Trans-Species Interfaces: A Manifesto for Symbiogenisis

Ken Rinaldo

Abstract Artist/inventor Ken Rinaldo looks to natural living systems, mimesis and communication to reveal the underlying coevolved wisdom of the biological world as it intertwines and coevolves with our technological world. He postulates the symbiotic junctures where machine, animal, plant, bacteria and humans meet are where our future as a species exist. He reveals this philosophy by showing numerous interactive robotic installations showing how we are becoming symbiont and his works pioneer interspecies communication, where the biological and technological naturally intertwine. Using coevolution as model, Rinaldo proposes we can, as a species design technologies that are more sensitive to other living things focused on directing technology for the good of all living species, we share the planet with.

As a child we had a bright orange and grey-stripped cat named Catabu. With large green eyes staring longingly into my eyes he would jump to my lap. I would scratch and rub the crown of his head working my hand to the side of his mouth as he purred approvingly. He would force the crown of his head hard against my hand and his pupils would roll upward to the back of his skull showing the whites of his eyes as his eyes would drift closed. He would slink over and relax exposing his belly with his paws outstretched he would go completely limp.

After minutes of stroking, Catabu would suddenly pop up on his back paws and place his front paws on my shoulder. He would then begin to probe my inner ear with his scratchy tongue. His whiskers tickled as he dug further, licking my ear slowly and deliberately. This was somehow a pleasurable experience, though his tongue was sticky. Cat behaviorists, would speculate he was claiming me as littermate. I think we were exchanging love and affection.

This was my first trans-species experience. Here was a cat, finding pleasure in the taste of my earwax while we provided mutual affection. This cat/human relationship

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left a lasting legacy and deep-probing questions for me about animal-human communication, symbiosis and the contemporary notion of the computer interface.

These childhood experiences further served as a model for developing and thinking about new forms of interactive robotic art and the possibilities for unique biologically inspired interfaces. Questions arise; given the tactile nature of the human animal should interfaces have a physical component? Can interfaces play into the social norms of both human and animal? Can interfaces be used to break down interanimal and human/machine barriers?

The house cat, now a domestic breed for over 12,000 years [1] has found comfortable habitation in human homes. Within it's own evolutionary space is the propensity for social interaction and hierarchy. Dogs another domestic breed found human symbiosis much earlier, when we were hunter-gatherers. Research now places the cat, as emerging into symbiotic interaction with humans, when agriculture in the Fertile Crescent (Mesopotamia and land surrounding the Tigris and Euphrates river) required effective rodent control.

These developments lead to questions about how do animals, plants, insects and bacteria develop co-evolutionary paths? How do they develop relationships with the others in the span of natural time? How is this related to our emerging co-evolutionary and now symbiotic relationships with technological systems?

How can we by design model these animal-to-animal, animal to plant, animal to bacterial co-evolutionary systems while thinking about mimesis as a deliberate design strategy? How can these strategies be used to imagine interactive and robotic works that may advance the traditional notions of what constitutes a robot and the interface? What can we learn from these natural relationships and how are they different given the speed of intertwining technology versus the speed of natural coevolution?

As with natural, symbiotic relationships I believe there is inevitability to the arising of artificial machine intelligences. I further believe it will, by necessity, develop self-sustaining relationships with humans. Author Kevin Kelly notes in his book, What Technology Wants, "large systems of technology often behave like a very primitive organism". In particular, "networks, especially electronic networks exhibit near-biological behavior", but even taking this assertion into account it is clear that all this technology requires an interface.

The "interface" while by design is an ineffable space between humans, animal or machine interacting with one another, where each tries to understand, direct and anticipate the future behavior of the "other".

For humans, isn't culture and art, the ultimate interface? As they frame and condition how we view the natural and technological world surrounding us. Aren't artists asking the really difficult questions and advancing the field in the most profound ways given our critical stances and separation from market driven forces? Branden Hookway made me feel as if I was reading my own philosophy about the interface when he says:

> The interface is a form of relation that obtains between two or more distinct entities, conditions, or states such that it only comes into being as these distinct entities enter into an active relation with one another; such that it actively maintains, polices, and draws on the separation that renders these entities as distinct at the same time as it selectively allows a transmission

or communication of force or information from one entity to the other; and such at its overall activity brings about the production of a unified condition or system that is mutually defined through the regulated and specified interrelations of these distinct entities [2].

The central focus of my artwork has been to work at these junctures where machine, animal, plant, bacteria and humans meet. Living systems have provided the ultimate models for me as artist. Communication is at heart of my work with a desire to break down behavior, processes, patterns and the underlying beauty inherent in the intercommunication of all species (organic and machinic) at all scales.

Within the context of co-evolution and natural time (measured in billions of years) deep co-evolution has evolved, as it has been exhibited by mitochondria, foreign organelles that inhabit our cells with their unique DNA. Biologist, Dr Lynn Margulis one originator of the theory endosymbiogenisis, has written extensively on how symbiotic relationships between organisms often of different kingdoms, are the driving force of evolution. So now it is becoming true with technology and the human species [3].

With the emergence of machines and computers, we now have something we call machine-time. The computer clock-cycle and chip, GHz speeds of code execution are changing our notion of evolutionary time. While DNA and biological time, genes, have given rise to idea based MEMES and cultural evolution as Richard Dawkins has theorized in the Selfish Gene [4] genes still move more slowly. My research into living systems theory, as framed by researchers such as Miller [5] set me on a path over 35 years ago to work on artificial evolution governed by machine time.

The path is to emulate and create interactive systems, objects and art installations that blur the boundaries between living and non-living entities. Studying biology and computer science and earning an MFA in art, I was fascinated to conflate and discover process and structural relationships between natural and technological cultures. As with computer scientist/artist Myron Krueger and his work Videoplace 1978, I was also interested in embodied interaction that was not purely symbolic. I also moved away from keyboard centered interaction, though unlike Krueger, I was more interested in physically based works versus projected screen based interaction. I made a distinct decision to really directly emulate living systems and artificial life developing fully sensorial and corporeal ways of experiencing and engaging the works.

The evolution of my artwork involves the development of unique robotic interfaces for humans and other species. I have been evolving approaches to artificial-life programming techniques and unique interactions with biological systems. My process always starts as idea based inspiration with rough sketches. It moves forward with reading and research 3D modeling, fabrication, electronics in the creation of large-scale installations. Coding and interface design are always very much a part of this process.

In my work I have become one of the founder proponents of the notion of trans-species artworks, bio-based systems art and interactive robotics. It is exciting to see further developments surrounding these specialties. In defining new interfaces and functional installation works, artists are often at the vanguard in realizing unique ways of creating innovation and disruptive work, as artists are not constrained by market forces or manufacturing practicality.

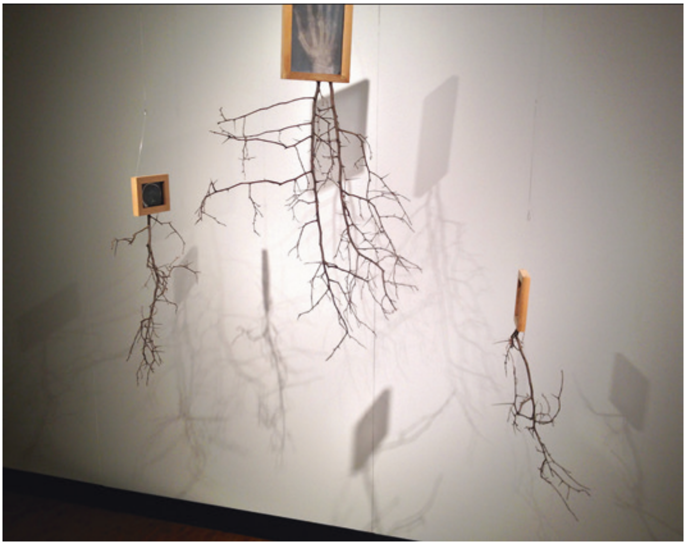

Fig. 1 Two sides of one branch—, by Ken Rinaldo

Formally, I am compelled by open structures that define form, but do not close the interiors of form off to the viewer. I often use exposed electronics and mechanics as part of the aesthetic, in proposing structural and process relationships between natural and technological systems. Wires and circuits are juxtaposed with natural branching structures as they share structural and process characteristics. For me, tree structures, are the primordial intelligent forms of our universe. They are found in neural and vascular systems as well as VLSI chips, maps of Internet connections, rivers, telephony networks and really all are constantly moving and processing matter, energy and information (Fig. 1).

Philosophically, I believe it is imperative that technological systems acknowledge and model the evolved wisdom of natural living systems. My idealistic and somewhat romantic wish is natural and technological systems will inherently fuse, to permit an emergent and interdependent earth. I see our species now better understanding the structural, behavioral and process based aspects of natural living systems as we are beginning to emulate natural worlds, in making technological systems that sense, respond, behave, evolve and sometimes misbehave. Still, technology has yet to learn the recycling/reuse strategies of natural living systems in all their intertwined integrations with bacterial cultures and their ability to break down living matter into reusable material.

