Symbiogenic Experience and the Emergent Arts: Cybernetics, Art and Existential Phenomenology

by

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Abstract

This dissertation is an exploration of the ways in which certain forms of interactive art can and do elicit experiences of co-evolution with a technologized environment. These “emergent arts”, I argue, give rise to a sensory experience of a sense of being embedded and co-emergent with this environment. The term “co-evolution” is often taken to allude to Darwin biological processes of interaction between two or more species. However, much like humanities scholars such as Katherine Hayles and Mark Hansen do in their analyses of technology (Hayles 1999; Hayles 2002; Hayles 2007; Hansen 2006; Hansen 2005; Hansen 2009a), I recast the term to refer to processes of emergence, self-organization and autopoiesis.

By examining these artworks and experiences via the interlocking frames of cybernetics, phenomenological philosophy, posthumanism and interactive/new media art, this dissertation articulates the movement towards a framework that fuses theoretical and experiential modes of inquiry to provide insights relevant to both interactive artists and humanities scholars. New approaches to understanding and studying technologically-based artworks are proffered that attend to how these artworks are contributing to a new range of experiences that more adeptly attune us to our techno-ecological context. Experiences that I refer to as “symbiogenic”.

The framework centers on the exposition of four theoretical concepts: Ambiguity and Unknowability, Boundary, Distributed Intentionality and Collectively Emergent Autonomy. In addition, a taxonomical model of artworks is put forth that outlines a number of characteristics of new media and interactive arts practice that engage in processes that establish a foundation for the shifts in perceptual and embodied experience that I characterize as symbiogenic.

Along with the textual exegesis, this dissertation details the conceptualization, design, construction and exhibition of two interactive artworks: *Protocol* and *Biopoiesis*. Their function in this research is threefold: first as a concrete method of putting theories to the ontological test beyond conventional textual means, second, a way developing new

concepts and techniques and modifying existing ones (this applies to both the philosophical ideas and to the technical systems that are developed specifically for each artwork) and third they serve as embodiments of theoretical concepts in their own right.

Keywords: interactive art; phenomenology; cybernetics; autopoiesis; co-evolution; emergence

For my mother

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Glossary

Autonomy	The property of being self-determining. An autonomous system perpetuates itself and maintains its viability through the maintenance of a boundary by which it engages in sets of circular relations with its environment. In the context of enaction and autopoiesis, living beings and cognitive agents are understood to be autonomous systems (Maturana and Varela 1980; Thompson 2007).
Autopoiesis	Literally, self-production. This describes processes by which a system produces its own components and maintains its own organization. The term was first introduced in 1972 by Chilean biologists Humberto Maturana and Francisco Varela and is used to describe the property of systems whose autonomy is maintained via the recursive network of interactions among system components that produce the very same network of interactions that produce the components. An autopoietic system is operationally closed and structurally state-determined with no apparent inputs and outputs. A biological cell, an organism, and perhaps a corporation are examples of autopoietic systems (Maturana and Varela 1980).
Boundary	That which distinguishes a system from its environment, or more broadly an inside from an outside or a foreground from a background. In autopoiesis, boundaries are considered to be semi-permeable (Maturana and Varela 1980).
Circularity	Contrary to the classical Newtonian concept of cause and effect, circularity (or circular causation) describes a phenomenon wherein the effect of an event, variable or state returns nonlinearly to influence the original event, variable or state. Cybernetics discovered that circularity, if modeled adequately, can help us to understand fundamental phenomena, such as self-organization, goal-directedness, identity, and life, in a way that had escaped Newtonian science (Heylighen and Joslyn 2001). See also Feedback.
Constructivism	A philosophical perspective that maintains that knowledge and learning are not static attributes of a reality that is "out there" and must be passively received but is in fact constructed by active learners and knowers. Constructivists argue that the concepts of science are mental constructs proposed in order to explain sensory experience. Constructivist learning emphasizes active, thoughtful reflection on experience (von Glasersfeld 1995; von Glasersfeld 1987).
Control	Refers to the maintenance of a goal by active compensation of perturbations. A directing influence on the behavior of a system. While often associated with authoritarianism or domination,

cyberneticist Gordon Pask defined control as a “coming to terms with” or as method of learning, solving problems by subjectively relating between experiences (Pask 1971). In this sense control may be seen as a method of adaptation.

Co-evolution — From a biological perspective, co-evolution can be characterized as an evolutionary change in one organism or population of organisms, in response to a trait or behaviour of a second organism or population of organisms, with these changes being passed genetically to succeeding generations (Janzen 1980). While it draws broadly from biological metaphor, the conception of co-evolution developed for this dissertation draws from cybernetic theories and concepts such as circularity, autonomy and autopoiesis in order to articulate — from and artistic and cultural perspective — dynamic processes of constant change, adaptation and reconstitution that occur in relation to an environment and a lifeworld that is also dynamic, complex and adaptive. Describing how this lifeworld experience is heightened and intensified by interactive art is where this rethinking of the concept of co-evolution comes into play.

Emergence — A phenomenon or set of processes that result from the collective self-organization of networks or ensembles of elements wherein the whole cannot be dislocated from these constituent elements nor reduced to them. In a qualitative or aesthetic sense, emergence is that “something more” that evokes feelings of surprise and wonder due to its mysteriousness and unpredictability. From a 2^{nd}-order cybernetic perspective, what counts as emergence is highly dependent on what variables one chooses observe, sometimes called the “observational frame” (Cariani 1993).

Enaction — Rooted in the concept of autopoiesis, this paradigm explains how cognition emerges when system and environment, through networked interactions, trigger and select in each other structural changes. The enactive view maintains that cognition emerges from self-organizing circular process of continuous sensorimotor interactions involving the brain, body and environment (Varela, Thompson, and Rosch 1992).

Evolution — A non-deterministic, non-goal-directed process of gradual change in response to environmental pressures, wherein variety is both generated and destroyed over time. In the biological sense, this is the change in the inherited traits of a population of organisms through successive generations. Human evolution however, has been known to also have been influenced by the use of technology (Ambrose 2001). More broadly then, evolution can be seen as an active, process of adaptation, with the patterns of adaptation being incorporated into the organism’s morphology, behavior and genetic make-up. This can be contrasted with learning, which while also active and adaptive (at least in theory)

	is also deliberative, purposive and goal directed, characteristics that evolution does not posses.
Feedback	A cybernetic concept describing a flow of information back to its origin. Feedback relations are relations of circular causation and typically result in nonlinear/nonproportional outcomes. Thus, they can be seen as alternatives to linear cause and effect relationships. Emergence typically features feedback relationships (Thompson 2007, 419). See also Circularity.
Intentionality	The philosopher's term for the "aboutness" of something, it refers to the notion that human consciousness is always directed towards things in the world (Brentano 1973). We do not simply see, hear or taste but see, hear or taste particular objects or phenomena. The intentional structure of consciousness is vital to human experience.
Interaction	In a new media arts context, this refers to experiences where there is novelty, in which no participant has formal control over the situation and which involve the construction of shared meanings via various modalities (e.g. motion, gesture, sound, etc.)
Lifeworld	The cultural, social, historical and intersubjective/inter-corporeal constitution of the human world as directly experienced in the subjectivity of everyday life. In phenomenological philosophy the lifeworld is the already pregiven (and generally unreflected) intentional background of experience (Husserl 1954). For example, the lifeworld of modern western societies may be said to be a technologically-textured one (Ihde 1990).
Ontology	The philosophical study of the nature of being, existence or reality.
Self-organization	This refers to the decentralized reduction of environmental complexity in a dynamic system. An organism that changes its structure as a function of its experience and environmental interactions. Cyberneticists Ross Ashby and Heinz Von Foerster assert that self-organizing systems cannot be understood outside of their environmental context and that in fact systems and their environment self-organize together (Ashby 2004; von Foerster 1960).
Structural Coupling	Derived from autopoietic theory, this is a term for the engagement of a given system with its environment and/or another system. This process effects a "...history of recurrent interactions leading to the structural congruence between two (or more) systems" (Maturana and Varela 1992, 75). Thought of in this way, structural coupling suggests connections to co-evolution.
Symbiogenesis	The merging of two distinct organisms to form a single organism; believed by biologists Lynn Margulis to be a predominant force in

evolution. Emphasizes cooperation between organisms, rather than competition, as in the Darwinian model (Margulis 1998).

1. Introduction

The aim of this dissertation is to lay the groundwork toward developing a coherent theory of what I call “symbiogenic experiences” in the interactive arts. These are experiences of co-evolution with an increasingly technologized environment. Themes of evolution and symbiosis are common in contemporary Western society, often engendering fascination and wonder in popular culture. The biological sciences define evolution as changes in the inherited traits of a population of organisms through successive generations and has typically been considered to be synonymous with Darwinism. Beyond the use of the concept in the biological sciences, evolution is also a powerful a metaphor that is employed in a range of diverse fields. In computer science and artificial intelligence (AI) for example, evolutionary metaphors such as genetic algorithms for “evolving” optimal solutions are used to describe techniques of optimization and search in digital computers (Holland 1995; Koza 1990). In the humanities and cultural studies fields, human-technology relations are an area of growing interest. The theme of human-technology co-evolution is nothing new in this field, though it does seem to be approaching a new stage. Katherine Hayles for instance, argues that “[w]e have become symbionts”. A 2009 Washington Post article (Higgins 2009), which quotes Hayles and other notable scholars states that “[j]ust as a lichen is the marriage of a fungus and an algae, we now live in full partnership with digital technology, which we rely on for the infrastructure of our lives”. In this article, Hayles is quoted as saying our dependence on technology has evolved to such a degree that we cannot go back, and must instead become accustomed to this new lifeworld. "If every computer were to crash tomorrow”, she says, “it would be catastrophic. "Millions or billions of people would die. That's the condition of being a symbiont."

Whether symbiotic, parasitic or other, themes of human-machine coupling also pervade popular culture. Both utopian techno-fantasies and dystopian visions of human-machine mergers have been popular themes in Hollywood films, television shows and science fiction novels for many years. While most of the relationships depicted cannot be characterized as symbiotic in the manner that Hayles suggests, and are in fact better characterized as Darwinian struggles for supremacy, the overarching theme of human-machine mergers is prevalent nevertheless. This kind of thinking even seeps into mainstream scientific research (Thacker 2000).

The theme of human-machine coupling is also popular in contemporary arts, which is the field most relevant to this dissertation. Influenced and inspired both by technological achievements and popular culture, contemporary artists — interactive/new media artists in particular — often advance or examine notions of connectivity and symbiosis with technology, both physical and virtual (Goodall 2005; Wilson 2002, 731–732). This research began informally about eight years ago while preparing to enter my MFA in digital media arts. Having survived the hype and euphoria of the early Internet revolution (complete with its dreams of uploading one's consciousness to a sentient Internet) — in part by reading Katherine Hayles's *How We Became Posthuman* (Hayles 1999) — I began asking questions about what exactly is our embodied relationship to technology and to technology's impact on the larger environment (and our experience of it). My research has led me the following realization: within the interactive/new media art field I propose that there are a range of artworks and aesthetic experiences that examine, bear witness to, and engage with the observation that humans are embedded and co-emergent with an increasingly intelligent technological environment. The interactions involved can be seen as leading to an expansion of human consciousness and can characterized as a dynamic in which humans and technology influence or trigger structural changes in one another (Ascott 2003a). All of which leads to alteration of our perceptions and lived experience.

