An Aquarium of Machines: A Physically Realized Artificial Life Simulation

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Fig. 1. Helium dirigibles controlled by an artificial life simulation, called Aerobes, interacting with visitors in the Turbine Hall at Tate Modern. Concept by Anicka Yi with software by Sitara Systems. (© Sitara Systems)

This paper describes the public art installation *In Love With The World* by artist Anicka Yi, which embodies a complex virtual ecosystem of autonomous agents in a physical space. The agents, called Aerobes, are inspired by the lifecycle of the *Aurelia* sp. jellyfish, and use artificial life techniques designed by the authors to simulate the behavior of two distinct phenotypes. These agents are embodied in the Tate Modern's Turbine Hall using

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lighter-than-air soft robotics utilizing helium that can respond to museum visitors through sensors embedded in the space. By creating organic-looking fully autonomous agents that are capable of real-time interaction, we hope to create an experience that causes viewers to question what living with machines might feel like in a speculative far-future, and to imagine an alternative form of artificial intelligence that is neither threatening to humanity nor subservient to it, but exists in an altogether parallel track as a new form of life.

CCS Concepts: • **Applied computing** → **Media arts**; **Fine arts**; • **Computing methodologies** → **Artificial life**; • **Human-centered computing** → *Human computer interaction (HCI).*

Additional Key Words and Phrases: Autonomous Agents, Behavioral Animation, Interactive Robotics, Interactive Installation

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1 INTRODUCTION

This project begins with a central question: what would it be like to live with new, emergent forms of intelligence? In the public imagination, we think of machines in binary dichotomies – either as a master or slave to the human race. Either machines exist to serve us, or if they become intelligent enough, will take over and control us. But what might a world look like where machines have broken free of this dichotomy, and instead we think of them as a new branch in the tree of life?

In this paper, we document and reflect on our role as technical artists in collaboration with conceptual artist Anicka Yi in the development of her piece *In Love With The World*, shown at the Tate Modern. Anicka Yi's work explores the shifting relationships between technology, humans, and the biological world through multisensory experiences. When Anicka Yi was commissioned to create an installation for the Turbine Hall at the Tate Modern, she sought to create an experience that evoked the industrial history of the hall while drawing parallels between the technological transformations and societal changes that occured in the eighteenth century as well as the present. Given both her body of work and the nature of the Turbine Hall, Anicka Yi wanted to use this opportunity to explore the relationship between humans and machines.

Artificial intelligence has most frequently used human intelligence as a benchmark[Minsky 1988]. However, this comparison to humans has largely limited discourse to thinking about artificial intelligence as a *replacement* for human intelligence, rather than a *complement* to it. This comparison not only confuses the actual capabilities of thinking machines but also creates fears about replacement in the workplace and in interpersonal relationships[Darling 2021]. For this reason, this project sought to create an artificial intelligence that reminded an audience not of humans, but of animals instead – like our machines, animals perceive the world in ways unlike humans, make their own decisions, and act upon the world. Animals have been collaborators in work, war, and society for millennia without replacing humans; we hope that by making our machines more reminiscent of animals than humans, it will encourage our audience to think of machines in a new way as well.

For her commissioned piece, Anicka Yi wanted to create an experience that allowed visitors to experience what a speculative future with machines might feel like – one where we could develop relationships outside of the master-slave binary. To accomplish this, she set out to create intelligent agents that felt more like an animal-machine hybrid than a human-machine hybrid. We collaborated with the artist to develop a fleet of artificial lifeforms, called Aerobes, based loosely on both the appearance and behavior of the *Aurelia* sp. jellyfish (Moon Jelly). To give these agents a sense of autonomy and freedom that mimicked real lifeforms, we developed a novel artificial life simulation to create a virtual ecosystem with two distinct phenotypes that could co-exist in the Turbine Hall.

In this paper, we will provide a summary of this artificial life simulation, as well as reflect on interrelationships between art, technology, and society in the context of this project.