While my works are conceptually inspired, I have also taken a strong stance as sculptor and person of craft. I make deliberate and provocative material choices with a hope the works better resonate with viewers. Materiality is a critical consideration for me as I believe we must first compel the eye/hand/body with corporeal ways of knowing, in order that a viewer/interactant will wish to further observe and intellectually engage the ideas inherent in a work. Recent work has also more fully engaged and modeled natural systems in recycling strategies I have brought forward in my work.

Fig. 2 I Yam what I Yam living systems painting 1988–1989, by Ken Rinaldo

In this text, I will discuss the conceptual, theoretical and ethical aspects of emulating and using living systems. This will be done with illustrations, sketches, schematics and where appropriate I will describe the central drives in my art/science practice. I will briefly navigate a few early works to demonstrate a progression in my thinking about the relationships between interactive art, interface and the ultimate symbiosis of natural and the technological.

As a younger artist, I was often frustrated with formal, static and material/craft based motivations to art making. Upon studying Marcel Duchamp and Jack Burnham systems aesthetics [6]. I was completely set free, in realizing that artists' could create culture and could construct and appropriate culture, as a way of systematically impacting ideas about contemporary media art and technological culture broadly.

With this new Duchampian freedom to "construct and grow" culture, I created a living systems painting, called **I Yam what I Yam in 1988**. This systems painting was constructed of potatoes, yams, dirt and eggs filled with tempera paint. This was a systems sculpture involving interaction and meant to subvert the notion of the precious art object. During the opening people were given stones, to throw at the painting, thus exposing the bed of yams and potatoes to the paint injected into each egg. During the opening, I was completely overwhelmed with how exuberant people were. Individuals ran up and took bites out of the potatoes and yams, while others smeared tempera paint on the frame. Seeing, "passive viewers" transformed into active and emotionally invested participants, was eye-opening and set me down the path of questioning human/art/life interfaces and wanting more interaction.

This living painting **I Yam what I Yam** continued to transform as it was moved outside receiving rain and sun and the leaves and buds bloomed while hungry slugs occupied all. They loved it till it was eaten and evolved (Fig. 2).

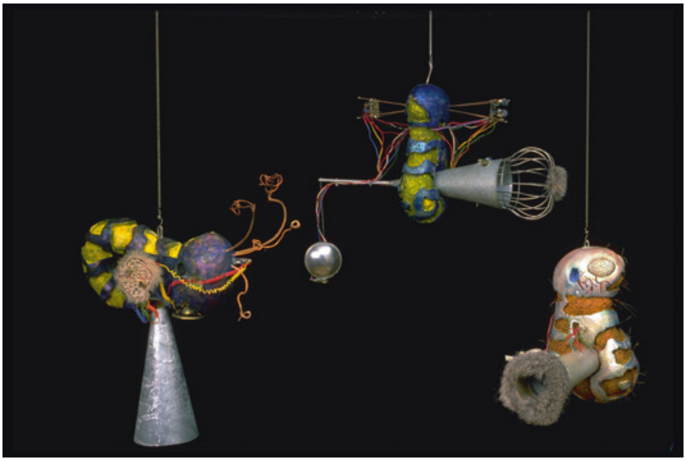

Fig. 3 Cybersqueeks Image du Futur, 1988, by Ken Rinaldo

While it was an epiphany to create an interactive living-systems painting, critical reflection also suggested a form of interaction that was more rapid, evocative and evolutive. Clearly electronics were going to be necessary for my next works.

The **Cybersqueaks 1989** were to be my first electronic digital pets. When touched they emitted emphatic and pleading sounds, triggered by motion. They hung from the ceiling with springs. Fifteen works in all, they create a cacophonous sound environment of burping and squeaking. In the creation of this work, I was able to develop a method to sew fiber optics into silicon rubber molds and I used dry-transfer circuit patterns, to create functional and formally suggestive electronic copper traces that also were the sound producing elements (Fig. 3).

Changing light allowed changing sound as photo resistors were placed near soft fur to draw the hand in. When participants touched the Cybersqueaks rocking and touch induced small mercury switches to allow them to squeak their first words. The sounds emitted were like pleading babies crying. The physical size of these works was about the scale of a fetus and this had important lessons for me. Further, art objects that emit their own voices are seen as more "alive" and touch also created important empathy for participants involving corporeal knowledge. The types of sounds induced a socially engaged emotional state of empathy.

As I was modeling living systems and symbiogenic ways of creating interactive works for humans, it seemed logical to look at interactive art for other species. Could a fish for example learn to use an electronics interface? ***Delicate Balance***, 1993 is the first fish driven robot and is an interactive work designed to allow the fish to make a "choice" using the power of design, sensors and robotics (Fig. 4).

The "choice" it had was to determine the direction that it moves along a tightwire (stainless steel cable) so it could explore its environment, beyond the limits of the tank. Though, this is not a real choice, given the two directions the fish could

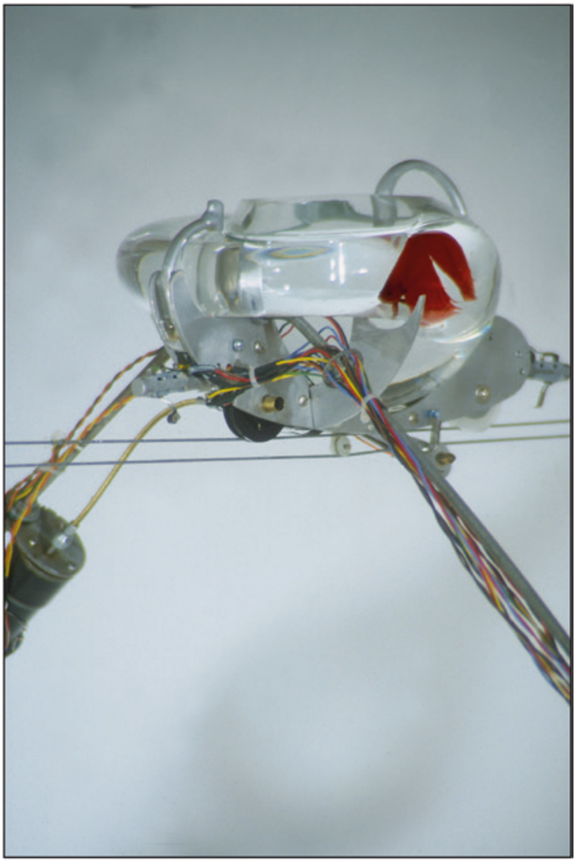

Fig. 4 Delicate Balance at Ukrainian Museum of Contemporary Art, Chicago by Ken Rinaldo

travel along the wire the work became a metaphor for the precarious balancing act of straddling natural and technological systems. With only two directions of travel the work also references environmental systems overwhelmed by technological systems.

This inceptionary work allowed to me think about how to better design interfaces for living creatures, that were more sensitive to their needs. Using custom-built circuit boards, electronics and hand blown glass, it stimulated dialogue surrounding the ethical use of animals in artwork.

When I first encountered the Siamese fighting fish, I was astounded to see they were being sold in small glasses of water. This caused me to psychoproject myself, into the space of the fish. I thought if I was that fish, I would at least want to drive my tank around. This work chose animal centered questions and concerns versus human centered concerns (Fig. 5).

The circuit design used comparators, to allow the shadow of the fish to activate sensors, which then activated motors to slowly move along the wire. Microprocessor and motor power was brought into the robot by the steel wires carrying voltage and ground. A small mirror sat on a tower and the fish would

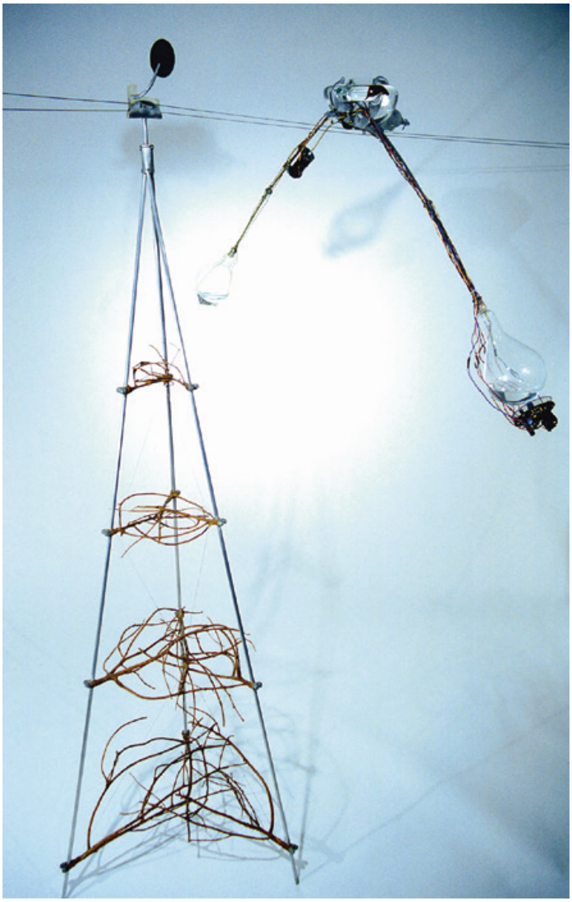

Fig. 5 Delicate Balance at Ukrainian Museum of Contemporary Art, Chicago by Ken Rinaldo

often just sit looking at self and competing with his mirror image. I was thrilled to observe that the fish was comfortable in this artificial environment and not at all afraid of the slow moving speed of the tank along the wire. This became a critical design feature for later works and I felt this was in fact a really ethical and kind way to allow the Siamese fighting fish to explore.