This dissertation engages with these ideas and sketches out an account of what I refer to as "symbiogenic experiences" via the interlocking frames of interactive/new media arts, cybernetics, posthumanism and phenomenological philosophy. Symbiogenic experiences are those that give rise to a sense that we are co-emergent, that is, that we exist in mutually influential relationships with our increasingly technological environment. As an interactive artist and researcher, I am interested in exploring these concepts from within the context of interactive/new media art. Doing so requires identifying the characteristics of pertinent artworks within the interactive arts field that may provoke such experiences as well proposing a model for analyzing them. The explication of this research will result in an outline for an interpretive framework that helps demonstrate how (somewhat paradoxically) a range of technologically sophisticated and often "intelligent" artworks that I refer to as the "emergent arts" may engender shifts in perceptual experience that enable us to view ourselves as connected to and embedded in, an infinitely complex (and increasingly technologized) physical environment. Cybernetic ideas such as autonomy, autopoiesis and self-organization will be read through the lens phenomenological philosophy, constituting the core of this dissertation's theoretical framework. In addition, the interactive artworks constructed for this dissertation serve as way of actuating the theories as well as helping to form them.

The core hypothesis of this research then is that these emergent artworks, more so than other forms, facilitate or amplify a construction of a reality that is active, dynamic and collaborative with our increasingly technologized environment. By doing so they suggest a reality that is heterogeneous, subjective and always already emerging, constituted by dynamic relationships rather than objective facts. This ontological vision resonates with constructivist and phenomenological theories of reality as well as cybernetic notions of "observer-participants" (Cariani 1993; Pask 1958) and "enactive perception" (Varela, Thompson, and Rosch 1992). What is proposed here is that these emergent artworks can go further and actually provoke or enable a bodily, felt sense of this co-emergent dynamic, and thus bring into greater consciousness what can be described as the co-evolutionary nature of our relationship with our technological environment. The central question explored is:

Can certain forms of interactive art facilitate experiences that elicit an embodied, felt sense and awareness of co-evolution with an increasingly complex and intelligent technological environment? And if so how?

I will explicate these experiences and argue that the emergent arts can facilitate in bringing them to the level of awareness, however fleetingly. Furthermore, I assert that while these experiences can be identified, they lack a cohesive theoretical framework from which to study and analyze them. Thus to aid in the explication of these experiences, the term symbiogenesis — redeployed as *symbiogenic* — is used as a shorthand term so as to better discuss these experiences and the issues they inaugurate.

Answering the questions posed above requires theoretical argumentation in conjunction with first-person reflections and analysis of my own projects as part of a framework for analyzing the experiences of these works. To this end, this dissertation details the construction and exhibition of interactive art systems, describing and analyzing my experience with them while further developing the necessary theoretical framework that results in new perspectives from which to approach interactive art practice and offer new theoretical and practical approaches to its analysis. The field of interactive arts is uniquely suited to this type of inquiry, as it features a myriad of unusual forms of physical interaction and experiences.

While explicating this theoretical framework and articulating what symbiogenic experiences are will be addressed later in this dissertation, I can provisionally sketch out some possibilities and avenues for exploration here. It must first be said however that an inquiry that centers around an "embodied felt sense" of co-evolution necessarily requires a rethinking of the concept of co-evolution (for as mentioned earlier the term is most often associated with Darwinism). The concept of co-evolution addressed here draws broadly from biological metaphor, is inspired by cybernetic research and is about investigating biological or cognitive processes from a subjective, first-person perspective. With this in mind I can state here that I conceive of a symbiogenic experience in an interactive arts context as one where mind, body and an increasingly technologized environment interrelate to give rise to a sensory experience that arises from a dynamic wherein human conscious and pre-conscious processes can be thought of as locatable both within the traditional bounds of the subject and also dispersed without, in a myriad of intelligent technological structures. A theory of symbiogenic experiences then can be classified as either one or a combination of the following:

> *A theory that accounts for an awareness of an already existing co-evolutionary dynamic; an awareness made possible by the heightened, intensified experiences characteristic of the arts* (Dewey 1958)*.* In other words, human-technology co-evolution already exists and interactive art can make us more aware of it.

> *Increasing technological change is bringing about an almost imperceptible historical shift in our embodied relationship with technology (which can be*

characterized as co-evolutionary). Interactive art can give us a sort of advanced notice of it and a theory of symbiogenic experiences can help in discussing and analyzing it by developing a language and set of understandings. A simple example would be the "horseless carriage" era of automobiles, where an unfamiliar technology is described and discussed in familiar terms (and its accompany impact on society arguably obscured) until a new set of languages and understandings were developed.

A theory that identifies a contextual change, perhaps a tipping point where technological sophistication and saturation (as exemplified by the proliferation of intelligent technologies) has reached a certain level where we can then start to sense a corresponding change in our embodied relationship to technology (which we can refer to as co-evolutionary in nature). Interactive art can again help us become aware of this already existing dynamic that is nascent or incipient. This may be as simple as identifying a quantifiable change in the time we spend with intelligent technologies or the number of said technologies and analyzing it phenomenologically, within an interactive arts context.

A theory that provides a microscope-like lens that (with the help of interactive artworks) enables us to see elements of our relationship with technology that we otherwise would not see and in doing so may provide a different way of thinking about that relationship.

The goal of this research is not to provide a technical framework for something like interactive co-evolutionary systems, nor is it primarily concerned with outlining specific methods or techniques for changing one's artistic practice (at least not directly). Rather, it is concerned with meanings of co-evolution of humans and technology and how they may be constructed through the development and first-person experience of interactive art systems. I investigate multiple meanings and perspectives of human-technology co-evolution by using a common practice in philosophy and cultural studies of “unpacking” terms in order to use them more precisely.[1] As a result of this research, a model of symbiogenic experiences is articulated that fuses theoretical and experiential modes of inquiry to provide insights to both interactive artists and humanities scholars, particular those who have an interest in art, cybernetics, systems theory and artificial intelligence (as well as technology more broadly). This dissertation provides a new interpretive framework from which to understand and approach interactive art practice and from which to study and analyze it. This dissertation will begin to fill a gap between themes and concepts of co-evolution that are often either purely discursive or objective (as in the humanities and sciences respectively) and experiences of co-evolution (and the meanings applied to them) in an interactive arts context.

1.1. Method

This research combines both theory and practice. It utilizes discursive argumentation in addition to artistic and first-person explorations in order to build the foundations of a theoretical framework for identifying and analyzing symbiogenic experiences in the interactive arts. This includes an overview of existing interactive art projects as well as theoretical expositions of the field and of larger questions of human-technology relations. In order to see interactive art as a system that showcases and amplifies a sense of being in constant relation to one’s increasingly technologized environment — where reciprocal interplay and mutual co-determination are the threads through which human experience is woven — I propose in this dissertation to use a cybernetic approach combined with phenomenological descriptions and analyses. Cybernetics and autopoietic theory share many characteristics with phenomenology

[1] Because the terms I employ have various meanings according to who is using them, I include a glossary (starting on page xvi) that lists relevant terms and how *I* am using them in this dissertation.

such as a constructivist epistemology and a concern with the subjectivity of observers.[2] Together they form a useful model from which to base my exposition and analyses of what call co-evolution and symbiogenic experience. What follows is an overview of these approaches.

1.1.1. Phenomenology

Art is first and foremost about experience (Dewey 1958). This is particularly true of interactive art, which requires varying degrees of active participation for its realization. Artists think about the world and make things as a way of exploring ideas or as a means of expression. Thus, artistic practice, experience and reflection are inextricably linked. Similarly, every philosophical tradition has a "method", a lens through which it enables us to see the world, and a way of "doing" philosophy. Phenomenology is a method of philosophical analysis, a rigorous and systematic method of analyzing experience. It studies the structures of consciousness and the phenomena that appear to it from a subjective, first-person perspective. Phenomenology is an approach to life, politics, ethics and meaning which has gone in and out of favour since its introduction and formalization by Edmund Husserl in the late 19th century (Kozel 2007, 4ff.). Its goal is to lead us back to the world as we directly experience it in pre-reflective perception (this notion of pre-reflective experience is discussed in greater detail in Chapters 2 and 4). In order to do this (according to Husserl), we must set aside our "natural attitude" which consists of any preconceived ideas or assumptions we normally make about the world and ourselves for scientific and practical purposes. This setting aside of theoretical preconceptions is known as epoché or bracketing, a method of phenomenological reduction.

Because a symbiogenic experience is a highly subjective phenomenon, analyzing it necessitates a methodology that takes concrete experience — particularly

2 Epistemological Constructivism is a philosophical view about the nature of scientific knowledge. Constructivists maintain that scientific knowledge is actively constructed by scientists and is not simply a passive reflection of an external objective reality. They argue that the concepts of science are mental constructs proposed in order to explain sensory experience. In this sense, Constructivism is opposed to Positivism, which is a philosophy that holds that the only authentic knowledge is based on actual empirical evidence derived from human sense and what trusted individuals tell us is true. See von Glasersfeld (1995; 1987).

mind/body experience — seriously. This is why I have chosen the existentialist phenomenology of Maurice Merleau-Ponty as my core methodological approach, as it mixes theory and concrete examples. In Merleau-Ponty's interpretation of it, phenomenology is a philosophical view rather than a distinct system of philosophy. While Merleau-Ponty accepts the Husserlian idea of reduction, he argues that it is not a complete withdrawal from all engagement with the world but rather entails a loosening of the “intentional threads” which bind us to the practical world (Merleau-Ponty 2002, xv, 83), thus letting the sheer strangeness and ambiguity of the world and our existence in it become more apparent (Matthews 2006, 17). By describing experiences just as we find them in our direct embodied experience, analyzing them and relating them to relevant contingent features, we may begin to change the way we perceive the world. Merleau-Ponty stated that the arts could help in this regard, allowing us to let go (if just for a moment) of the comfortable and rationally defined parameters of the world. Because interactive allows us to adopt a new experiential lens, Merleau-Ponty’s approach may allow us to begin to see the world as more dynamic and emergent.

Merleau-Ponty presented an abstract framework containing complex conceptualizations and theoretical analyses that were coupled to examples drawn from real world experiences and phenomena. He did this primarily by citing medical studies of patients with motile and/or cognitive disorders such as aphasia and phantom limb syndrome, as well as examples of everyday actions such as a blind man using his walking stick or a woman walking while wearing a feathered hat. In combining theory with concrete examples, Merleau-Ponty’s observations revealed important aspects of perception and intentionality. His work has influenced many of the thinkers referenced in this dissertation (perhaps most notably Francisco Varela and the neocybernetic concept of enactive perception that he helped develop). The inquiry in this dissertation draws from Merleau-Ponty’s approach as well as from relevant cybernetic theories and practices (discussed below) and is focused on identifying portions of felt experience that may not always be felt directly but which nonetheless leave a sense, alter an aptitude or somehow transform awareness.