2 RELATED WORK

Artificial life (also known as autonomous agent research) is a technique used for solving problems that require a system to autonomously fulfill several goals in a dynamic, unpredictable environment. The first work on autonomous agents focused on its application to navigation and goal-driven behavior[Arkin 1987], inspired by ethology[Beer 1990], neurology[Frederiks 1969], and psychology[Piaget 1972]. The approach found limited applications in real-time robotics due to issues with scaling; the tools and techniques of autonomous agent design were found unsuitable for designing sufficiently complex agents to solve real-world problems, and emergent behavior was difficult to predict or control[Maes 1993]. However, the work of Craig Reynolds in his landmark "boids" experiment[Reynolds 1987] bridged the gap between autonomous agents and computer animation, spawning a new branch of artificial life research oriented towards applications in animation[Reynolds 1988][Blumberg and Galyean 1995], frequently inspired by the real-life behaviors of animals[Tu and Terzopoulos 1994]. This new branch of research demonstrated how animations that mimicked biological systems could emerge with little effort on the part of the animator through these complex systems.

In addition to animation, the ideas, themes, and techniques of artificial life have been extensively borrowed for applications in the arts. At the same time that early research was being used to explore applications in robotics, artists such as Laurent Mignonneau and Christa Sommerer[Sommerer and Mignonneau 1999] and Naoka Tosa[Tosa 1993] were utilizing artificial life techniques to imagine alternative ways of collaborating and interacting with machine intelligence. The current public interest in artificial intelligence has led artists to create works that interrogate our relationship with machines once again. Works such as Wayne McGregor's *+/- Human*[McGregor 2017], *Can't Help Myself* by Sun Yuan and Peng Yu[Yuan and Yu 2016], and Ruairi Glynn's *Fearful Symmetry*[Glynn 2015] all interrogate the sense of life in interactive objects and environments, and how this sense will affect our relationships with technology moving forward.

Our piece takes this history of interrogation one step further by creating not just a single life-like entity, but an entire ecosystem of artificial entities. This allows visitors to experience the machines in an environment that feels native to them, rather than placing machines in traditional art contexts like museums or theaters. Our audience is invited to immerse themselves inside an aquarium of machines, where the machines live as independent entities in their own natural environment.

3 ARTIFICIAL LIFE SYSTEM

3.1 Inspiration

We chose to model our virtual ecosystem on the lifecycle of the *Aurelia* sp. jellyfish, commonly known as Moon Jellies. Recent research has shown that the polyp and medusa forms of the jellyfish are not temporally separated; that is to say, neither form is considered an "adult" or "larval" form, but rather, two dimorphic presentations that the *Aurelia* sp. may present depending on environmental conditions[Ceh et al. 2015]. This multi-modal lifecycle was the inspiration for our two species of Aerobe, shown in Figure 2. The Xenojelly is the more active and animalistic of the two species, directly seeking interactions with visitors and having a form that has more range of motion. The Planula, being more plant-like, is less active than the Xenojelly and largely only interacts with other species and visitors indirectly through its environment.

For our artificial life simulation, we designed a system based on the cognitive architecture developed by Burke et al. for C4 [Burke et al. 2001] and further refined by Stephens et al.[Stephens et al.

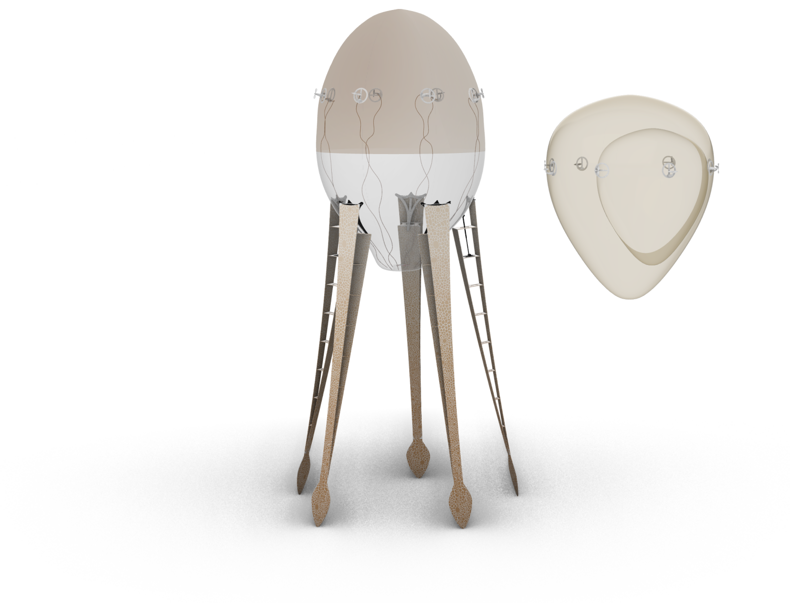

Fig. 2. Renderings of our proposed dirigible designs: the Xenojelly, based on the medusa form of *Aurelia* sp. (left); and the Planula, based on the Planula form (right) (© Anicka Yi Studio)