As my electronics experience grew, I had the good fortune to meet a group of extraordinary Silicon Valley engineers excited to collaborate. ***The Flock* 1994**, by Ken Rinaldo and Mark Grossman (Co-founder of Silicon Graphics) was a work partially inspired by research with the flocking software agents, such as the Boids by Reynolds [8] (Fig. 6).

The conceptual and aesthetic questions The Flock asked were, could a group of physical and actual robotic sound sculptures be programmed to exhibit behaviors analogous to the flocking found in natural groups such as birds, schooling fish, or flying bats? In this process my collaborator, and I innovated on the science of soft robotics currently an emerging area of research. We constructed robots of natural

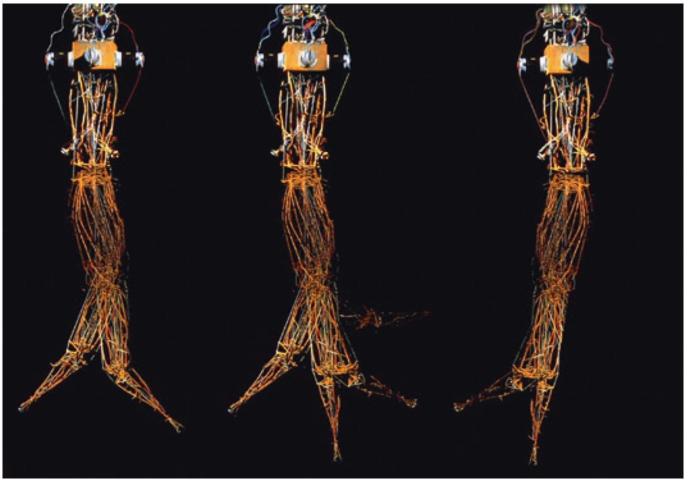

Fig. 6 The Flock by Ken Rinaldo and Mark Grossman. *Photo* Liz Civic

materials (cabernet sauvignon grapevines) glued together with cyano acrylate and baking soda to allow these robots to exhibit unnatural flocking behavior toward sound.

They employed new pull string mechanisms I invented and steel springs, which functioned as universal joints to allow the robots to have a full 360 degrees of motion. Most importantly, the morphology and programming allowed the robots to interact in unstructured environments with humans in safe and engaging ways. They were early examples of creating flexible and compliant structures that many researchers are now pursuing such as Festo Corporations 2010 bionic Tripod [7]. These robots were conceived in thinking about the way tendons and muscles can move through the hand, arm and legs, allowing complex and flexible motion in all degrees of freedom (Fig. 7).

Mark Grossman developed flocking algorithms programmed in c+ and the robots were able to interact autonomously in real-time very rapidly, flocking toward human voices. Custom circuit boards harvested from obsolete Silicon Graphics workstations were interfaced to four microphones, inset in conical tubes, either collected or dissipated sound and relative volumes determined response of the robots. When one of four microphones heard sound directionally, they would send their signals to custom motor drive units and move toward that sound and then communicate with the other arms to also move in that direction. The robots spoke to each other through audible telephone tones (a musical language) that would not miss trigger their responses. Telephone tones with a primary tone and secondary tone, cannot be confused with human voices, which made them an ideal choice for massive wired telephone networks and for this artwork.

Using grapevines a soft natural material was an innovation that would continue in many other works. This installation allowed me to theorize and develop ideas about

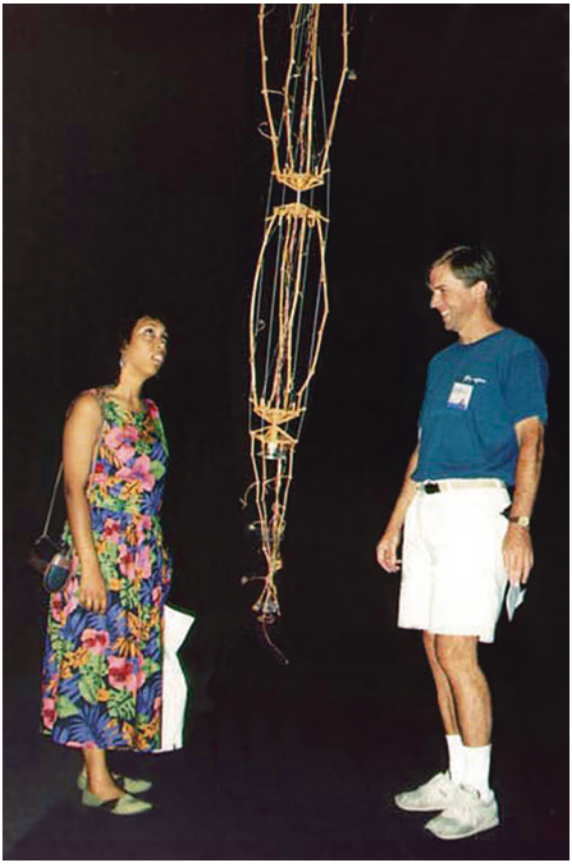

Fig. 7 The Flock at the Machine Culture show by Ken Rinaldo and Mark Grossman, Siggraph, 1993. *Photo* Ken Rinaldo

transparent interfaces in which the viewer/participant only need enter the space and the robots themselves “know” the most appropriate ways to behave and interact.

The ***Mediated Encounters*** **1996** installation was a continuation of the research involving socially engaged Siamese fighting fish augmented by robotics. The idea here was to empower four fish to interact socially and engage further into fish/human social spaces.

Integrated as aesthetic and functional elements custom built circuit boards, imbedded microcontrollers, dried grapevines and hand blown glass supported the fish environment. Infrared break-beam systems allowed microcontrollers to sense the position of the fish in the tank and allowed the fish to spin the sculpture, in one of two directions and at multiple speeds. Two male and two female Siamese fighting fish were able to use the interface to move the sculptural robotic trusses to meet and compete across the gap of the glass bowls.

A custom brush-system at the top of the robots, delivered power to the on-board microprocessors that allowed the microprocessor systems to locate and sense the position of the fish (Fig. 8).

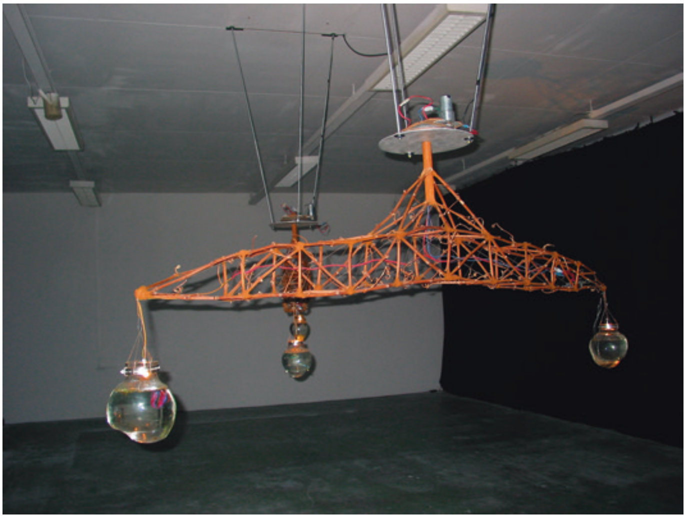

Fig. 8 Mediated encounters at robots 2004, Lille France by Ken Rinaldo

Hand blown glass fish tanks, which hung off the grapevine trusses, were designed to spin within inches of each other allowing visual intercommunication between male and female. The works hooked into the social space of sexual interest and male-to-male competition as well as male to female sexual interest and both sexes interested in human interaction presumably because of association with feeding.

This installation further stimulated dialogue surrounding living animals in public installation works of art and again, given the fish bubble nests that the males built, I felt they were comfortable habitable spaces for these fish. The glass tanks were large for Siamese fighting fish and varieties of plants suspended inside each bowl also added to this complex constructed semi natural world. This robotic work empowered the fish to interact, though also allowed a distance, where they could not fight outright. As fish often associate humans with feeding the fish tend to drive the robotic tanks toward humans, when they enter the installation (Fig. 9).