1.1.2. Cybernetics

The transdisciplinary arts practices discussed in this dissertation compel one to assume artistic, technical, scientific and humanistic viewpoints more or less simultaneously. Because disciplinary worldviews sometimes differ, threading these heterogeneous elements together requires engaging in a curious dance among alternating perspectives: inside/outside, abstract/concrete, subject/object. This often leads one to question whether there are in fact any sharp divisions between these and, at least in my case, leads to a sense of their ultimate intertwinement. The methodological process deployed in this dissertation draws significantly from cybernetic concepts and is discussed in terms of observer/observed, making/thinking and artwork/audience. The constructivist epistemology of cybernetics and its constituent notions of circularity, self-reference, boundary, closure and autopoiesis — especially when combined with phenomenology — provide a useful model for analyzing the process of viewing, making and experiencing interactive art, as well as of the construction of the artwork itself. Structurally, most interactive/new media artworks can only be seen as complete when the relations between the system and its environment (often human interactors) and contributions by interacting observers (often those same interactors but not always) are taken into account (Lautenschlaeger and Pratschke 2011, 1092). In addition, as discussed in Chapter 2, cybernetic concepts help us account for the observer's actions in the process of observing systems and also aid in examining the interdependence and autonomy of the relationship between the observer and the observed, the system and the environment. When interactions between technical systems and contributions by interacting observer-participants are taken into account, the exchanges between a given piece's technical system and a given interactor's mental and sensory system may been as establishing circular relationships of conversation, rather than simple input output operations (Figure 1.1). As discussed in Chapter 4, this essentially amounts to an establishment of a mutual, collective autonomy. In some ways this mirrors Merleau-Ponty's notion of reversibility, which broadly speaking, refers to a questioning of traditional dualisms such as mind/body, subject/object and self/other. Merleau-Ponty uses the image of the right hand touching the left to represent the body's capacity to simultaneously perceive and be perceived. Yet this is still experienced as one sensation perceptually, as the hands alternate the roles of touching and touched (Merleau-Ponty 2002, 106–107). For Merleau-Ponty, this begins to evince the complexity of subjective experience and its foundation upon the intertwinement of these (formerly conceived of) dualisms.

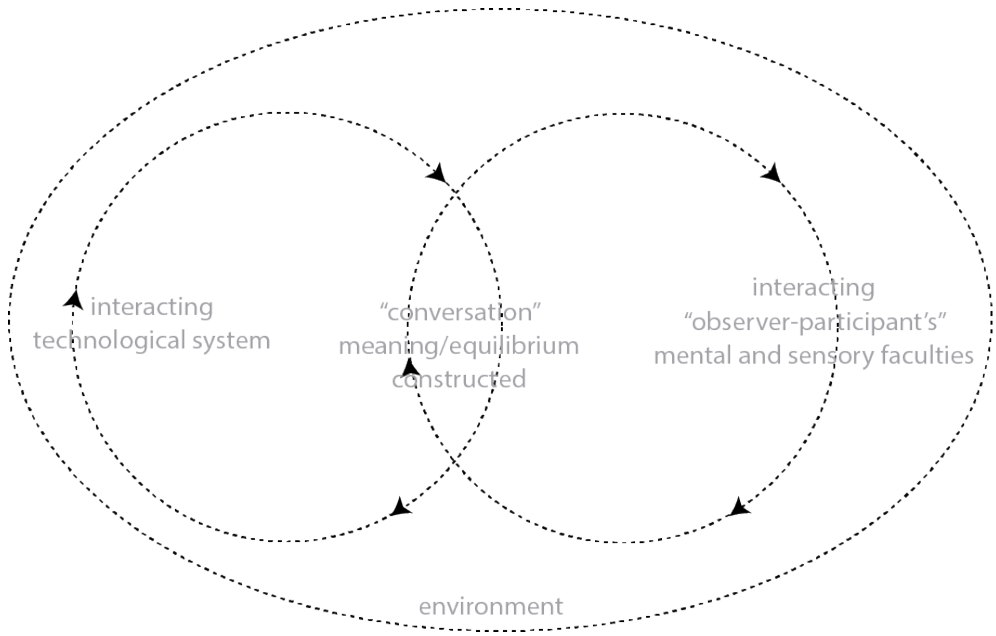


Figure 1.1 Artwork/system and interacting "observer-participants" — both embedded in an environment — engaged in conversational interactions.

1.1.3. Phenomenology and Cybernetics as a Method for Interactive Arts Research

Since the aim of this dissertation is to lay the groundwork toward developing a coherent theory of symbiogenic experiences in the interactive arts, artistic explorations are necessary components of inquiry. Since the questions raised in this research are ultimately ontological in nature, it is necessary to go beyond the limits of purely discursive or textual activity, particularly when dealing with questions of embodiment and subjective experience. Thus concrete and experiential instantiations — that is, the creation and exhibition of artworks along with phenomenological descriptions and analyses of my experiences with them — are an important aspect of this research. Theory and practice continually inform one another and function not just side-by-side, but as part of the same continual, hermeneutic and reflexive process (Figure 1.2).

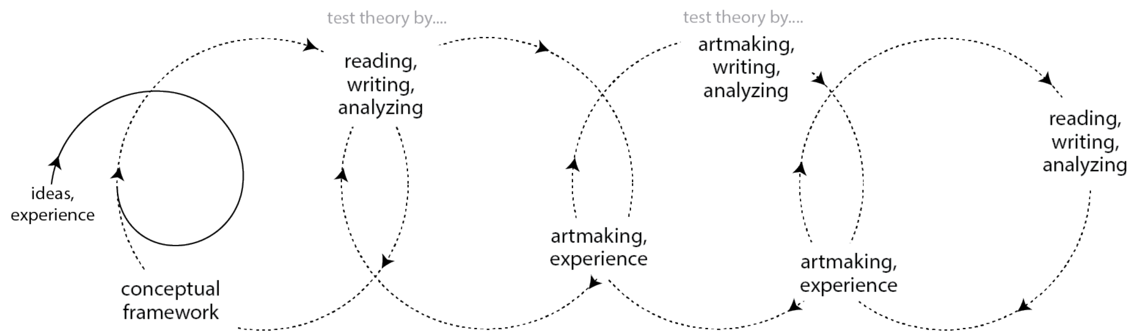


Figure 1.2. Art research process used in this dissertation, integrating a constructivist epistemology

The research presented in this dissertation approaches the production and iterative analysis of interactive art from a cybernetic perspective combined with an existentialist phenomenological lens based on the philosophy of Maurice Merleau-Ponty. Like Merleau-Ponty, my inquiry draws significantly from the sciences, but does so through the adaptation of a constructivist epistemological lens. Therefore, reductionist approaches and testable, reproducible and verifiable experiments will not be undertaken. Instead of seeing the world as an ultimately knowable place, through the detached "view from nowhere" that forms the ontology of classical science and engineering (Nagel 1989), my inquiry rests on the assumption that there are multiple ways of looking at the world. Similar to other analyses of interactive art (N. Stern 2011; Hansen 2006), this dissertation combines phenomenological analyses of the role of embodiment in the interactive art experience with a move away from the linear observer->observed relationship (that is common in art analyses) to a circular enactor-to-enactor relationship (that hints at amalgams of phenomenological and neocybernetic concepts such as enactive cognition [Varela, Thompson, and Rosch 1992; Thompson 2007]). Much like the British cyberneticists who staged for us a "nonmodern" ontology (Pickering 2010; 2008; 2007), I propose that it is useful to see the world as only knowable through the complexity of constant adaption, embodied action and performance of agency. This allows us to rediscover this world *as we perceive it* and not as we have come to accept it for practical and scientific purposes (Merleau-Ponty 2004). This "ambiguity of experience", which plays such an important role in Merleau-Ponty's ontology, serves as a productive model from which to base my own analysis and from which I have constructed the conceptual framework of this dissertation (Sapontzis 1978; Matthews

2006, 17). This dissertation explores this ambiguity via intertwinement of artwork and scholarly writing. Inspired by and based upon cybernetic models it will contribute to a rigorous and systematic theoretically-based artistic practice (Elkins 2009; Sullivan 2005).

This approach has analogs in other fields. In design and education for instance, Donald Schön's work has been particularly influential (Schön 1983). Schön characterizes design as a hermeneutic circle that is developed by means of "a conversation with the situation" (103). Schön adapts the model of the hermeneutic circle and shows the centrality of conversation to its successful development and implementation. This notion of understanding and knowledge generation as arising from action-grounded conversations, wherein a problem space is explored and a mutual agreement is reached that represents a new understanding has strong similarities to cybernetic models of observer-participant's, concept formation and conversational learning. Cyberneticist's Gordon Pask and his model of conversation, which features interaction and communication wherein each participant (human or machine) constructs his or her (or its) own understandings via continual circular processes of adaption and/or meaning construction, is of particular note here (Pask 1959; 1960; 1975; 1976).

The methods of analysis and exploration I have devised for this research allow me to understand, in phenomenal terms, the characteristics of what I call "emergent arts practices" (discussed in Chapter 3) and ultimately to better understand the symbiogenic experiences that arise from them. I particularly use neocybernetic theories of enaction, structural coupling and autopoiesis to illustrate the mutual, reciprocal relationship that we have with our environment. Combining this with Merleau-Ponty's embodied phenomenology, I show how interactive art can amplify a sense of this mutual co-emergence, ultimately leading to a co-evolutionary experience, which I refer to as symbiogenic. I argue that one can discern connections between cybernetics and Merleau-Ponty's existentialist phenomenology. Examples of these connections include:

- A constructivist epistemology, in that they each share a concern with the subjectivity of human experience and its role in the processes of conducting scientific research and of coming to know. Both agree that knowledge is not passively received either through the senses or by way of communication, but is actively built up by the cognizing subject. Thus, both are concerned with this unavoidable limitation of what we can know: our own subjectivity.
- Taking into account the observer's actions in the process of observing

- An approach that features interacting with systems as a form of observation and knowing (as opposed to a detached God's-eye view).
- The circularity, interdependence and autonomy of the relationship between the observer and the observed, subject and object, system and environment.
- A dynamic of mutual co-specification between a system (such as the human perceptual system) and an environment and how such systems specify their autonomy and bring forth a world for themselves via these co-emergent interactions.
- A performative ontology that does not separate people and things and focuses on interaction and reciprocal interplay with the world, not a dualistic detachment from it (Pickering 2010).

Because the goal of this research is to explore meanings of co-evolution that arise from the heightened experiences of the emergent arts, phenomenology and cybernetics will be used to complement, reinforce and "mutually specify" relevant concepts and theorizations from each field.

1.1.4. The Role of Artistic Practice

This research is conducted in the context of interactive art using interactive art systems that I have created. Two projects, *Protocol* and *Biopoiesis* are discussed in Chapter 6 and 7 respectively. These systems are intended to explore (and perhaps evoke) different facets of what I term symbiogenic experience. These artworks are created mostly as experiments but also function as critical points to be made that can enact or embody a textual argument. Their function in this research is threefold: first as a concrete method of putting theories to the ontological test beyond conventional textual means, second by providing what Diane Gromala calls an *embodied tool-to-think-with* (Gromala 2007), a way developing new concepts and techniques and modifying existing ones (this applies both the philosophical ideas and to the technical systems that are developed specifically for each artwork), and third they serve as embodiments of theoretical concepts in their own right. These artworks use specific techniques and technologies drawn from cybernetics, machine learning and biomedical research that at some level feature specific kinds of coupling of technology with the human or the physical environment and sometimes have their theoretical and conceptual potential imbued in their very materiality.