2003]. At a high level, our artificial intelligence is divided into three modules: *perception*, *mind*, and *body*; these three modules correspond to sensing, thinking, and acting, respectively. The *perception* module encompasses the sensors and hardware that gather data about the environment, as well as the software post-processing and filtering of the data to give each Aerobe its individual representation of the world. The *mind* module contains each Aerobe's internal motivations (represented as internal state variables), as well as an action selection model that produces behavioral choices based on motivations and perception data. Finally, the *body* module contains all of the hardware and software necessary for the Aerobe to move in the physical world based on the output of its mind module.

The design of each of these modules will be discussed in the following sections.

3.2 Xenojelly

3.2.1 Perception. As a matter of systems architecture, we opted to reduce each individual dirigible's net weight (and thus maximize battery life) by omitting the use of onboard sensors, and instead used external sensors mounted in the space to build a complete model of the environment. However, during each computation cycle, when each Aerobe's perception module requests sensory information, it is only given a limited model of the environment based on each individual units perceptual limitations.

Like real jellyfish, our Xenojellies can only detect objects in their immediate vicinity; they can only respond to obstacles that are within 2.5 meters of their hull. Object detection was implemented via an ultrawideband positioning system; this positioning system was used by individual Aerobes to

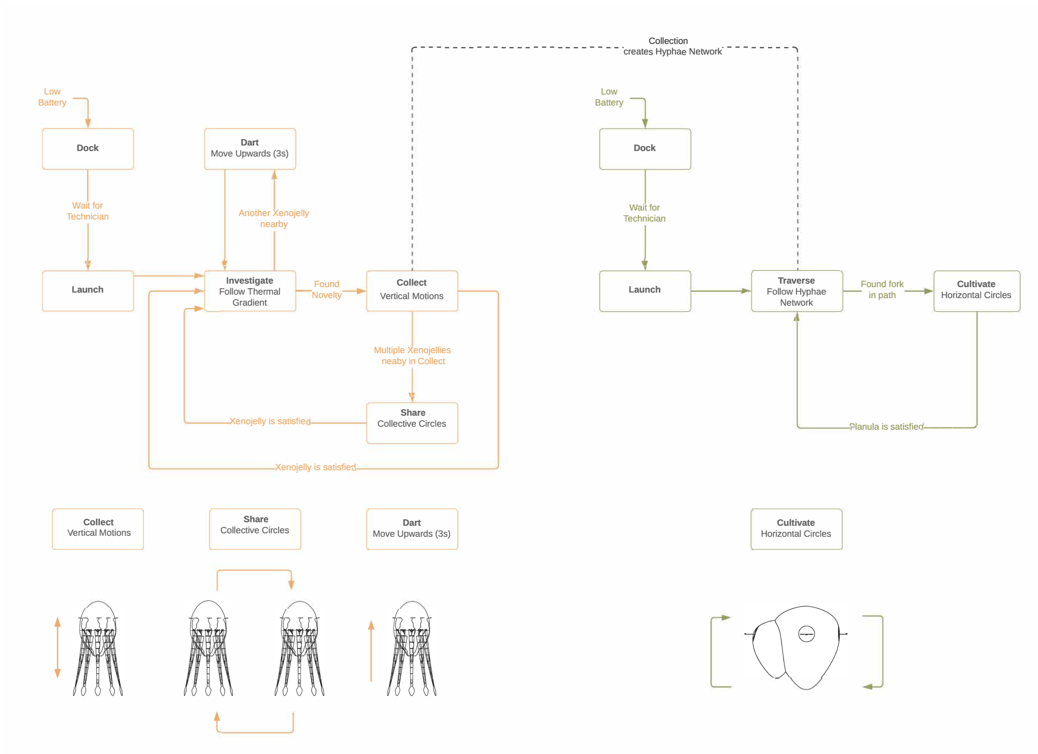

Fig. 3. An overview of the state machine that governs action selection in the Aerobes. (© Sitara Systems)

determine their own positions in the environment as well as the position of obstacles. Ultrawideband anchors were placed around the hall in approximately 10-meter intervals to provide proper coverage for all Aerobes. A centralized gateway computed the positions of each Aerobe relative to the environmental origin and was then compared against a pre-existing model of the Turbine Hall to determine the position of obstacles.