In continuing research with soft robotics, transparent interfaces and affective computing ***Autopoiesis***, **2000**, is a series of fifteen artificial life sculptures that constructs an immersive and dramatic interactive environment. Artificial life programming techniques allow this installation to evolve in real-time and are most "fit" for the particular user/s environment. Autopoiesis is a word coined in1972 by Chilean biologists Humberto Maturana and Francisco Varela to define the concept of self-maintaining cells or self-making systems as this work in essence is always evolving it's own behavior [9].

The software coded in c+ was a variant of the subsumption software architecture developed by Rodney Brooks who headed the AI Laboratory at MIT [10] (Fig. 10).

These musical and robotic sculptures allowed this series to interact as both individuals and as a group consciousness of robots, as they display complex emergent behaviors.

Fig. 9 Mediated encounters at robots 2004, Lille France by Ken Rinaldo

The use of grapevines integrated with blue and red cast plastic parts, created a calming and approachable sculpture. They communicate to each other through an RS485 network for noise immunity and audible telephone tones, which were used as a musical language. This gives humans sonic emotional feedback about the robots internal states and creates a systems evolution as well as an overall group sculptural/sonic aesthetic.

Autopoiesis utilizes smart sensor organization, which allowed minimal sensors, while maximizing the abilities of the software to cope with the incoming data. These lessons were learned from neuromorphic engineering. Neuromorphic engineering is a word coined by Carver Mead in which perception, motor control and multisensory integrations are based on neuro-biological principles [11] (Fig. 11).

For example, at the top of each sculpture, four (1 bit) passive infrared sensors face north, south, east and west. When two sensors are triggered, the software knows that someone is located in that vicinity and the sculptures move in that direction, giving viewers a sense of being observed. Four sensors allow eight

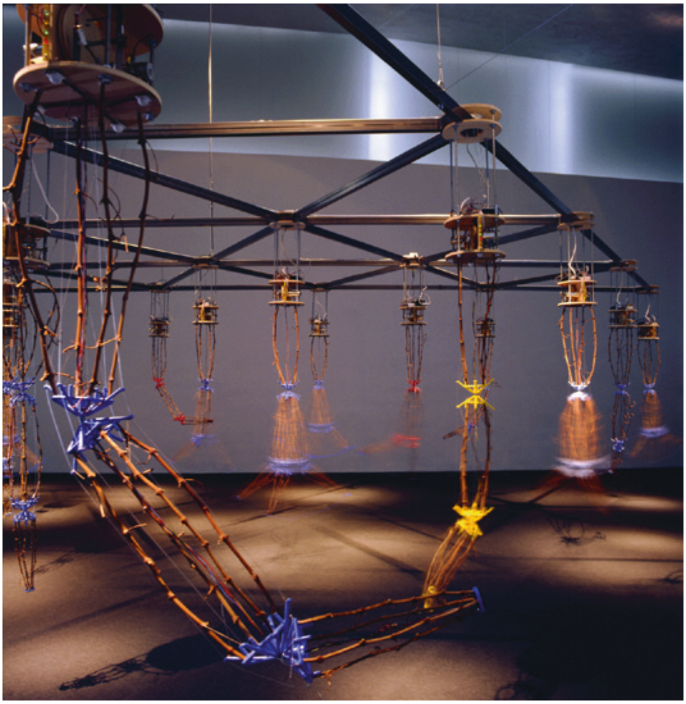

Fig. 10 Autopoiesis by Ken Rinaldo at the Kiasma Museum in Helsinki Finland, curated by Erkki Huhtamo. *Photo* Yehia Ewies

quadrants of sensing. Active infrared sensors located at the tip of each robot, stops the arm as it arrives within inches of the viewer. This allows the sculpture to display attraction and repulsion behaviors, an analog to animals sensing their world and displaying similar exploration strategies in approaching food, though cautiously approaching predators and mates.

Additionally, the robotic sensors compare their sensor data through a central—microcontroller that connects all robots as a group, so the viewer/participant is able to walk through the installation and have the arms interact uniquely each time. As each arm has it's own on-board computer control the speed of reaction is rapid and therefore life-like (Fig. 12).

Curator/Professor Erkki Huhtamo at the Kiasma Museum, Finland, interacting with Autopoiesis.

Local robotic interaction always supersedes group interaction when a local sensor is aware of a human nearby an analog to biological systems.

At the tip of two robotic arms, lipstick video cameras grab live footage and that is transmitted to projector via a transceiver. This is projected onto the walls of the space giving interactants a sense of being observed and seen by this artificial life installation. Seeing the robot vision also suggests robotic agency.

Fig. 11 Autopoiesis at the Kiasma Museum in Helsinki Finland, curated by Erkki Huhtamo. *Photo* Yehia Ewies

From a software perspective individual sculptures count and report sensor activations, which effects the overall group behavior. When there are large crowds within the installation group behaviors are less vigorous. When there are fewer interactants within the installation, less data allows the overall group behaviors to be more vigorous.

As the telephone tones are a musical language, higher rapid tones are associated with fear and lower deliberate tonal sequences, with relaxation and play. Other telephone tones give the impression of the installation whistling to itself. The touch-tones serve as a language of intercommunication and create a sense of overall robotic group consciousness where, what-is-said by one, effects what is said-by-others.

Autopoiesis continually evolves its own behaviors in response to the unique environment and viewer/participant presence. This group consciousness of sculptural robots manifests a cybernetic ballet of experience, with the computer/machine and viewer/participant involved in a grand dance of one sensing and responding to the other.

Augmented Fish Reality, **2004**, was a further evolution of works that looked at fish cognition, social interactions and the creation of gentle environments that are friendly

Fig. 12 Autopoiesis by Ken Rinaldo at the Kiasma Museum in Helsinki Finland, curated by Erkki Huhtamo. *Photo* Yehia Ewies

and considerate of fish. They are the first free roaming robotic fish tanks on the planet concerned with fish desire and empowerment through sensitive interface design.

They explored interspecies and trans-species communication using closed loop video to magnify the scale of the fish. These "bio cybernetic" sculptures empowered Siamese fighting fish to use intelligent hardware and software to move their robotic bowls at their will. Peace Lilies within each glass bowl created miniature cleansing ecosystems and a comfortable while complex environment for the fish. Peace lily plant roots served as resting place for the fish to build bubble nests and attract mates.

This work hooks into the inherent social interactions of the Siamese fighting fish, as they are prone to want to fight given human interbreeding. As the fish swim to locations in the tank toward other fish in other tanks, the sensor placements allow the robots to transparently respond, by moving in that direction (Fig. 13).

As with many of my works, extensive research into the fish and robotic systems proceeded with sketches, 3D-models and then building prototypes. Laser cutting and machine fabrications have become increasingly important parts of my process. Custom code, integrated with imbedded microcontrollers allowed the fish to travel

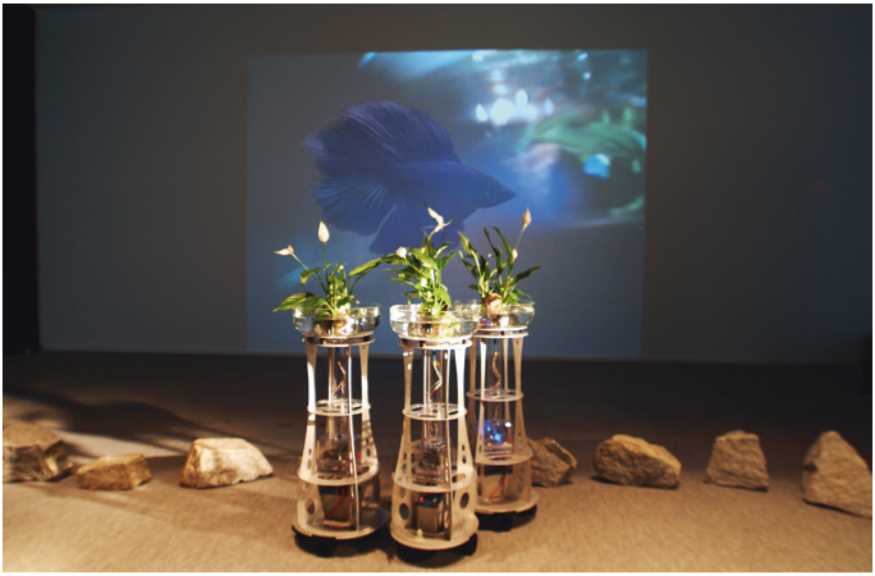

Fig. 13 Augmented Fish Reality Ars Electronica by Ken Rinaldo

anywhere in the installation they wished. Barriers of stones are often used to keep the robotic fish tanks within the bounds of the installation.