1.1.5. *Methodological Procedures*

The procedures for constructing the analyses in this dissertation occurred in two distinct but overlapping phases:

1. the construction of the projects and testing of prototypes

2. the exhibition and interaction with completed projects (or distinct iterations of them)

Generally speaking, the methods of documentation include diagrams, code, photographs, video and textual writing, notes and reflection. It also features combinations of immediate and shortly or long after-the-fact reflections, notes and commentaries as part of these analyses. Details of particular procedures are reserved for chapters 6 and 7, where the projects are discussed. However they can broadly be summarized as follows (refer to Figure 1.2 for a visual representation):

<u>Making:</u> I record my ideas and experiences via notes, photographs and video. This occurs "in the middle of" both constructing and exhibiting the projects.

<u>Theorizing:</u> I then draw from this immediate experience and record analytical and conceptual ideas over time (hours, days or a week after). This analysis and conceptualization was done primarily via reflections and theoretical writing and commentary. The goal here is to search for deeper conceptual and theoretical relevance. This often entails finding relevance between something I am reading at the time, for example Evan Thompson's *Mind In Life* (Thompson 2007), and some concrete or theoretical aspect of one of the projects I am working on. For example, the idea of analyzing Merleau-Ponty's concept of ambiguity through a neocybernetic lens occurred while working on *Biopoiesis* and thinking about how self-organization and learning were in some sense "unknowable" (in the sense described by cyberneticist Stafford Beer) and how *Biopoiesis* and other interactive artworks stage this complexity and unknowability for us to find connections between. This type of dynamic evolution of the theoretical arguments presented in this dissertation, where there is interplay between concrete descriptions of phenomenal sense experience and exposition of

theoretical abstractions continued over several months. I visited and revisited my notes and reflections, had discussions with colleagues, revised the voice (e.g. first-person, third person) and tone of the writing (e.g. critical, analytical, Deleuzian) and finally began to write deeper analyses and more concretely formed my theoretical arguments, which included the analytical methods of phenomenology, cybernetics and close reading. Revising this document (which ultimately became this dissertation), as well as my artistic and phenomenological process, continued throughout.

1.2. Relevance/Resonance

A first-person method like phenomenology is received subjectively. Similarly, some cybernetic methods attempt to account for the observer's subjectivity. The arts, perhaps more than any other field, are almost completely based on subjective interpretations and critical analyses. Finally humanistic, scholarly writing relies primarily on subjective, critical or philosophical analyses and conceptual "unpacking". For most researchers, this would seem to beg the question of how do artworks and written phenomenologically-based analyses that rest on subjective methods contribute to knowledge? What is the nature of their truth claims?

The simple answer here is that all fields of knowledge, whether objective/scientific ones, philosophical ones and more recent constructivist ones like arts and cybernetics do in fact contribute new insights and perspectives, and like objective research, do so within a community of experts who have familiarity with the concepts and procedures used. Thus, while not always repeatable, subjective and critical accounts are also not purely personal but are open to intersubjective validation from this "interpretive community" (Fish 1980). All research in fact has this subjective-social dimension in that what we take as "objective" is what, according to Varela and Shear, "can be turned from individual accounts into a body of regulated knowledge" (Varela and Shear 1999). Thus, one must not presuppose that this dissertation will yield "results" that need to be "validated" in the conventional sense. These terms have a specific meaning and criteria for evaluation in quantitative/objective research than can be problematic in this context, often distracting one from the goal of understanding what is going on

(Wolcott, 1990). The knowledge contribution offered here might best be understood via what Susan Kozel (drawing from Gaston Bachelard) says about phenomenologically-based knowledge claims. Kozel states that the truth offered through phenomenology is better expressed through the concept of "relevance" and best described in terms such as "reverberation" and "resonance". She states that this is part of a general impulse towards the construction of a "transsubjectivity" (Kozel 2007, 24ff.). Echoing 2nd-order cybernetic thought (though likely not intentionally), Kozel states that "[w]e are not a collection of monads, but live in worlds of shared and overlapping experience and cultural, social and historical formation" (ibid., 24). In other words, we live in an intersubjective world. One person's lived experiences and his or her interpretation of them can inform another person's perspectives and orientation toward the world, thus contributing to a collective network of intersubjectivity. This occurs in peer-reviewed academic publications but also among curators, art critics and participants. Phenomenological accounts and direct experiences of artworks as well as phenomenologically-based scholarly writings have the potential to resonate with others on numerous levels (cognitive, physical, visceral). Such is the position taken in this dissertation: it represents an attempt to communicate a certain *relevance* and *resonance* to an interpretive community of experts. In essence, the question of "how will I know" is answered (as it has traditionally in the humanities) primarily through the coherence, persuasiveness and validity of my theoretical arguments, as determined by this community of observers. My contribution then is to posit a new lens from which to view interactive arts practice, a new approach to its analysis, interpretation and construction.

1.3. Scope and Limitations

As mentioned above, a wide range of artists and academics have considered questions of human-technology coupling and co-evolution. In this dissertation, I will not cover entire fields of intelligent systems or cybernetics, nor will I exhaust all types of phenomenology and theories relating to co-evolution. I am investigating co-evolution from an interactive arts perspective in particular settings created from tangibly actualized interactive art systems. These will include my own works as well as a taxonomy of artists and art projects (discussed in Chapter 3) that contain aspects that I argue are relevant to human-machine co-evolution and symbiogenic experience in the interactive arts.

1.4. Structural Overview

This dissertation is structured as follows:

Chapter 2 consists of the literature review and explication of the conceptual framework that has shaped the inquiry into symbiogenic experiences. It introduces the principal theoretical perspectives and relevant technological aspects informing my inquiry and analyzes their relationships to each another. A variety of approaches are discussed, such as posthumanism, cybernetics, phenomenology and art. While certainly different, they all share an interest in human subjectivity and action, as well as an ontology that de-centers of the human subject.

Chapter 3 introduces the Emergent Arts model. This is a taxonomical model that outlines a number of characteristics of new media and interactive arts practice that engage in processes that establish a foundation for the shifts in perceptual and embodied experience that I characterize as symbiogenic. The Emergent Arts model represents the range of interactive art practices that I consider relevant to human-machine co-evolution and symbiogenic experience.

Chapter 4 outlines the conceptual basis of the symbiogenic framework, allowing us to go deeper into examining the dynamics of what I call co-evolution by explicating four theoretical concepts that I consider to be the cornerstone of symbiogenic experiences in the emergent arts. This chapter consists primarily of a set of close readings of neocybernetic and Merleau-Pontian ideas. It outlines the relevance of Merleau-Ponty's existentialist phenomenology to intelligent systems, neocybernetic theory and the material practices of cybernetics.

Chapters 5, 6 and 7 detail the development of the four interactive artworks that comprise the tangible/practical component of this dissertation. Chapter 5 briefly discusses two interactive projects: *Naos* and *BodyDaemon.* These works serve as precursors to the research in this dissertation and thus aid in establishing context. Chapters 6 and 7 describe the development of the conceptual, aesthetic and technical structures of two artworks: *Protocol* and *Biopoiesis*. These chapters include phenomenological descriptions and analyses of my own experiences with the works and analysis of the deeper conceptual connections to the symbiogenic framework.

Chapter 8 concludes the dissertation with reflections and understandings that emerged from it, as well as possible future directions.

2. Conceptual Framework

This chapter provides an overview of the six key areas of inquiry that have emerged as a framework for the development and evaluation of the theory of symbiogenic experiences. Fully appreciating the transformation of experience, which I am calling symbiogenic, and the role of interactive arts in it, necessitates a navigation of various theories of **ontology**. While a detailed account of Western ontological perspectives is beyond the scope of this dissertation, this chapter provides an overview of the primary theoretical perspectives that have come to form the conceptual framework utilized in my research. The diagram in Figure 2.1 outlines the principal theoretical and critical perspectives and relevant technologies informing this inquiry and their relationships to one another. Beginning by defining co-evolution and symbiogenesis, I sketch out an account of symbiogneic experiences via the interlocking frames of interactive arts, the existentialist phenomenology of Maurice Merleau-Ponty, cybernetics and autopoietic theory and posthumanism. In addition, various technologies and methodologies from a range of fields that can be loosely categorized as information systems and intelligent systems are reviewed. At the broadest level, they signify ways in which couplings between human and machine may occur. More specifically, they represent a specific set of relevant technologies and methodologies that I borrowed in order create the interactive art projects featured in this dissertation. Overall, this framework emphasizes the complex interdependent ways in which humans interrelate with technology and with their world, the importance of human embodied subjectivity and the embodied and situated nature of intelligence. Much like cybernetic concepts of **feedback** and **circular causality**, as well as my own hermeneutic method described in chapter one, each element in this framework may be read through or may otherwise influence the development of ideas from other elements. For example, the making of an interactive artwork may be influenced by cybernetic or autopoietic concepts, while the understanding of these concepts may be influenced by the making and experience of the artwork. In addition, reading the cybernetic concepts and the material practices of cybernetics through the lens of Merleau-Ponty's philosophy, may guide our understanding of both the making and experiencing of the artwork. Collectively, the elements contained in this conceptual framework encompass the foundation of what I describe as a co-emergent and co-evolutionary ontology and serve in explicating an account of the embodied self and its intrinsic quality of embeddedness and intertwinement with in an increasingly complexified and technologically intelligent world and how aesthetic experience may serve a means to expand awareness so as to make this embeddedness and intertwinement perceptible to us on some level.

