life Spacies,* **interactive computer installation, 1997. Home page. (© 1997 Christa Sommerer and Laurent Mignonneau. Permanent collection of the NTT-ICC InterCommunication Museum, Tokyo, Japan.)**

themselves determine how the creatures look and how they behave. One can therefore never really predict how the work will evolve and what kind of creatures will emerge. Its evolution depends on how many people send messages, how complex these messages are and how the creatures reproduce among themselves and through the selection of visitors at the museum.

Life Spacies is a system where interaction, interrelation and exchange happens on human-human, human-creature, creature-creature, and human-environment, creature-environment and real life–A-Life levels. By touching the creatures with one's hands, one can interact with them on-site at the ICC Museum in Tokyo. The creatures are basically shy, and one needs to look for them carefully because they hide in the branches of the vegetation. Once a creature is caught by the visitor, it will clone itself as a perfect copy. However, if two remotely located people are in the same virtual space, they can each catch a creature with their hands, which causes these two creatures to mate and to create offspring. The system thus changes and evolves according to the visitors' interactions and the creature's behavior.

The interaction rules are non-deterministic and multi-layered; our aim was to create an open-ended system in which each entity—whether real life or A-Life, whether actually present (visitors at the ICC Museum) or virtually present (the users on the Internet or the creatures as code)—are equally important components of a complex, life-like system.

ART AS A LIVING SYSTEM

In the various examples above, we have stressed that the art we create does not result in static objects or pre-defined multiple-choice interaction, but in the processes of living systems [20]. The artwork is characterized by complex interrelations and interactions of real and virtual entities that engage in dialogues and result in the appearance of different expressions of mind and matter.

Relativity theory proved that the cosmic web is alive by showing that its activity is the very essence of being. At an abstract level, the activity of our interactive systems could be considered alive as they are processes of continuous change, adaptation and evolution.

THE NEW POSITION OF THE ARTIST

Artists who create truly interactive computer installations merely set the framework within which the inherently evolutionary image processes and the interaction of visitors develop the work itself. The artist thus takes on a new role, no longer creating autonomous and elevated artworks but radically giving up control over the art itself. The public is responsible for what it sees and the worlds it creates. As artists, we expect much of the public: a visitor must become part of the system to realize that there are no pre-defined solutions of what to do and what to see and that instead the artwork develops through his or her interaction. One could say that the visitors themselves become part of the resulting artwork.

CONCLUSIONS

Interactivity and A-Life teach us to rethink our definition of art, broadening our view by allowing us to integrate personality, variety, processes of nature and new perspectives on art and life. As the images in our installations are not static, pre-fixed or predictable, they become living processes themselves, representing the influences of the viewers' interactions and the internal principles of variation, mutation and evolution. The image processes are no longer reproducible but continuously changing and evolving. Such artwork can therefore be considered a living system itself, representing the relationship and interaction between life and A-Life.

References and Notes

1. The Institut für Neue Medien, Frankfurt, Germany, is a post-graduate institute that as founded by Peter Weibel as part of the local art academy, the Städelschule. The institute dedicated itself mostly to the development of interactive art, educating some of the best-known artists in this field: Christian Möller, Agnes Hegedüs, Ulrike Gabriel, Akke Wagenaar, Michael Saup, the authors and others. Since 1994, the institute has been under the leadership of Michael Klein. For more information, see the institute's Web site at <http://www.inm.de>.

2. "Phyllologia," a term I invented in 1990, means "the science (*logia*) of leaves (*phylla*)." I used a well-known botanical leaf-shape classification table developed by Swedish naturalist Carl Von Linné (1707–1778) to create different art objects in various media such as wood, prints, drawings, a book and light boxes.

3. A. Turing, "Computing Machinery and Intelligence," *Mind* 59 (1950).

4. C. Sommerer and L. Mignonneau, "Interactive Plant Growing," in K. Gerbel and P. Weibel, eds., *Ars Electronica 93—Genetic Art Artificial Life* (Vienna: PVS Verleger, 1993) pp. 408–414.