Some ask does the fish have the intelligence to learn the interface? Fish Scientist Dr. Cullum Brown discusses revisions in thinking about fish intelligence, which seems much greater than formerly imagined. Fish are "steeped in social intelligence." In his work he discusses how fish have the ability to mentally map their environments to find food and avoid predators.

> The article reports that fish pursue "Machiavellian strategies of manipulation, punishment and reconciliation" while also displaying "cultural" traditions and cooperation to elude predators and obtain food. It is said that fish track the relationships of other fish in their environment and even monitor the social prestige of other fish. It is now widely supported that fish build nests as well as exhibit "impressive long-term memories" [12].

The robotic fish bowls feature four accurate infrared sensors attached to custom coded imbedded microcontrollers. As they swim about sensing their world, each fish activates the motorized wheels in their personal vehicles and side sensors empower the fish to move the robot forward and backward and to turn the robots left or right, so they may interact. Soft foam wheels and rubber bumpers under each fish tank isolate the sound and vibration of the motors, as sound travels through water quickly.

When I saw the fish building bubble nests to attract females I was really happy, as this is a sign the males have accepted this as their home (Fig. 14).

Humans interact with the work simply by entering the environment. But these robots are under fish control, and the fish will choose to approach and/or move

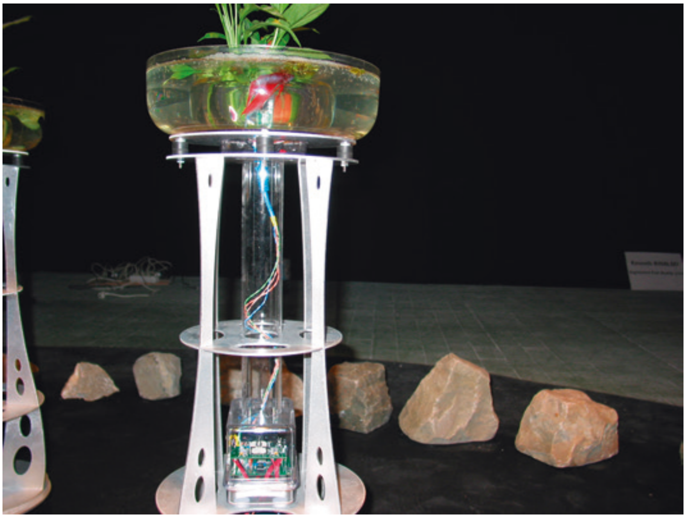

Fig. 14 Worldwide premiere of the Augmented Fish Reality in Lille France Lille 2004 commissioned by Richard Castelli

away from the human participants whenever they wish. Siamese fighting fish are top breathers and very comfortable in an oxygen deficient environment.

Both male and female Siamese fighting fish are within this installation and this tends to heighten their competitive nature. The robots are designed to exploit this fact as they allow the fish to get within 1/4 in. of each other for visual communication and interaction.

Small lipstick video cameras mounted on 45° angles, inside two of the bowls transmit images from within the tank to show the perspective of the fish. This also allows the viewer/interactant to psycho-project self, through the eyes of the fish into the tank. Here again, a transparent interface allows the fish to move toward the other fish without distinct knowledge of the interface. Here the vision system of the robot "knows" how to respond and allows humans within this interspecies artwork to empathize and see the fish on an enlarged scale to better understand their delicate and complex beauty.

In looking at engaging natural systems such as interacting fish and human cultures it is also evident that we can construct artificial nature. The ***Autotelematic Spider Bots*** by ken Rinaldo and Matt Howard 2005 is a work inspired by looking at the "rule-driven" nature of ant colonies. The idea was to construct a series of robots that could act like ants to find their own food source in a swarm like manner. As with real ants, energy autonomy in robotics is a complex issue. For these robots, finding food and communicating that to others, was key to their survival and staying charged up.

I designed these robots, to demonstrate a distributed intelligence and my hope was that the robots could "emerge" into energy autonomy through random foraging by first finding and then communicating their energy source "food source" back to the other robotic spiders (Fig. 15).

Fig. 15 Worldwide premiere of the Autotelematic Spider Bots at the Sunderland Museum and Winter Gardens by Ken Rinaldo and Matt Howard

These works utilize artificial life programming and neuromorphic engineering principles in creating an installation of 10 spider-like sculptures that interact with the public in real-time and self-modify their behaviors. The overall behaviors are based on interaction with the viewer, themselves (the robots) and their food source. The spider bots were designed virtually first, rapid prototyped and then built by both machine and human hands.

In this process they advanced new robotic morphologies of a unique tension-compression leg structure. Integration of custom designed circuit boards, embedded microcontrollers and software running in parallel; on a right/left hemisphere approach to code processing was unique. It allowed them to exhibit complex interaction and emergent behaviors, as they moved around their artificial environment.

The spider bots communicate to each other through Bluetooth communications and body languages to coordinate their activity. They find their food source through random foraging, looking for a 40 kHz infrared beacon that sits under a recharge rail. They are programmed so when the voltage charge is low they would go into a "seeking behavior" and sensors on each robot allow them to hone in on the food source.

In demonstration at the exhibition, one robot was able to find and attach itself to the recharge station and communicate that to others. Still, in it's current state the robots remain charged for 45 min and because the 9.6 V NiCad batteries take 2 h to charge the "emergence" of a self-charging, ecosystem of robots will be fully

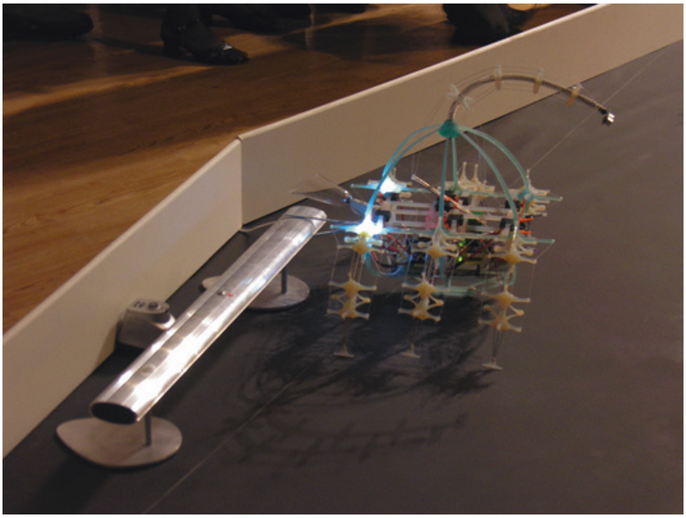

Fig. 16 One robot recharging on the recharge rail AV Festival England commissioned by Honor Harger. *Photo* John Marshall

realized, when battery technology sufficiently evolves. Bluetooth is also a really power intensive technology so lower power communication protocols will be used for future innovations (Fig. 16).

For human feedback the robots talk to the interacting public with high pitched chirping sounds giving participants a sense of the "emotional" response of the spider bots. To see the vision of the robots, one of the robots has a mini video camera and video transceiver to transmit to a video projector which projects this vision to a voronoi (web like) screen, giving viewer/participants a sense of being captured in the installation's web. This screen also shows the spiders in larger scale then the viewers, subtly manipulating the power structure of the human/robot relationship (Fig. 17).

As art and robotic research these works defined a new robotic leg morphology based on a tension-compression structure and pull string mechanics. Each set of two legs acts like a flexible arch held into compression by springy plastics and monofilament. When servomotors pull the monofilaments, the arch bends allowing the leg to move organically. Six legs (biological spiders have eight) allow the robots to walk forward in a tripodic gait and turn, in either direction. This tripodic gait simulates six legged insects.

Inspiration for the robots came from a lecture by Dr. Guy Theraulaz at the Centre National de la Recherché Scientifique who reports that ants operate on rule driven systems [13]. With this in mind, it became apparent that computers and software as rule-driven-systems could be structurally coupled with their environment, allowing them to emerge and feed/recharge themselves.

The software is organized in what I term a bio-sumption architecture, which allows individual behavior to be subsumed for the fitness of the group as well as

Fig. 17 World wide premiere of the Autotelematic Spider Bots at Sunderland Museum and Winter Gardens in England. *Photo* John Marshall

interaction with human participants. Behaviorally when the robots are “hungry” they have food finding, as their primary behavioral concern and ignore human interaction. This is a variation on the subsumption architectures of Rodney Brooks.

The robots were designed in the 3D software, which allowed a customization of motors and parts fitting to absolute accuracies and allowed for a rapid evolution of this complex integrated morphology (Fig. 18).

The final robots were printed with rapid prototyping plastics. The colored portions were cast in semi-clear polyurethane plastic, impregnated with Pantone™ colors, which gave each robot an individual look.

As the robots were output from rapid prototyping robotic systems, means the robots were given birth, by other robots and of course suggest interesting futures or robotic birthing machines in a kind of post human evolution.