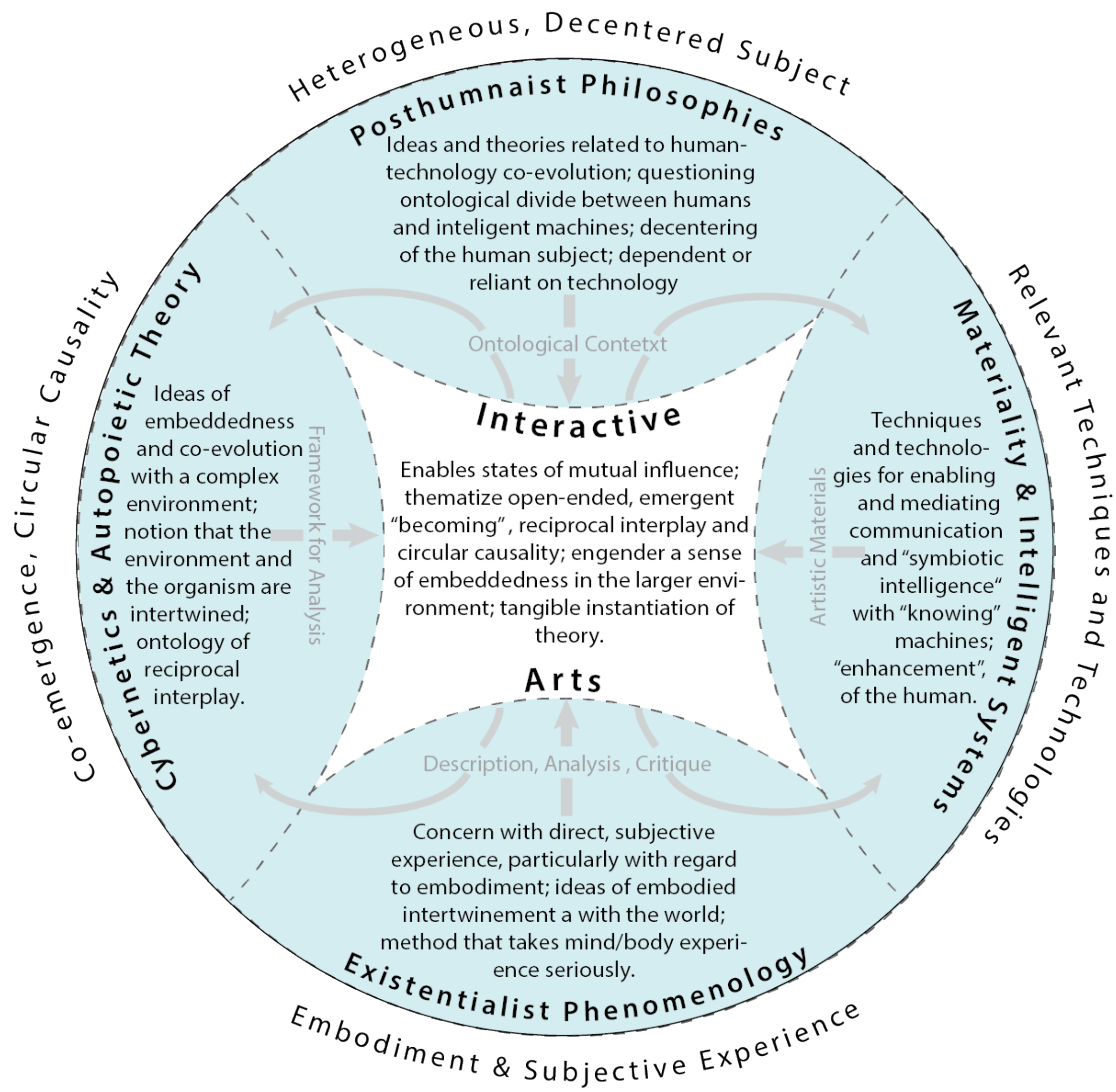


Figure 2.1 Conceptual Framework

The concept of symbiogenesis developed by biologist Lynn Margulis serves as a metaphor and point of departure from which to form my own artistic-phenomenological inquiry into the notion of human-machine coupling and co-evolution (and also as a way to steer clear of Darwinism). In addition, the idea of cooperation and complex interactions between organisms are for her an essential element of life and evolution. I am investigating how these and other related concepts (e.g. those from cybernetics and autopoietic theory) may be applied to the analysis and description of aesthetic experiences related to technology.

Artists and theorists who have explored cybernetics and artificial intelligence provide a framework for examining themes of human-machine coupling, co-emergence and co-evolution in the interactive arts. Concepts such as Jack Burnham's "symbiotic intelligence" and Roy Ascott's cybernetic model of interactive arts are combined with analyses of artworks utilizing and exploring artificial intelligence, machine learning, artificial life or cybernetic techniques. This conceptual framework involves a threading together of these perspectives, forming the foundation for the analysis of what I see as a range of artworks that occupy a unique domain of art experience: one that amplifies a sense of and coupling and co-determination with an increasingly intelligent technological environment. This will also be elaborated further in Chapter 3 when I discuss what I call the "emergent arts".

Posthumanist theories provide an ontological context for examining human-technology relations, analyzing interactive artworks and for the symbiogenic framework more broadly. Posthumanist thinkers such as Katherine Hayles, Mark Hansen, Andy Clark and Cary Wolfe explore the nature of our relationship to technology and its role in reconfiguring the human as a heterogeneous de-centered subject, thus lessening its controlling position. They question the ontological divide that supposedly exists between humans and their technological creations.

Existentialist phenomenology, particularly the work of Maurice Merleau-Ponty and those who have extended his work, are employed as a framework for understanding and analyzing co-evolutionary experiences in interactive art. These thinkers emphasize the crucial role of embodiment in the construction of experience, particularly with regard to technology. Many of their core ideas, such as Merleau-Ponty's embodied motor intentionality, Shaun Gallagher's analysis of the body schema and its role shaping the contours of perceptual awareness and Don Ihde's analysis of human-technology relations have come to influence many of the important philosophical components of this conceptual framework. This includes the examination of the technical dimensions of embodiment and how embodied phenomenology relates to the fields of artificial intelligence and cybernetics. Existentialist phenomenology serves as the core method of philosophical analysis with interactive art projects serving a crucial role as reservoirs of experience that inform and function alongside scholarly writing and argumentation. The phenomenological method employed here combines accounts of direct experience, philosophical analysis and reflection, with relevant aspects from cybernetics and autopoietic theory in an artistic-theoretical inquiry into the nature of our relationship with intelligent systems and technologies.

Cybernetics and autopoietic theory emphasize the notion of reciprocal interplay and open-ended emergent interactions between system and environment as well as the notion that the environment and the organism are intertwined and cannot be understood except in relation to one another. In essence, it blurs the division between people and things that has been so common in Western thinking. **Autopoiesis** outlines the ways in which living systems and their environments co-determine and mutually specify one another. Cybernetic ideas related to system **boundaries**, **autonomy** and adaptability are employed in this research as a framework for analyzing and understanding: (1) the design and behaviour of "intelligent" interactive artworks, (2) how intelligent technological systems (and an intelligent technological environment more broadly) can couple with and effect change in the human and (3) through the lens of existential phenomenology, analyze the recursive art production process itself and how it may lead to new ideas and new understandings.

This research includes the production of interactive artworks as an important aspect of the research process. Certain computational and biomedical methods from research areas such as machine learning and sensory substitution have been employed in the development of these artworks. These provide the relevant scientific and technological background, and artistic inspiration, from which to build these works. At the broadest level, they represent an interest in exploring the coupling of human and machine, sometimes with the goal of providing some sort of "enhancement" to the human. Entire research fields are not covered here but rather, a specific set of references concerning the most important and relevant technological aspects of the research and art-making contained in this dissertation.

2.1. Symbiogenesis and Co-evolution

2.1.1. Symbiogenesis as Metaphor

In the opening chapter of her book *Symbiotic Planet: A New Look at Evolution* (Margulis 1998), biologist Lynn Margulis observes that the concept of symbiosis, which describes the close interactions among species living in close physical contact with one another, "strikes us as an arcane concept and a specialized biological term" (5). This is due, Margulis claims, to our ignorance of its "omnipresence" — noting how even our very own eyelashes are "festooned" with symbiotic life. The central theme of this opening chapter (titled "Symbiosis Everywhere") is that we cannot see the forest for the trees. Symbiotic life is all around us, part of our everyday environment — so much so that it recedes far into the background of our thinking.

Margulis's vision is encapsulated in her belief that symbiogenesis, or the merging of two distinct organisms to form a single organism, is a predominant force in evolution (Margulis 1981; Margulis 1993; Margulis 1998; Margulis and Sagan 1986). Drawing from as diverse a set of research as that of the Russian plant biologists of the early 20th century (Khakhina 1992, 34–50; Wallin 1927) and James Lovelock's Gaia Theory (Lovelock 1979), Margulis argues that symbiosis is crucial to the emergence of evolutionary novelty, from the eukaryotic cell to, controversially, the planet itself. Considering the Darwinian model of natural selection and mutation incomplete, she avers that symbiogenesis is the dominant force in evolution, emphasizing cooperation and other more complex interactions between organisms that go beyond mere competition for resources. Margulis and Sagan note, for example, that "Life did not take over the globe by combat, but by networking" (Margulis and Sagan 1986, 15). This more holistic approach has slowly but surely been gaining acceptance within the scientific community over the years.

Perhaps the true mark of how a concept gains traction however, is when it is taken up outside of its narrow discipline and applied to seemingly unrelated ones. Marked by the fact that technology has been shown to have been a strong influence on human biological evolution (often leading to skeletal, muscular and cognitive changes (Ambrose 2001)), the arts and humanities have explored concepts of human-technology co-evolution from many different perspectives. Both utopian techno-fantasies and dystopian visions of human-machine mergers have been popular themes in Hollywood films, television shows and science fiction novels for many years. While most of the relationships depicted cannot be characterized as symbiotic per se, and are in fact better characterized as Darwinian struggles for supremacy, the overarching theme of human-machine mergers is prevalent nevertheless.

Thus, with the term *symbiogenic* serving as metaphor, Margulis's more holistic model is used in this dissertation as a point of departure from which to form my own artistic-phenomenological inquiry into the notion of human-machine coupling and co-evolution (and also as a way to steer clear of Darwinism). In addition, the idea of cooperation and association between organisms are, for her, an essential element of life and evolution. I am investigating how these concepts may be applied to aesthetic experiences related to technology.

2.1.2. Defining Co-evolution

From a biological perspective, co-evolution can be characterized as an evolutionary change in one organism or population of organisms, in response to a trait or behaviour of a second organism or population of organisms, with these changes being passed genetically to succeeding generations. Ehrlich and Raven (1964) were the first in the scientific community to specifically mention the term. They define co-evolution (if somewhat ambiguously) as "patterns of interaction between two major groups of organisms with a close and evident ecological relationship" (586). Janzen (1980) defines co-evolution as "an evolutionary change in a trait of the individuals in one population in response to a trait of the individuals of a second population" (611). In the arts and humanities, the question of human-technology co-evolution is often more of an ontological one (that is, of the nature of being and existence). Philosophers and cultural studies scholars such as Katherine Hayles (1999; 2002; 2007) and Mark Hansen (Hansen 2005; Hansen 2006; Hansen 2009a) are perhaps the most prominent scholars to have often examined notions human-technology co-evolution, often drawing from new media art in their analyses.

For some, the word "co-evolution" may conjure up images of Darwinian processes of natural selection or long term changes in genetic make-up that take place over many generations. Indeed the concept of evolution (at least in its vernacular usage) has come to be more or less synonymous with Darwinism. Within the scientific community however, the explanatory supremacy of Darwinian natural selection has been questioned. I have already mentioned Margulis. Another opponent of Darwinian orthodoxy is theoretical biologist and complex systems researcher Stuart Kauffman. He argues that the complexity of biological systems and organisms might result as much from **self-organization** and far-from-equilibrium dynamics as from Darwinian natural selection (Kauffman 1993). His work has lead to the incorporation of self-organization and complexity models into evolutionary theory. I am arguing, for a conception of evolution not unlike Kauffman's, but from a cultural-perceptual-experiential perspective. Evolution in this context is a dynamic process of constant change, adaptation and reconstitution that does not occur in isolation but in relation to an environment and a **lifeworld** that is also dynamic, complex and adaptive. In this sense, all evolution is co-evolution, as any change in one system can potentially influence change in another system and/or in the environment as a whole. Cultures evolve, perceptions evolve, societies evolve, climates evolve, and so on; always in relation to larger forces. Like Hayles, Hansen and other humanities scholars I am drawing from cybernetic theories and concepts such as circularity, autonomy and autopoiesis in order to sketch out the symbiogenic framework and its conception of co-evolution. Thus, in addition to those just mentioned, I will be using terms such as co-emergence, co-determination, enaction, boundary, closure and **structural coupling**, and grouping them under the rubric of co-evolution, presenting a unified term that encapsulates the dynamics these terms reference.