Xenojellies are also capable of thermal sensing, allowing them to detect human visitors in their environment. While they can sense heat in their environment, they do not possess a highly refined sense that can provide them with exact positions or shapes of thermal objects; instead, they only sense residual heat from where objects have previously been located. This sense was implemented using a network of thermal cameras positioned overhead in the exhibition space, with their respective images stitched together to provide an overhead view of the environment. The limited vision of each Aerobe was simulated by post-processing each image with blur and morphological operators. The heat from detected objects was fed into a diffusion simulation to create a simulation of the heat trails left by objects in the hall, which provided the basis for Xenojelly behavior.

3.2.2 Mind. The mind module of each Aerobe is responsible for making decisions for its next movement based on internal motivations and external perception information. The decision-making and motion planning of each Aerobe is abstracted into three different layers: *motivations*, *schemata*, and *behaviors*. *Motivations* are modeled as internal state variables that track the intensity of a particular desire for each Aerobe; each of the Aerobe's motivations was set to further the artistic goals of the project. *Schemata* serve as the basic unit of behavioral specification for our agents[Arbib 1992]; multiple concurrent schemata may run in conjunction with one another to execute a *Behavior* that represents the concerted action and intent of an Aerobe. Each individual schemata we use is inspired by the work of Arkin[Arkin 1989] and Reynolds[Reynolds 1999].

Xenojellies possess three primary motivations: *sustenance*, *xenophilia*, and *sociability*.

Sustenance is their desire to continue their independent motion in the hall. This motivation is related to their battery life; when the Aerobes' battery life runs low, this motivation grows stronger until it reaches a threshold value, after which the Aerobe uses the *dock* behavior to return to their maintenance area. Once in the maintenance area, the Aerobe will wait for a technician to change its battery; upon confirmation from the technician that the battery is swapped, the Aerobe will *launch* into the air and continue to navigate the space.

Xenophilia is their desire to experience new and novel things. As the Xenojellies are machine-based entities, the thing most different from them is biomatter, which they can experience through their heat signatures. Xenojellies will initially engage in the *investigate* behavior to follow thermal gradients in search of biological matter; once they find a critical mass of biomatter of suitably novel shape and size for their particular taste, they will engage in the *collect* behavior to learn more about it. The physical motion of the *collect* behavior is inspired by the vertical motions of jellyfish, where they will rise and fall in place in the water[Albert 2011].

Sociability is the desire for Xenojellies to share their findings with conspecifics. Once a Xenojelly has begun to *collect* information about biological material, it will begin to *share* information if it is approached by a conspecific. This behavior is presented as all involved Xenojellies swimming in a large vertical circle; this behavior has been observed in real-life *Aurelia* sp. jellyfish as well[Albert 2011].

In addition to these three primary motivations, Xenojellies will also swim upwards when they get too close to a conspecific; this mimics the somatosensory response of *Aurelia* sp.[Albert 2011].

These behaviors are summarized as a state machine in Figure 3.

3.2.3 Body. The Xenojelly, based on the medusae form of the *Aurelia* sp. jellyfish, is an egg-shaped dirigible with five articulated tentacles. Each Xenojelly stands approximately 2.6 meters tall and 1.3 meters in diameter. The hull is constructed from a polyurethane film that is cut and thermally welded into the desired shape to make a helium-tight membrane. Attached to the hull are eight 3d-printed bidirectional propellers; four providing vertical propulsion and four that are utilized for rotational and translational motion (Figure 4). The eight propellers allow each Xenojelly to translate itself in three dimensions, as well as rotate azimuthally. There are also five tentacles constructed from polyurethane foam attached to the hull; each tentacle is controlled by a single servo that synchronously causes the tentacles to open and close in the manner of a jellyfish. A custom PCB contains the processor for each Xenojelly, as well as ultra-wideband (UWB) positioning tags and a 2.4 GHz radio receiver, and is contained in a thermoformed plastic enclosure at the bottom of each Aerobe. Each Xenojelly is controlled by a Graupner MX-20 radio transmitter, which is sent commands by control software on a central computer.