The electronic system design allowed the hardware to distribute as much of the intelligence of the robot to integrated smart sensors and motor controllers, so the servo motor controller functions like an autonomic nervous system. This allows the motors to receive walking commands without tying up individual microprocessors. It also allows quick processing and rapid sensor/motor responsivity. The brains, microcontrollers also used a left/right hemisphere approach to parallel processing with a four-wire corpus collosum between the two hemispheres. This permitted coordination between the two-hemispheres some handling sensing like ultrasonic sensors and others servo motor control for walking and further mirrors how natural systems have evolved with left and right hemispheres in their brains.

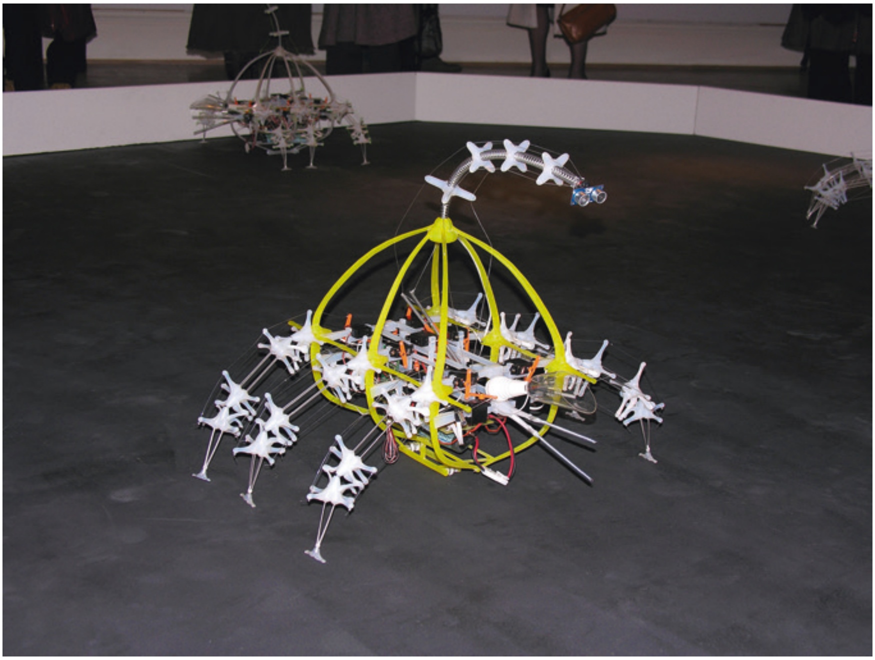

Fig. 18 Yellow Autotelematic Spider Bots Sunderland Museum and Winter Gardens in England *Photo* John Marshall

The Autotelematic Spider Bots installation is an artificial life chimera; a robotic spider, eating and finding its food like an ant, seeing like a bat with the voice of an electronic twittering bird.

In thinking on a larger and grander scale about food systems and human culture ***The Farm Fountain* 2008** by Ken Rinaldo and Amy Youngs my partner and wife, was a work designed to explore and find solutions surrounding urban agriculture that also engaged the bacterial scale. The Farm Fountain is a robotic aquaponic garden designed for an ethical and environmentally friendly way of farming food both plants and fish. This food producing robot, is designed to allow fish waste to feed edible vegetables. Humans can consume the vegetables and fish and all are regulated by microprocessor systems.

This creates a symbiotic relationship between edible plants, bacteria, fish, humans and machines. With the use of pumps, gravity and systems engineering, the fish waste flows through tubes and serves as nutrients for the plants. The plants and bacteria in the system symbiotically cleanse and purify the water for the fish.

This living work creates an indoor healthy environment by providing oxygen to the humans working and moving in the space. The sound of water trickling through plant containers also creates a peaceful relaxing waterfall environment (Fig. 19).

The fish that are part of this food robot also provide a focus for relaxed viewing. The plants in this fountain are edible leafy greens, lettuces, radicchio, cilantro,

Fig. 19 Worldwide premiere of the Farm Fountain by Ken Rinaldo and Amy Youngs at the Te Papa Museum New Zealand. Commissioned by Randy Rosenberg. *Photo* Amy Youngs

mint, basil, tomatoes, chives, parsley, arugula, mazuna, mabuna and tatsoi. In our home version multiple tilapia were raised from fry to full-grown. Tilapia has been farmed for thousands of years in the Nile delta. Programmed microcontrollers integrated with pumps and controlled lighting systems allow participants to witness the future of farming.

As continuation of this research we built a solar powered version in Portugal during a residency at Cultivamos Cultura commissioned and curated by Marta de Menezes and Luís Graça (Fig. 20).

It is the hope of Amy Youngs and myself that these works will provide a real model and local solution to the 1500-mi salad. 1500 miles is the average distance salad travels from farm to fork. As part of this project we have set up a how-to website to engage the power of social networking, to allow others to build and eat their own.

In further exploring social interaction mediated by machine culture and cameras in particular the ***Paparazzi Bots*** **2009** is a series of five interactive robots that critically engage the power of cameras to reformulate private versus public space. With a focus on self in the age of Facebook and the selfie, these robots follow

Fig. 20 Worldwide premiere of the Farm Fountain 4 by Ken Rinaldo and Amy Youngs at Cultivamos Cultura Residency Portugal. *Photo* Amy Youngs

the viewer and shoot their photos, manipulating viewer to feelings of "celebrity". By being captured by the robots they "anoint" and capture participants through the machine "choice" of them.

Here machines are allowed to make decisions about beauty and prefigure future technological interfaces, where biometrics and machine vision will further become gates, through, which humans will, or will not pass.

Laser cut aluminum, cameras, custom built circuit boards and imbedded micro-controllers running in parallel allow these robots to be the first autonomous, paparazzi photographers (Fig. 21).

Comprised of microprocessors on a custom-built rolling platform, they move at the speed of a walking human while avoiding walls and obstacles. They seek one thing which is to capture photos of people and to make these images available to the press and the World Wide Web as a statement of culture's obsession with the "celebrity image" and especially our own self-images (Fig. 22).

Each autonomous robot can make the decision to take the photos of particular people, while ignoring other humans in the exhibition, based on whether or not the participants are smiling or the shape of their smile. When the robots identify

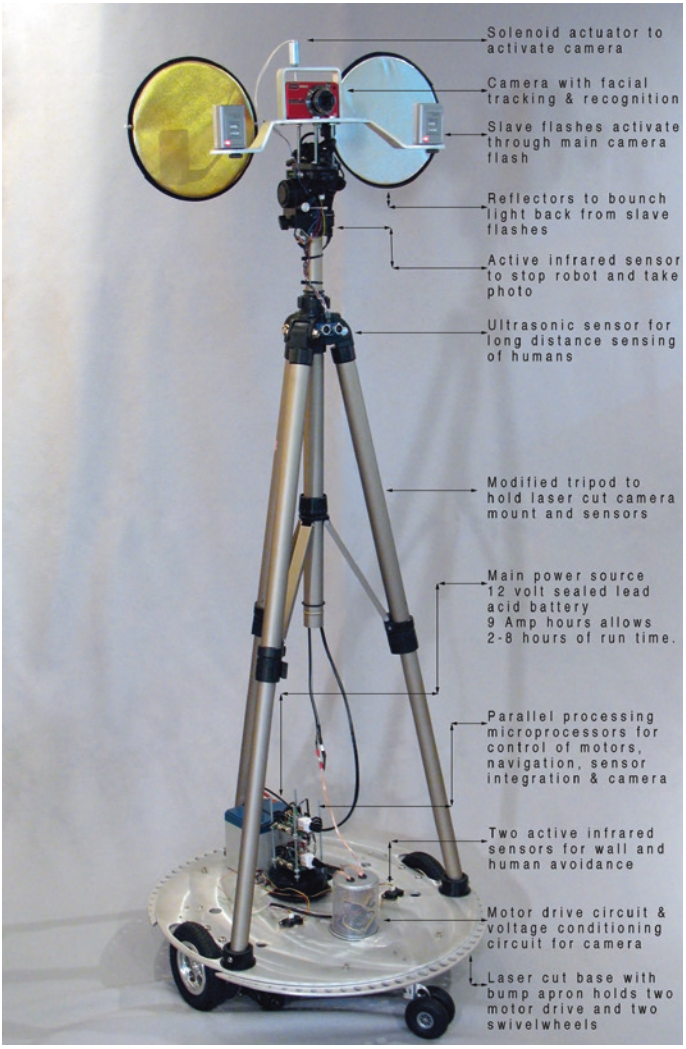

Fig. 21 Diagram of the functional elements of the Paparazzi Bots commissioned by curator Dmitry Bulatov and the Vancouver Olympics. *Photo* Ken Rinaldo

a person they automatically adjust their focus and use a series of bright flashes to record that moment (Fig. 23).