2.2. "Symbiotic Intelligence" and "Technogenesis" in the Interactive Arts

This section looks at theoretical inquiry within the arts that has examined notions of connectivity, symbiosis and autopoietic structural coupling with technology. Themes of co-evolution and symbiosis are of course not uncommon in the interactive arts, as the work of Stelarc and Ken Rinaldo (to give just two examples) shows (Goodall, 2005;

Rinaldo, 1998a). The theorists discussed here outline a domain of art experience and analysis that examines, bears witness to, and engages with the observation that humans are increasingly cooperating and merging with their intelligent technological environments.

2.2.1. Aesthetics of Intelligent Systems

Artist and theorist Roy Ascott, notable for introducing cybernetic theory into the arts (Ascott 2003b), has noted that interactive arts, perhaps more than any other previous forms of fine art, engage a participant's sensory and embodied faculties (Ascott 2003a). Ascott describes interactive art as "characterized by a systems approach to creation, in which interactivity and connectivity are the essential features, such that the behaviour of the system (the artwork, network, product or building) is responsive in important ways to the behaviour of its user (the viewer or consumer)". Noting its transformative potential, Ascott describes the interactive artwork as constituting a "structural coupling," thus making the work "inherently cybernetic" (281).

This "systems approach to creation" was analyzed in 1968 by art theorist Jack Burnham in his historically important paper, "Systems Esthetics" (Burnham 1968). More specific to the discussion here however is his analysis of the human-machine communication loop in the then emerging field of systems art. In his paper *The Aesthetics of Intelligent Systems* (Burnham 1970), Burnham offers a consideration of art that utilizes intelligent systems as establishing a dialogue that can expand the horizons of the art experience by enabling us to tap into the information-rich environment. The crucial insight offered by Burnham is his realization that this emerging expansion of the art experience "encourages the recognition of man [sic] as an integral part of his environment" (100). Drawing from work both in the arts and systems theory, Burnham argues that computer technology can make us more aware of how thin the boundaries between organism and environment are and how a well-executed technological art system can lead the way toward increasing this awareness. Among the first in the art world to recognize the potential of the computer beyond its common usage as a ultra-fast data processor, Burnham realized that an interactive art experience was fundamentally different from that which came before it, primarily in its ability to better attune us to the technological environment, "sensitiz[ing] us to information that would otherwise be ignored" (108). Particularly incisive, as it resonates well with 2^{nd}-order cybernetics and autopoietic theory, is his perspective on the significance of technology for the "classical view of art and reality." Burnham states that interactive art is forcing us to dismiss the view "which insists that man stand outside of reality in order to observe it" (103). Burnham envisioned possibilities for a reconfiguration of the aesthetic experience in Western art; one where "symbiotic intelligence" was its ultimate outcome and one's own "bodily activities" — rather than object contemplation — were at its foundation (108).[3] This opening up of perception to "information that would otherwise be ignored," may (in the right context) lead to experiences where these ideas of symbiotic relationships with technology are understood not just as metaphors, but as something tangibly felt, even if indistinct or fleeting.

2.2.2. Technogenesis

Similar to Burnham, but from a more phenomenological perspective, philosopher Mark Hansen claims that there is an "inescapable correlation" between human embodiment and technology (Hansen 2005). Hansen argues that new media art is not only at the forefront of opening us up to this interpenetration of the human and the technical but also at the forefront of evoking it. Drawing from Edmond Couchot's and Norbert Hillaire's concept of second-order interactivity (which itself draws upon concepts from second-order cybernetics), Hansen asserts that the increasing cooperation between human and machine raises the prominence given to human embodiment, which he calls the "vehicle for emergence". Agency is then expanded through this co-functioning (or co-evolution), while the autonomy of each is preserved (its "operational closure" is maintained). In *Bodies in Code* (2006), Hansen expands on these ideas of how new media and digital technologies influence and transform bodily experience by drawing from the embodied phenomenology of Merleau-Ponty to sketch out what can be characterized as a co-evolutionary phenomenology of technics realized through interactive art. Contrary to most previous technoculture theories where media, technologies and bodies are understood as primarily discursive, Hansen's

[3] It should be noted that Burnham would later temper significantly his enthusiasm for technology-based art. See (Burnham 1986).

phenomenology of new media insists on bodily relations to digital technologies and environments. Similar to Burnham, Hansen sees new media art as unique in its ability to incorporate the surrounding environment into our always-emerging embodiment. He notes how our interactions in the world and our sense of embodiment have always been potentially technical and that increasingly this embodiment "can only be realized in conjunction with technics" (20). In addition to drawing upon and updating Merleau-Ponty's work, Hansen also points to various "thought-catalyzing" new media artists such as Myron Krueger and Simon Penny as exemplars. Though criticized for treating the body as if it merely responds to technology (N. Stern 2011), as a whole, Hansen draws upon a diverse range of sources from fields such as cultural theory, cognitive science and of course art, in order to sketch out a plausible account of how new media are "shepherding" our ongoing "technogenesis" (his term for the co-evolution of humans and technology) by expanding the scope of bodily agency and transforming our collective existence.

2.2.3. Emergence, Autonomy and Interactivity in New Media Art

When dealing with "aesthetics of intelligent systems", it becomes necessary to shift from purely technical concerns to those of process, flow and dynamic interactions (in order to understand how these function on a cultural level). The work of all the artists reviewed in this dissertation can be read across the three broad but interrelated concepts of emergence, autonomy and interactivity. Each one is bound up with the other. Emergence requires an "observer-participant" in order to determine that emergence has in fact occurred (Cariani 1992). Autonomy, defined here provisionally as "self-governed", is necessary for interactivity or emergence to take place. Interactivity is often thought of as real or worthwhile only if it takes place via emergent interrelations between humans and intelligent "others" (e.g. intelligent machines); a certain level of surprise and a feeling of almost uncanny connectedness are required. The "embodied felt sense" of co-evolution that characterizes a symbiogenic experience is tied to these concepts. The concepts of emergence, autonomy and interactivity that I draw from come primarily from cybernetics and autopoietic theory (discussed in Section 2.5). This section will try to provide at least a provisional overview of these concepts as well as insight into how they can be thought of within an arts context.

Emergence

Emergence is a notoriously difficult concept to define. Indeed, its ambiguous and subjective nature is part of what gives the concept its appeal. A common definition is that of a phenomenon that results from relations between parts of a system that cannot be deduced from knowledge of the functioning of the parts themselves. Much like intelligence itself, it is not a pre-existing property but is relative and exists mainly from the point of view of the observer. Emergence is that surprising element, that "something extra" that all are looking for. As Mitchell Whitelaw notes, many a-life artists invoke the concept explicitly and claim it as their central concern (Whitelaw 2004). Ken Rinaldo is a prime example. Rinaldo defines emergence as "the coming together of systems with no central controller guiding their behaviour" (Rinaldo 1998a, 406). While at first appearing quite pedestrian, further reading reveals that his conception of the term is actually quite sweeping. Rinaldo describes emergence as "the new paradigm for a global change encompassing this earth"; exemplified by a collapse of the divisions between art and science and silicon and carbon-based life forms (Rinaldo 1998b, 371–372). His idea of emergence is intertwined with a certain thematization of symbiosis and co-evolution evident in his artworks and writings. According to Rinaldo, his desire is to echo the forms and interactions of living systems and "[assert] the confluence and co-evolution of organic and technological cultures" (ibid., 407).

Philosopher Ernst Nagel has critiqued similar expansive views from the sciences. Nagel critiques "the doctrine of emergence" by demonstrating how a given property is characterized as emergent if it possesses characteristics relative to one theoretical model but not to another. This doctrine "must be understood as stating certain logical facts about formal relations between statements rather than any experimental or even 'metaphysical' facts about some alleged inherent traits or properties of objects" (Whitelaw, 2004, p. 211). In other words, emergence is an epistemological rather an ontological phenomenon, involving scientific theories and models of observed phenomena; any connection to being or experience is, as Whitelaw states, "argued away" (p. 211).

Still, if emergence is so crucial it would seem to be of some importance to have at least a provisional understanding of what it is. Perhaps in the context of art, having a subjective and arbitrary definition of emergence is enough, and can even be a plus (Gaver, Beaver, and Benford 2003). But for analytical purposes, it is useful — with Nagle's critique in mind — to consider a more formalized notion of emergence from which to base our analysis.

Within the context of generative art, Gordon Monro posits a conception of emergence which he calls *generative-art emergence* (Monro 2009). This is an emergence that is mysterious and unpredictable and evokes feelings of surprise and wonder, even when there is complete knowledge of the system and its construction. He argues that this definition comes closer than other definitions to capturing what artists are looking for when they discuss the phenomenon. Unfortunately, this definition is still unsatisfying, as all it does is raise the status of subjectivity, emotion and other qualitative disjunctions that while devalued or set aside in scientific conceptions, are nevertheless the wellspring from which most studies of emergence arise.

As already mentioned, common conceptions of emergence generally describe it as a phenomenon that results from relations between parts of a system that cannot be deduced from complete knowledge of the functioning of the individual parts in isolation. Though there are highly formalized, computationally-focused conceptions of emergence from fields such as computer science (Dessalles, Müller, and Phan 2007), in the context of this research, a more suitable definition that accounts for subjectivity — while not relying too heavily on rules and formalisms — is better suited, as it allows for greater flexibility in allowing for experiential and ontological considerations. Peter Cariani (1992) provides a theorization of emergence that eschews the singular focus on both the "bottom-up" conceptualization of emergence common to a-life as well as top-down conceptualizations in favor of what he calls "semi-autonomous levels of organization" (776). Centrally, Cariani questions whether emergence is even possible via the purely computational approaches common to a-life research. Drawing upon cybernetics and systems biology, Cariani sketches out a definition of emergence that he calls "emergence relative to a model". Under this definition, an emergent event is one that occurs when the observer's model breaks down. For Cariani, what counts as emergence is highly dependent on one's "observational frame" or point of view. He argues that "all computer simulations can be described in terms of finite state automata, as networks of computation state transitions, as formal symbol manipulation systems" (789). Depending on what “observables” we choose the nature of computation is such that any combination of algorithms or complex mathematics will always correspond to pre-determined rules and will progress through the same computational states. Thus, it will ultimately yield the same results (if the initial conditions are the same). In other words, it will never deviate from its model. Thus, a notion of emergence as a highly contingent and context dependent phenomenon has the effect of essentially rendering all current a-life (and a-life art) non-emergent.

For Cariani, the key feature of a system capable of emergence is its open-endedness, specifically its ability to measure and respond to changes in its environment; and through this open-endedness, develops a capability at adaptive growth and self-alteration of its sensing and effecting capabilities. In other words, a truly emergent system must be able to grow or evolve its own sensors and effectors in response to environmental conditions, without that capability being pre-programmed or pre-defined by its designer. In essence the device must be able to choose — independent of its designer — those aspects of the environment to which it will respond. It is also important to note that the connection between material substrate and emergent behavior. Unlike, conventional a-life approaches which Cariani describes as “platonic” (776), emergent behavior is inextricably bound up with the material from which it arises in a “semi-autonomous” (i.e, non-hierarchical) fashion. Changes in the structure of the material substrate leads to different emergent results, which in turn lead to further changes in structure, and so on.