3.3 Planula

3.3.1 Perception. The Planula, being the less animalistic of the two species, possesses fewer perception abilities than the Xenojelly. The Planula has the ability to see physical obstacles the same as the Xenojelly but lacks the thermal sensing ability of the Xenojelly. We also desired a method for the Planula to exhibit intelligent motion but did not want this species to interact with the audience. To accomplish this, we wanted to use stigmergy to allow for Aerobe species to indirectly coordinate through their environment. While the Planulae could not directly modify the

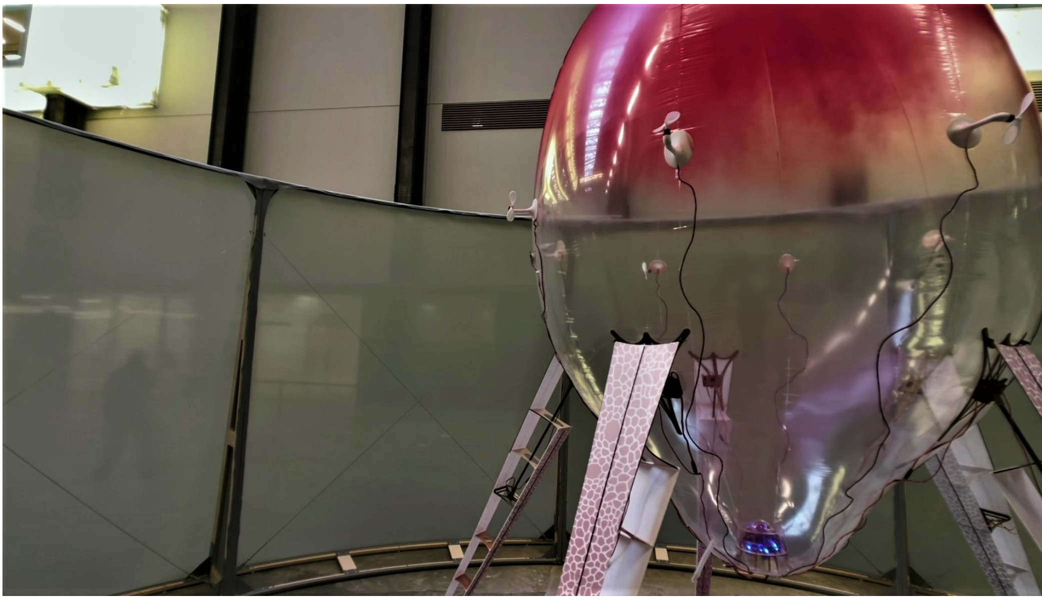

Fig. 4. A close-up of the Xenojelly, showing how tentacles and propellers are mounted onto the hull using 3d-printed fixtures. (© Sitara Systems)

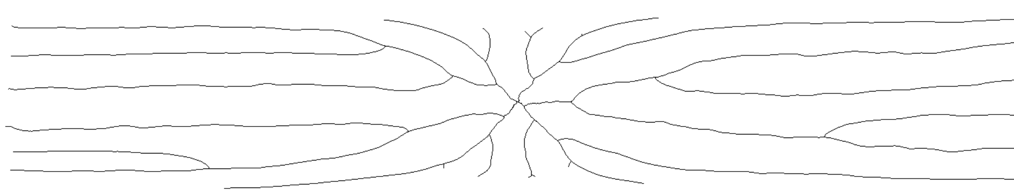

Fig. 5. A representation of the virtual Hyphae Network; the network is drawn by connecting nodes generated from Xenojelly behavior using a leaf venation algorithm. (© Author)

environment, we gave them the ability to modify a purely *digital* environmental form called the Hyphae Network; this is a network of nodes that connects the locations where Xenojellies have previously been in the *collect* behavior near visitors. While purely digital, this behavior is similar to the use of pheromones as an environmental marker in some species. The nodes are recorded in a database and then connected using an open venation pattern simulation[Runions et al. 2005].

3.3.2 Mind. The Planulae have two primary motivations: *Sustenance* and *Preservation.*

Sustenance works exactly the same as with the Xenojelly, with the Planula periodically returning to a maintenance area to change its batteries for a fully charged one.