Surveillance technologies straddle a delicate balance in contemporary culture, where we are all photographed without our knowledge by cell phones, hidden cameras and sometimes we are "celebritized". This work explores ideas surrounding the shifting territories of self and machine and how machines can manipulate the other (us) in a grand co-evolutionary dance of emerging robot-human relations (Fig. 24).

Fig. 22 The Paparazzi Bots at Nuit Blanche Toronto invited by curator Shirley Madill

Fig. 23 The Paparazzi Bots at Transmediale, Germany invited by Honor Harger

Fig. 24 The Paparazzi Bots by Ken Rinaldo capture Stelarc at the Arte e Ciência exhibition, Lisbon Portugal, curated by Leonel Moura

The recent emergence of social networks and their ability to connect people through software prompts via the World Wide Web is a prime example of the co-evolution of humans and their intelligent machines. (Fig. 25).

The fact that the software prompts use our social needs for connectivity and social space is so easily exploited in this new critical juncture, in our emerging machine-human relations.

With an interest in further looking at bacteria as the ultimate models for robotics and the mediating force of all biological life, ***The Enteric Consciousness*** **2010** is a glass stomach filled with living bacterial cultures. The work creates an interface allowing control of a robotic tongue that gives you a deluxe massage, if the bacteria are happy and healthy. This work senses the health of the bacterial cultures in the artificial stomach and mediates a touch-based interaction, through massage. It realizes new ways of considering and thinking about interactive art that may now be more fully focused on corporeal experience and touch.

Theoretically, it is focused on the coevolution of human and bacteria in the creation of our enteric nervous systems, which co-inhabit our stomachs and bodies. When you sit on the bacterially mediated robotic chair, if the bacteria are healthy, the robotic tongue reclines and gives you a deluxe, 15-min massage. For me this is in symbiotic sympathy with the bacterial cultures within all of us. (Fig. 26).

The glass artificial stomach that houses the bacterial cultures has a tube moving through it, with cooling liquids. The glass stomach is filled with the same bacteria that occupy our natural stomachs. Our stomach is part of our enteric nervous system, which is lined with symbiotic bacterial cultures. Our ENS consists of one hundred million neurons, about one thousandth the number in the human brain (Fig. 27).

Fig. 25 The Paparazzi Bots at Transmediale, Germany

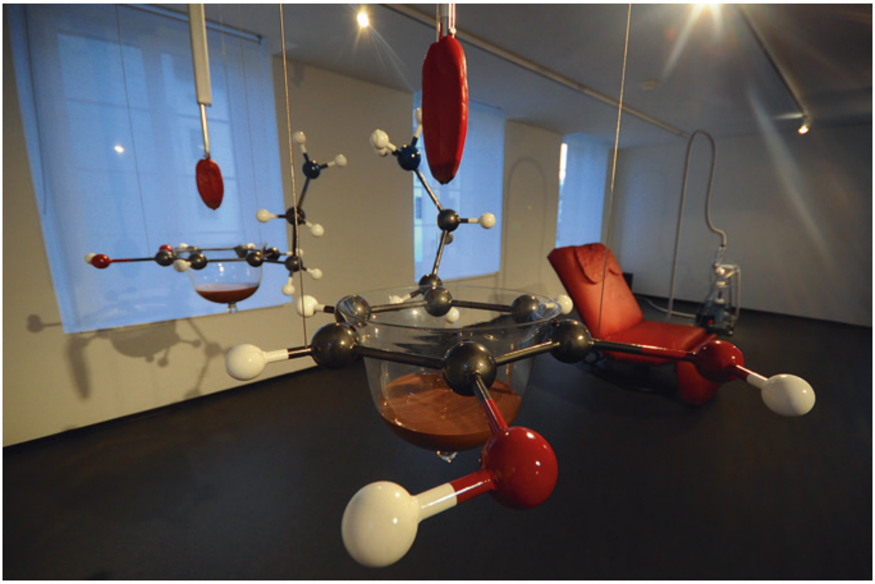

Fig. 26 Enteric Consciousness by Ken Rinaldo at the Maison d'Ailler Museum of Science Fiction and Future Journeys. Commissioned by Patrick Gyger. *Photo* Joana Avril

Fig. 27 Enteric Consciousness installation; glass and bacterial stomach by Ken Rinaldo. *Photo* Nicholas Nova

The enteric nervous system in the stomach shares the same neuro-transmitters as the brain, such as dopamine, serotonin and epinephrine. If the finger can be seen as an extension of our human brain, then the tongue can be seen as an extension of the enteric nervous system, seeking out what it prefers to ingest.

I have chosen in this work to focus on our sense of taste and touch and corporeal experience as a way to explore interactivity, as our largest sense organ is in fact our skin. When thinking about interactive art, I realized there are few examples where touch is central to the work. Here the touch of the robotic tongue is much more visceral, emotional and well, sexy (Fig. 28).

As peristaltic muscle movements propel food and bacteria through our natural stomachs, so a peristaltic pump, artificially replicates and moves cooling water through the artificial glass stomach. A PH meter measures acidity and basicity of the bacteria, monitoring its health in the artificial stomach and these signals are interfaced and activate a series of relays and micro controllers that allow the tongue robot to activate, relax and massage the viewer/interactant. The robotic tongue is covered with red emu leather giving it the appearance of swollen taste buds.

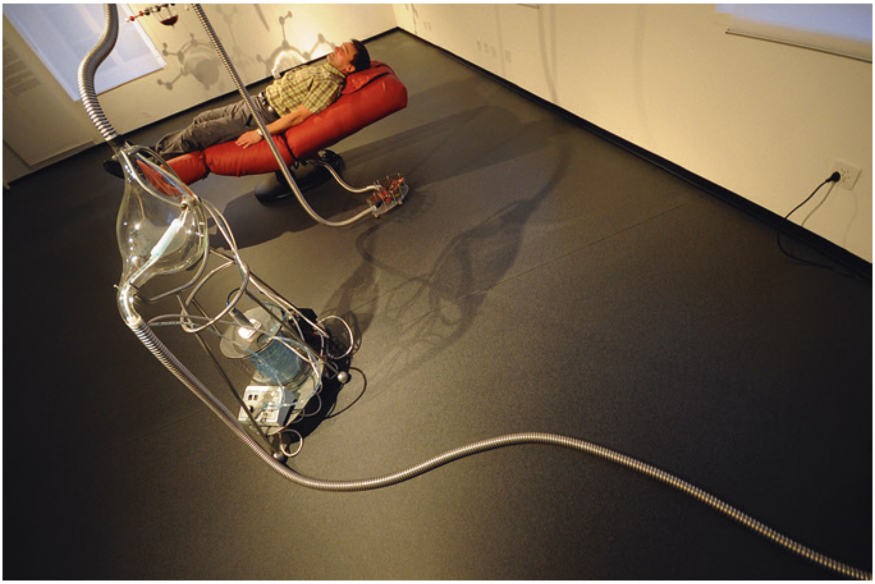

Fig. 28 Enteric Consciousness; robotic tongue and glass stomach. *Photo* Joana Avril

While our natural stomachs are sterile at birth they are soon colonized by 1,000s of kinds of bacteria, which mediate and influence what we eat and enjoy. The enteric nervous system and our brains carry on bi-directional communication and share many common neurotransmitters.

Acid-loving milk-bacterium, Lactobacillus acidophilus is a species in the genus lactobacillus, are the activators of this robotic tongue in concert with human interaction. Lactobacillus acidophilus occurs naturally in human gastrointestinal tracts in addition to vaginas and mouths. Strains of L. acidophilus have probiotic characteristics and many are used commercially in the production of yogurt.

Another element of this installation are smaller robotic tongues that dip in and out of chocolate pools, located in large glass containers. Large dopamine molecules constructed in steel hold up the glass containers. The dopamine molecule is believed to mediate the subjective experience of pleasure in humans and other animals. Chocolate and cheese (sugar and fat) are two substances that the tongue and the stomach desire. Research has proven that chocolate can boost serotonin; an antidepressant molecule and it can also stimulate secretions of endorphins that create pleasurable sensations.

This work is mostly inspired by the notion of the conscious stomach, although it is also inspired by the ideas that humans are not individuals so much as clouds of intertwined human, bacterial, and now machine cells.

We have co-evolved into hybrid symbiotic ecosystems that consist of trillions of living bacteria. Humans have ten times as many bacteria cells in and on us as we have human cells in our entire human bodies. Our armpits, crotches, and guts are like rainforests teeming with microbial life and our backs are like deserts.

The bacteria within and on us are eating and surviving and our bodies provide for their sustenance. There are one thousand trillion bacterial cells versus one hundred trillion human cells in each of our bodies, yet the human body does not end there. Bacterial cells are an important part of our health, helping us to digest indigestible foods as well as making essential vitamins and, ultimately, impacting and forming our immune systems.