What does all of this mean for art that utilizes AI, a-life and cybernetic approaches and techniques? No AI or a-life art can be considered emergent under Cariani’s conception of emergence. The sensors and effectors in Rinaldo’s *The Flock* for example, do not adapt and the devices that house them certainly do not grow new ones. However, as Whitelaw notes in his review of Cariani’s model of emergence, the point is not to debunk the claims of artists in this field by invoking Cariani’s taxonomy as some kind of final word on the concept. Rather it can be used as a tool for further inquiry and experimentation to help “bring into focus larger questions about the realization of the aims of artificial life and a-life art” (Whitelaw 2004, 220).

Autonomy

Autonomy in this context is also a term that is a bit tricky to define. This is not a term that is usually discussed by interactive artists but is nevertheless implied, as any emergent, interactive artwork would have to have some ability to govern its own interactions with others. In autopoietic theory, it is precisely the operational closure of the organism that gives it its autonomy and ensures the development of its own unique form of structural coupling to its environment. Autonomy refers to a system's ability to assert itself and (as Varela would say) to "bring forth a world" for itself. Living in an increasingly complex, highly technologized environment will naturally induce shifts in the perceptions, postures and affordances that make up our embodied experience. This dynamic flux is where autonomy is realized; as a continually emergent becoming, brought forth via our interactions with our environment as embodied beings. Autonomy then is an emergent property of these interactions. What I will show in the explication of the symbiogenic framework is how interactive arts explores aesthetic experiences that motivate a sense of being embedded in such an environment; where humans and intelligent machines may enact differing relations of alterity, what I refer to as "heterogenesis" or "enacting difference". Emergence and autonomy then, are implicated in one another.

Of central importance in the analysis of experiences of emergence and autonomy in the interactive arts is the notion of boundaries between humans and intelligent systems. Three analyses by three different theorists are of particular relevance here. First is Katherine Hayles, who essentially argues for dissolution of autopoietic boundaries altogether in favour of a "deep communion" with intelligent technologies characteristic of interactive art experiences (Hayles 2002, 308–309; Hayles 2005, 242). Second is Mark Hansen, who argues against Hayles's absolutist call for dissolution of boundaries. While Hansen offers a more fine-grained definition of boundaries and closure, arguing for provisional and contingent forms of these concepts (Hansen 2009a), he does not include these analyses in his phenomenology of interactive new media art (Hansen 2006). Finally, Nathaniel Stern eschews notions of boundary altogether in favour of a purely emergent performative body that is always already intertwined with its technological environment and where interactive art intervenes to amplify this dynamic (N. Stern 2011). Though these three analyses are largely complimentary, the conflicts over the notions of boundaries and closure (and to some extent the narrow definition of performance) tend to cause some confusion about the nature of embodied relationships to technologies, and intelligent interactive art systems in particular. In my explication of the symbiogenic framework, I will attempt to clear up some of this confusion.

Interactivity

Interactivity has often been considered the hallmark of computer-based art and media. Audiences are invited to take action to influence the flow of events and are often seen as co-creators of the works they experience. However, as Stephen Wilson has argued (Wilson 1993), the mere act of making choices from a pre-defined set of possibilities does not in itself constitute interaction; nor does it automatically result in good art. Wilson asserts that while artists can push interactivity in new ways, they are also in danger of succumbing to unquestioning approval of technology and its underlying assumptions. Similarly, artist David Rokeby has argued that interfaces (the locus point of interaction) act as mirrors that reflect back to us a transformed or distorted version of ourselves and thus cry out for artistic interrogation (Rokeby 1995).

Perhaps no other contemporary artist has written more about interaction than Simon Penny. Penny has argued that interactive art represents a "radical phase-shift" in western aesthetics (Penny 1996a; Penny 1996b). He claims that this largely unexplored territory of machine-mediated interactivity has no aesthetic tradition or precedent. Penny argues that the traditional visual arts and cinema have only a limited relevance, as they are not concerned with real-time experiences. For Penny, this lack of traditions or formal theoretical frameworks has allowed him and other artists to carve out their own unique territory. Though cautiously optimistic about the interactional possibilities of AI and a-life, Penny is critical of "the industry-driven rhetoric of freedom and liberation" (Penny 1996b, 65), and argues that interaction is often quite limited and constrained. Penny believes that AI & a-life may — through the phenomenon of emergent behavior — lead to an alternative to the "all too deterministic paradigm of interactivity as pre-set responses to user navigation through an ossified database" (ibid.). He describes his work as investigating "the aesthetics of real-space interaction", stating that his interest is in interaction that "takes place in the space of the body" (Penny 1997, 103). For Penny, this focus on embodiment no doubt serves as a tonic to the limits and constraints of more common interactive media (at least that of his time).

More recently, increasingly sophisticated analyses of interactivity have emerged, such as Nathaniel Stern's (2011) performative, co-emergent model and Mark Hansen's phenomenologically-based embodied technicity (Hansen 2006). Penny himself has offered a historical treatise of performative aesthetics of interactive art (Penny 2011). A simple question remains however: what special or unique attribute does interactivity (whether the kind envisioned by Penny, Stern, Hansen or anyone else) bring to the art experience? Are not traditional artworks also interactive, as they require active perceptual and cognitive engagement? For Ken Rinaldo, notions of interactivity are often discussed in tandem with notions of agency and (co)evolution. Rinaldo claims that with a-life techniques, richer interactive experiences are possible, stating his belief that humans and machines "will be able to evolve relationships" with each other. We can go "beyond the hackneyed replicable paths" that he suggests are commonplace in new media art and instead enjoy a "cybernetic ballet of experience" from a new breed of artworks that "far surpass our wildest dreams" (Rinaldo 1998b, 375). Rinaldo envisions a point where — through the co-evolution of biology and technology — interactivity reaches its zenith and crosses over into full-blown living agency (Whitelaw 2004, 192).

For a more measured definition of interactivity and arguments for why it constitutes a unique and novel aspect for art, we can turn to cyberneticist Gordon Pask. Pask asserts that one of the most important attributes of an "aesthetically potent environment" is its ability to "respond to a man [sic], engage him in conversation and adapt its characteristics to the prevailing mode of discourse" (Pask 1971, 76). He is quick to note that this applies to more traditional forms of art (such as painting) as well. For instance, we scan static art objects with our eyes and build internal representations and active perceptions of them that change over time. The same could more or less be said of time-based artworks such as music and theatre. They all constitute forms of internal dynamic interaction. However, none of these are interactive from the point of view of the artifact/system. For Pask, one possible advantage that an adaptive system might have is its ability to externalize and make observable (and embodied) this interaction: an interaction which is no longer a "discourse between the internal representation and our immediate selves" (77), but between two entities, each implicated with the other in an evolving state of mutual influence. For Pask, the chief merit of this externalization is its correlation with what he calls "ambiguity of role". Simply put, this means that in an adaptive installation (like his own piece *Musicolour*, discussed in Chapter 3) there is no clear distinction between viewer and viewed, controller and controlled. In a painting, this distinction is obvious. In an intelligent interactive installation, it is (at least ideally) constantly shifting, ambiguous and contingent upon the particular dynamics of the emergent human-machine "conversation". Pask extended this metaphor of conversation further in his development of Conversation Theory (Pask 1975; Pask 1976), a cybernetic model of interaction and communication wherein each participant constructs his or her own understandings via continual circular processes of meaning construction.[4]

Many of the artworks discussed in this dissertation can be seen as putting this notion of "ambiguity of role" and "conversation" into high relief. They all decenter the human subject to a certain extent and clearly offer an alternative to the limits and constraints that traditional "interaction" often places on the art experience. On a broader scale, they can also be seen as helping to re-attune our senses and perspectives towards a greater appreciation of our surrounding environments. Pask states "man [sic] is prone to seek novelty in his environment and, having found a novel situation to learn how to control it... in slightly different words, man is always aiming to achieve some goal and he is always looking for new goals... My contention is that man enjoys performing these jointly innovative and cohesive operations" (Pask 1971, 76). As Andrew Pickering notes, Pask is explicitly moving beyond the idea of interactivity (and cybernetics more broadly) as achieving predefined goals and more toward open-ended conversation (Pickering 2010, 321–322). Also important is Pask's notion of "**control**", which differs sharply from the cold, authoritarian image of cybernetic notions of the term. For Pask, control is "broadly equivalent to 'problem solving' but it may also read as 'coming to terms with' or 'explaining' or 'relating to an existing body of experience'" (Pask 1971, 76). Control in this sense seems like the opposite of the definition we are familiar with. Here, it is more akin to a coming together in order to develop protocols or sets of "understandings" from which to evolve more fruitful interactions in the future. One could even say this kind of control fosters an "ambiguity of role". Pask's thinking with regard to

[4] Andrew Pickering defines Paskian conversation as "any form of reciprocally productive and open-ended exchange between two or more parties" (Pickering 2010, 322). This was the central concern and core research topic for much of Pask's career.

interaction and can perhaps serve as a basis for understanding interaction in the emergent arts. Although neither *Musicolour*, nor any of the other pieces reviewed here can necessarily be said to formulate new goals, the general desire for more open-ended, dynamic conceptions of interaction is clear. Pask's view is that since humans are essentially adaptive, so must our technologies be. Thus any piece that strives to be "interactive" in this Paskian sense would reflect this.

2.3. Posthumanist Theories on Human-Technology Relations

Ideas of human-technology co-evolution are certainly nothing new. Many have questioned the ontological divide that supposedly exists between humans and the technological systems they create, as well as assumptions of technological determinism (the belief that a society's technology shapes or *determines* social and cultural development), arguing instead that social and cultural forces have significant influences on technological development (Feenberg 1991). This section provides a brief overview of key aspects of posthumanist ideas related to human-technology relations, embodied relations in particular that have shaped the development of the symbiogenic framework. The operating assumption proffered here is that cultural contexts shape our perceptions, and thus our technologies, which in turn shape our perceptions. While technologies cannot be considered culturally neutral, as Andrew Pickering and the British cyberneticists show us (Pickering 2010), they nevertheless tend to destabilize, distort and behave in unpredictable ways at times. For although the economic and political forces that no doubt influence or guide technological development must be considered, the unstable tendencies of technological behaviour virtually ensures us of a dynamic characterized not by a Heideggarian extreme of "enframing" or domination (Heidegger 1977) but one where there are continuous upheavals and reconfigurations; where technology can never fall completely under human control, or vice versa (perhaps this is a version of Heidegger's "revealing"). Thus, a more nuanced approach is needed when considering the relationship between technology and society. A simplistic cause-and-effect formula must give way to analyses that consider the various "intertwinings" between humans and technology, for all technologies involve human interaction. An overview of these major analyses are presented here as context for understanding the symbiogenic framework and its arguments, as it too sits within this space of questioning the ontological incongruities between humans and technology.