5. This work was later called "epoch making" by Toshiharu Itoh, not only for its use of a new and uncommon interface but also for its concept of interaction with a living being and the transformation and interpretation of this dialogue in virtual space. T. Itoh, "Approach to Life—The World of Christa & Laurent," in *Christa Sommerer and Laurent Mignonneau,* exh. cat. (Tokyo: ICC-NTT InterCommunication, 1994).

6. The Santa Fe Institute (SFI), New Mexico, U.S.A., is a nonprofit, multidisciplinary research and education center, founded in 1984. Since its founding, SFI has devoted itself to creating a new kind of scientific research community that pursues emerging science. For more information, visit the SFI Web site at <http://alife.santafe.edu>.

7. M. Kusahara, C. Sommerer and L. Mignonneau, "Art as Living System," in *Systems, Control and Information* **40**, No. 8, 16–23 (1996).

8. In Tierra, "digital organisms" compete for CPU time and memory space, creating a predator/prey situation where the prey evolves more quickly in the presence of predators, and simulated hosts become infected with parasites. The original seed is a self-replicating program; its descendants can be self-replicating as well. Over time, the digital organisms create strategies of how to exploit each other by inventing parasitism and hyper-parasitism. See T. Ray, "An Approach to the Synthesis of Life," in C. Langton et al., eds., *Artificial Life II* (Redwood City, CA: Addison Wesley, 1991) pp. 371–408. Tierra is a virtual computer simulated on a real computer.

9. C. Sommerer and L. Mignonneau, "A-Volve—An Evolutionary Artificial Life Environment," in C. Langton and K. Shimohara, eds., *Artificial Life V* (Boston, MA: MIT Press, 1997) pp. 167–175.

10. For further information about *A-Volve,* see C. Sommerer and L. Mignonneau, "Interacting with Artificial Life: A-Volve," *Complexity Journal* **2**, No. 6, 13–21 (1997).

11. C. Sommerer and L. Mignonneau, "Phototropy," in M.G. Mattei, ed., *Oltre il villaggio globale—Beyond the Global Village,* (Milan: Electra Edition, 1995) p. 134.

12. The 3D Video Key is a hardware system invented by Laurent Mignonneau in 1995. It allows three-dimensional, real-time integration of a visitor's image into virtual space by using a camera tracking system in combination with a background extraction method. As a result, visitors can cross virtual space pixel by pixel in three dimensions, completely unencumbered by devices.

13. C. Sommerer and L. Mignonneau, "Trans Plant," in T. Moriyama, ed., *Imagination* (Tokyo: Tokyo Metropolitan Museum of Photography, 1995) chapter 2.

14. C. Sommerer and L. Mignonneau, "Intro Act," in *3e Biennale d'Art Contemporain de Lyon* (Paris: Reunion des musées nationaux, 1995) pp. 378–381.

15. Pfinder is tracking software developed by MIT Media Lab (Alex P. Pentland, Travor J. Darrell and others) to track visitors' body gestures and body outlines in real time. For more information, see <http://vismod.www.media.mit.edu/vismod/demos/pfinder/>.

16. C. Sommerer and L. Mignonneau, "MIC Exploration Space," in *SIGGRAPH'96 Visual Proceedings* (New York: ACM Siggraph, 1996) p. 17.

17. C. Sommerer and L. Mignonneau, "GENMA—Genetic Manipulator," in *Ars Electronica' 96, Memesis The Future of Evolution* (Vienna/New York: Springer Verlag, 1996) pp. 294–295.

18. This exhibition took place in 1996 at the Kunsthalle Wien, Vienna, Austria; it dealt with different kinds of dreams machines (*Wunschmaschine*) invented by artists and scientists. Matthias Fuchs, a curator of this exhibition, refers to *GENMA* as a dream machine. See M. Fuchs, "Para Real," in B. Felderer, ed., *Wunschmaschine Welterfindung* (Vienna/New York: Springer Verlag, 1996) p. 212.

19. C. Sommerer and L. Mignonneau, "Life Spacies," in *ICC Concept Book* (Tokyo: NTT-ICC, 1997) pp. 96–101.

20. First published in C. Sommerer and L. Mignonneau, "Art as a Living System," in C. Sommerer and L. Mignonneau, eds., *Art @ Science* (Vienna/New York: Springer Verlag, 1998) pp. 148–161.

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