Preservation is the Planula's desire to preserve the Hyphae Network. Each branch of the hyphae network is assigned an age based on the age of Xenojelly *collect* events used to construct it. When a branch reaches a threshold age, the branch is removed from the simulation. The Planula utilizes a *traverse* behavior to follow nodes from its starting point, and upon finding a fork in the path, will begin a *cultivate* behavior that reinforces the branch by resetting its age. The *cultivate* behavior presents as the Planula moving in a horizontal circle with the branching point at its center.

Fig. 6. Multiple Aerobes flying in the Turbine Hall at Tate Modern. (© Sitara Systems)

3.3.3 Body. The Planulae are constructed using an almost identical technique to the Xenojellies. However, the hull shape is composed of two chambers that give the Aerobe an asymmetric aesthetic. The hull is also coated with a fine polymer fiber that is attached via a spray adhesive to mimic the look of small cilia on the body.

4 REFLECTIONS ON TECHNOLOGY IN ART

A fleet of twelve Aerobes (nine Xenojellies and three Planulae) were created to autonomously navigate the Tate Modern's Turbine Hall for a period of four months. These Aerobes autonomously navigated the hall for the entirety of these four months under their own behavioral programming, providing visitors to the Tate Modern an opportunity to interact with these artificial lifeforms in their own environment. The Tate Modern performed a qualitative survey three months into the exhibition where they observed and interviewed a range of visitors to examine behavior, attitude towards, and perceptions of the installation.

The Tate Modern's findings were that the installation was highly engaging and captivating to visitors, and succeeded at its intended purpose to provoke thoughtful questions and prompt debate. *In Love With The World* was cited specifically as a primary driver of attendance at the museum during its run, and visitors described themselves as being captivated by the work. The interviews revealed that visitor reactions varied widely – from calm and relaxed, to wonder and awe, to even intense debates about the technical underpinnings of the work.

We feel that the project was able to be successful precisely because of its hybrid nature as both technology and conceptual art; this duality made the project extremely well-suited towards encouraging thoughtful conversation around abstract topics, and reflected the greater interrelationship between art and technology.

Art is particularly well-suited to provoking discourse about the role of technology in our society precisely because it can appeal to our emotional minds in ways that more didactic debates simply cannot. Debates about technology that may otherwise be inaccessible to the layperson because of jargon or expertise suddenly become intuitive to grasp when presented as the choice between a speculative future and the present. Visitors to the Tate Modern were reported as feeling calm, peaceful, and relaxed watching the Aerobes – yet also felt a tension once they realized the Aerobes were autonomous. While the experience produces a feeling of captivation and awe, visitors also wondered how much autonomy the Aerobes truly had, and discussed if the future would be full of more autonomous machines like this. Presenting visitors with a vision of a speculative future proved to be an excellent strategy for encouraging discussion about how our present choices may influence possible technological futures.

We feel that there were two key technical insights that allowed the project to be technically and critically successful. First, we resisted the urge to create a more complex artificial life system, instead preferring simple rules over complex ones. As was proven through Valentino Braitenberg's early work in cybernetics[Braitenberg 1984], the key to compelling complex behavior is simple rules combined with a complex environment. In our case, this meant keeping the artificial life systems' rules simple while allowing visitors to the Turbine Hall to provide the complexity. This decision meant that visitors could intuitively understand the behaviors, and even if the Aerobes' motivations were mysterious, visitors felt that it was easy to project their own intentions onto the Aerobes' motions. Second, our collaboration chose to downplay the technology so that visitors could focus on the experience. None of the supporting media, labels, or staff training materials about the project focused on the implementation details, allowing visitors to experience the piece as-is rather than relying on technical explanations to connect with the art. This omission seems to have led to many conversations amongst visitors, who were found in the survey to frequently debate how the piece worked. These conversations inevitably led to greater discussions about artificial intelligence, helping to provoke the kind of creative and philosophical discourse that the artist had sought to facilitate.

Overall, we feel that the combination of a provocative artistic concept and a compelling technical implementation created a unique experience that succeeded at challenging visitors to the Tate Modern to think about the interconnected roles of art and technology in society.

We feel that this work was successful in provoking audiences to think of machines and artificial intelligence in new ways; by creating machines that reminded the audience more of life-like creatures than robots, it allowed them to open themselves to new possibilities of relationships with machines.

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Fig. 7. A visitor watches the Aerobes from a third-floor window. (© Tate)

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