Liping Zhao wrote in the *Journal of Biotechnology* that, "Humans are super organisms with two genomes, the genetically inherited human genome (25,000 genes) and the environmentally acquired human micro biome (over 1 million genes)." …"In contrast to the human genome, the gene composition of the human microbiome is rather flexible and can be modulated by foods and drugs" [14].

This cloud of cells finds analogs in "machine cells" which are also distributed above and below the earth as they regulate and feed human society. These machine cells are engineered, though also now self-regulating systems that serve to support human existence as they are networked smartwatch microprocessors, stoplights, hundreds of trillions of transistors in intelligent devices regulating our every need.

By thinking about our engineered human existence, we reveal a comfortable proto embryonic sac of chips and wires feeding into larger dendritic networks of 100,000-V power towers and pulse-coded and frequency-modulated telephony and uplink satellites, all in regulation of human needs.

We cannot imagine the human animal surviving without our now symbiotic relationship with these engineered systems and our coevolved bacterial symbionts that regulate our lives. Just as bacterial cells are autonomous living networks, our robots are now rapidly emerging into proto living systems as they self regulate, motor around our environments, and begin adopting caretaking roles for humans.

The Enteric Consciousness installation realizes a corporeal space, celebrating the symbiotic relationship between the bacterial cultures that live in and on us and an emerging ecosystem of human-engineered robotic entities that will inhabit our homes, workplaces, galleries and now our bodies. The Internet of things portends a future network that further blurs human, robots and bacteria in regulating human and soon to be; machine "desire".

In continuation of research into robots and desire entering our bodies and our bodies entering them, the ***Fusiform Polyphony* 2012** is a series of six interactive robotic sculptures that compose their own music with input from participant facial Figs. Micro video cameras mounted on the ends of these robots, move toward people's body heat and faces while capturing human snapshots. These images are digitally processed, pixelated and produce a constantly evolving generative soundscape, where facial features and interaction are turned into sound melody, tone and rhythm.

These elements manifest the viewer as participant/actor and conductor in defining new ways of interfacing and interacting with a group consciousness of robots while allowing the robots to safely interact with humans. A key element of this installation is to see self, through the robots eyes, as each bot captures images showing the nature of algorithmic vision. The title of the work refers to the part of the brain the fusiform gyrus that is optimized for seeing human faces. The work also alludes to microprocessors and expert systems developing with optimized abilities in this case to compose music (Fig. 29).

Fig. 29 Fusiform Polyphony by Ken Rinaldo worldwide premiere during Nuit Blanche Toronto invited by Shirley Madill & commissioned by Nuit Blanche

Blurring human and robots, these works are covered in natural human hair that serves to point to a human/robotic hybrid moment, where the intelligence of robots is more fully fusing with our own. Robots are absorbing bodies and our perceptual spaces as is most evident in teleoperated robotics.

The live camera-based-video of the robots is processed through MAX MSP and Jitter and projected to five massive screens for viewing. When the robot is at head height a sensor at the tip of the robot is triggered and a facial snapshot is taken.

This snapshot is held in the small area of the projected screen to the upper right. That snapshot is broken down into a 300-pixel grid and the variations of red, green and blue data of each pixel is extracted and interfaced to Max MSP to Ableton Live a sound composition tool. Max MSP and Abelton accept the facial data and mediate the rhythm, tempo and dynamics of each musical work produced by each robot (Fig. 30).

The robots are individually controlled with six Mac Minis, wired to midi-based controllers to a Miditron Midi controller, sensor and motor drive units. These are networked to a Mac Pro Tower that processes the video of the faces and interfaces these to the Abelton sound program.

Changing pixel data, directs the Ableton instrument sets with random seeds coming from the snapshots. The robotic structures were created with 3D modeled cast urethane plastics, monofilament and carbon fiber rods, laser cut aluminum elements supporting the computers microprocessor and motor drive systems.

These robots structure, inform, enhance and magnify, people's social behavior and interactions as they auto generate a unique and a constantly evolving generative soundscape. They take the unique multicultural makeup of each person and

Fig. 30 Fusiform Polyphony during premiere of Nuit Blanche Toronto 2011

create "facial songs" where those songs joining with 6 robotic/human soundscapes, creates an overall human polyphonic and video experience. They are peaceful and playful robots and sadly so many current human robotic pursuits are driven by violence, power and fear.

The ***Drone Eats Drone: American Scream*** **2013** is a robotic vacuum cleaner that is hacked and rewired, that carries a mini Reaper drone crashing into another reaper drone. It is designed as an interactive warning of the coming age of drones in domestic space. It responds to human body heat (as any drone would) by moving from a recharge station, moving about—turning its drone propellers on and returning to the charge station. The robot base is covered with a miniature bucolic prairie scene, with cows and humans to elicit peaceful notions of home, while menacing drones buzz above.

As many who study technology and the issues of borders know, drones in particular have become the weapon of choice, for crossing borders and carrying out undeclared war. These drones and the technology they employ, are playing an increasing role in world politics and in particular the military industrial complexes worldwide (Fig. 31).

As lobbyist work to fund domestic drones we are on the cusp of algorithmically deciding if a person is an "enemy combatant" or not. This work critiques businesses such as IRobot (producer of military robots and the domestic Roomba vacuum cleaners) drone manufacturers such as General Atomics. (Fig. 32).

The work questions and challenges the act of continuous war and the effect on populations especially in war torn regions where the Bureau of Investigative Journalism has reported that over a 9 years period, out of 372 flights 400 civilians were confirmed dead, 94 of them children [15] (Fig. 33).

Fig. 31 Drone Eats Drone: American Scream by Ken Rinaldo premiere at La Compagnie, France curated by Isabelle Arvers. *Photo* by Myriam Boyer

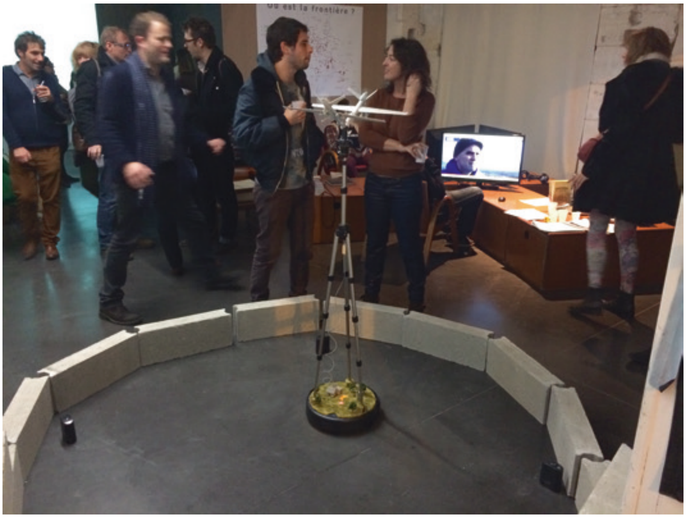

Fig. 32 Drone Eats Drone base showing bucolic scene with cows and human. *Photo* by Myriam Boyer

Fig. 33 Close-up of Drone Eats Drone base showing bucolic scene with cows and human. *Photo* by Myriam Boyer

This work challenges the idea that governments with military power and money can purchase new technologies and allow drone robots to fundamentally challenge the notion of national as well as individual autonomy and borders.

It conflates the land of other countries with the terrain of your living room and home. It seeks to join and help others understand the relationship between domestic consumer goods and our military industrial complexes who increasingly manipulate and create foreign policy with military robotic killing machines. With Google's purchase of Boston Dynamics maker of military robots as their buying satellite maker Skybox (uncannily close to Skynet) one only hopes that we are not on the cusp of being rendered obsolete, by artificially intelligent robots that "know" what is best for us. When we create robots whose sole vision is to see the world as threat and not as an exquisitely intertwined ecosystem we have lost touch with the nature of life and our future.

Each of these interactive artificial life artworks and symbio technoetic biologically based systems, work to demonstrate a philosophy of ecology and symbiosis. As robots become increasingly sentient and symbiotically intertwine with their creators I continue to hope for a time when robots emerge and do things they are not implicitly designed to do. Interfaces must become more sensitive to natural biological systems and allow a fuller spectral understanding of the natural world that surrounds us.

While many of these works engage natural systems as model we are currently in a stage on the planet where machines are more parasitic then symbiont and most are destructive to natural living systems, as evidenced by mountains of e-waste. These works show a gentle and possible future in order to express sensitivity to natural living systems and the models they provide.

In order to fully realize the dream of a symbiotic natural/technological world intertwining, we need to question understand, and emulate the lessons offered by natural living systems. We can begin by having computer/machine systems degrade in such a way they do not damage the environment and natural living systems to which they depend. Time for emerging bacterial computers. Then and only then will we begin the necessary long-term sustainable future of a process toward real trans-species animal/bacterial/machine culture, co-evolved coupling.

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