2.3.1. Historical Context

Heidegger's phenomenology of technology highlights the tension between these enframing and revealing aspects of technology. When considering the historical context from which notions of human-technology co-evolution arise it is useful to examine Heidegger's ideas a bit more closely. In "The Question Concerning Technology" (1977) Heidegger discusses the question of technology's *essence*, which he asserts is not itself technological and cannot be understood by discussing it within a purely technical framework. Heidegger questions the often unexamined assumptions that shape a view of technology as "instrumental" ("a means to an end") and anthropological ("a human activity") (288). While he accepts both of these definitions, Heidegger also maintains that it only scratches the surface of technology's true nature. Consistently turning to etymology in order to question fundamental and originary meanings of often used but rarely examined terms such as "technology", Heidegger argues that technology's essence lies not in the instrumental production of goods or manipulation of materials, but in a certain type of "revealing" or exposing of natural and human potential. This revealing ultimately leads to a transformation of the Earth and humanity where both are reduced to what Heidegger calls "standing reserve". This expansionist, all-consuming and ultimately dominating nature of technology is where its essence lies — in what Heidegger calls *ge-stell* or "enframing". For Heidegger, this enframing stems from the human (or at least the Western) drive for a "precise" and "scientific" knowledge of the world. Many have criticized Heidegger as presenting an essentially technological determinist argument (Feenberg 1991). Phenomenologist Don Ihde critiques what he calls Heidegger's "romantic thesis" (Ihde 1993). Ihde argues that what is left out of Heidegger's account of *technē* — particularly as it is exemplified in simple or "pre-modern" technologies and ancient works of art — is what Ihde calls the "politics of the artifact" (a term he attributes to Langdon Winner). Ihde claims that Heidegger ignores the social, cultural and political contexts that shape the development and deployment of any technology. He also points out what appear to be inconsistencies in Heidegger's ideas of what are "good" versus "bad" technologies. Ihde believes the reason for this is that Heidegger values simple embodiment relations with technology above all others. Thus, technologies "which express straightforward bodily, perceptual relations with the environment" (107) (as most pre-modern technologies do) are preferred over those that treat the environment as a "standing reserve" (or "resource well" to use Ihde's terminology). Though Ihde does not consider the effects of rationalization and industrial capitalism (as for example Sengers (1996) and Feenberg (2009) do), he does echo a claim made in his book *Technology and the Lifeworld* (Ihde 1990), where he claims that the idyllic time Heidegger yearns for — where human-technology-environment relations were balanced — has never existed.

It is also important to realize that discussions of the posthuman implicitly assume a particular conception of "the human" of which we are post. Don Ihde again reminds us that whether it be the anatomically modern humans that emerged 100-200 thousand years ago, the Enlightenment "Cartesian-Lockean" human or a decentered "closer-to-the-animals" postmodern human, all humans have cultural practices where technology is prominently featured (Ihde 2011). Furthermore, as Ihde notes, physical anthropologists are now recognizing that these cultural practices are involved in our biological evolution. Ihde critiques various techno-mythological fantasies related to posthumanism and transhumanism, stating that there is nothing new in current technofantasies of uploading consciousness or enhancing our bodies via techno-prosthetics or biotechnologies. "Our myths our indexed to our experiences", says Ihde. Whereas hunter-gather cultures had myths that reflected the importance that plants and animals played in their daily lives, contemporary life (at least in the West) is technologically-textured. Thus "technologies will provided the magic answers". The most relevant and salient aspect of Ihde's critique to the discussion here is his insight that technology has always existed and operated in relation to and within the context of its interactions with humans, and vice versa. Complex human-material interactions via what Andrew Pickering calls a "dance of agency" are how new technologies emerge. Interactions with these technologies spark new ideas, which then lead to still newer technologies, the co-evolutionary process continues. Ihde want us to consider the materiality and ambiguity of technology, with all of the "good", "bad" and unpredictable aspects that go with it. Most importantly however it is the intertwinement of humans with technology that he wants us to consider. All technologies whether it is tax preparation software or "intelligent" unmanned aerial vehicles require massive and complex deployment and interplay of human technical and cognitive faculties with existing matter and technology. This, Ihde argues, is the way it has always been.

Offering a more traditional historical account, especially with regard to the specific history of human-technology co-evolution is historian Bruce Mazlish. Though a complete historical account of humanity's relationship to machines is out of the scope of this dissertation, Mazlish's account — when considered alongside Ihde's — at least provides a basis from which to view contemporary questions. While still operating under a rational, Cartesian ontology that separates humanity from its environment, Mazlish's book *The Fourth Discontinuity: The Co-Evolution of Humans and Machines* (Mazlish 1995) nevertheless does an admirable job of describing how humanity has been struggling to come to terms with its relationship to machines for quite some time. Echoing Ihde's questioning of the historical possibility of an idyllic human existence without technology, he offers a rich historical context in which to understand these relations and argues that similar to the way in which Copernicus, Darwin and Freud forced us to rethink our relationship to the universe, nature and our own minds respectively, so too must the nature of our relationship to technology be rethought. Starting as far back as the early Renaissance, Mazlish states that "we are now coming to realize that humans and the machines they create are continuous". He describes humans as "continuous with the tools and machines they construct" (4-5). Mazlish's core argument is that the illusion (or "discontinuity" to use his words) that we are separate from our technological creations is beginning to break down. Mazlish describes the relationship between humans and machines as a continuum and asserts that "the same conceptual schemes that help explain the workings of the brain also explain the workings of a 'thinking machine'" (4). Starting from Descartes and moving through such diverse material as Mary Shelley's Frankenstein and scientist Carl Linnaeus's development of binomial nomenclature, Mazlish looks deeply at the three previous breaks of discontinuity in relation to their time.

Whereas Mazlish offers a historical account of Western ideas relating to human-technology relations, Bernard Stiegler offers what can be thought of as an anthropological account weaved through the lens of the entire Western philosophical tradition. In *Technics and Time 1: The Fault of Epimetheus* (Stiegler 1998), the first of (currently) three volumes dealing with technology and its effects on human temporality, Stiegler lays out an account of technics that places it at the core of what makes us human. With the myths of Prometheus and Epimetheus playing a key role in his philosophy, Stiegler argues that we exist not only in constant relation to technology, but realize ourselves through it. Central to his thesis is his assertion that the long philosophical tradition of separating *ēpistēmē* from *tekhnē* (where technical knowledge is devalued) can no longer be maintained. Drawing upon Heidegger, Simondon and archaeologist André Leroi-Gourhan among others, he argues that human memory — indeed all relation to time — is technologically rooted and describes a phenomenon where technics seem to move "faster than time" (15). For Stiegler, understanding the dynamics of how humans and technology interact is crucial for understanding both the future of technology and the future of the human. Much of the book can be seen as an overview and threading of historical and philosophical theories on the development of technology and the origin of the human species. The basic outcome of his analysis is that the human and the technical (the "who" and the "what" in Stiegler's words) each exist in an ambiguous and mutual "coming-to-be". Drawing on Derrida's concept of différance, he states that "the appearance of the human is the appearance of the technical" (141). Thus, one invents the other and vice versa. Part II consists largely of an analysis of the work of Heidegger. Here the central argument is that Heidegger does not adequately account for the role that objects and artefacts (in other words technology) play in grounding our sense of temporality, in essence providing us a way of accessing past and future. An extension and contrast to Stiegler's ideas of technological temporality can be found in Mark Hansen's notion of "processual" versus "objectal" time as well as his considerations of the overall temporalizing power of microprocessors and digital technologies that operate more or less autonomously (Hansen 2009b).

2.3.2. Overview of Posthumanist Thought

Perhaps more than any other philosopher or historian of science and technology, Katherine Hayles has examined the ways in which human embodiment was systematically removed from consideration in the earliest days of the computer age. In *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Hayles 1999), Hayles tells three interrelated stories on how this erasure came to be and how it affects our conception of what it means to be human. The first is how information "lost its body". That is, how it came to be conceptualized as an entity separate from the material forms that carry it. The second concerns the cultural and technological construction of the cyborg. The third focuses on how the traditional construction of the human, the so-called "liberal humanist subject", is giving way to a new construction. As she notes, the construction of information as "conceptually distinct from the markers that embody it" (25) would give life to the construction of a new "virtual" human and along with it, a myriad of techno-fantasies or dystopias (take your pick) of human-machine mergers, making them seem all the more plausible. Claiming that we have essentially been posthuman since Alan Turing devised his famous Turing test in the 1950s, Hayles argues formidably against the rhetoric of bodily erasure and the idea of information and materiality as distinct; a concept that she notes is evident throughout the history of cybernetics, informatics and cultural theory.

Hayles uses the term "flickering signifier" to refer to the experience of the human confronting the posthuman. She defines it as the realization that information and technological and computational paradigms are now the prism through which our culture understands itself. It is also a realization that intelligent machines are now superior to humans in there ability to manipulate and store information. Hayles however does not consider too seriously the cognitive and embodied implications of this significant event. While she does embrace embodiment and argues formidably against the rhetoric of bodily erasure evident throughout the history of cybernetics, informatics and cultural theory, her analysis seems to ignore the phenomenological and psychophysical experience of the individual. This is likely due to the influence of virtuality, a view prevalent during the 1990s that saw the lines between the real and the virtual as becoming less and less distinct. Hayles herself defines virtuality as the core concept of what she calls third-wave cybernetics. Thus her analysis, though it lays much necessary groundwork, must in a sense be viewed as a product of its time.

Nevertheless, Hayles's core vision is of great significance for the symbiogenic framework. Her conception of the posthuman as amenable to the effects of its relation to information-processing technologies, to the point of being dependent or reliant on them, effectively shatters the Western idea of a coherent and independent being. The human is now reconfigured "so that it can be seamlessly articulated with intelligent machines" (108). In addition to arguing against the rhetoric of bodily erasure and the idea that information and materiality are distinct, Hayles also notes the capacity of technology for extending human agency and cognition. Most importantly perhaps, her critique of disembodied information — which as she states, reduces intelligence to a “property of the formal manipulation of symbols rather than enaction in the human lifeworld” (19) — could be seen as a clarion call for both new media artists and theorists alike who believe that embodiment and materiality still matter in the digital age.

More recently, Hayles has taken on the question of co-evolution of humans and technology more directly. She has described our coupling with digital technology as a “cultural co-evolution” (Hayles 2007). She outlines a generational shift from deep attention to what she calls “hyper attention”. Deep attention is the cognitive style traditionally associated with the humanities and is characterized by concentration on a single object or task for long periods of time (such as reading a book). Meanwhile hyper attention entails a rapid switch in focus among several tasks. The preference here is for multiple streams of information that provide high levels of stimulation (such as playing a video game). Citing various studies of how media stimulation affects the brain, Hayles claims that “the brain's synaptic connections are coevolving with an environment in which media consumption is a dominant factor” (192). Drawing from Nigel Thrift’s notion of the “technological unconscious” (Thrift 2004), Hayles notes how our technological infrastructures (in the West) are changing the environmental context from which we establish our mechanisms of attention (Hayles 2012). These shifts change the nature of the technologies we produce, which in turn influence our attention, and so on.

Cary Wolfe posits a different type of co-evolution and posthumanism from that of Hayles (Wolfe 2009). Drawing upon systems theory, animal studies and the poststructuralist philosophy of Jacques Derrida, Wolfe outlines a vision of the posthuman that extricates it from the traditional humanist narratives of historical progression in which it is based and from which he claims Hayles’s conception of it is firmly situated in. Wolfe attempts to redefine posthumanism not simply as a state of “triumphant disembodiment” that de-centers the humanist liberal subject but rather one where the human is seen as part of a complex biological and technological environment; an environment it is in constant dynamic interplay and co-evolution with.

Like Hayles, philosopher Andy Clark draws from Edward Hutchins's concept of distributed cognition to sketch out a portrait of the human as having always been dependent on some sort of cognitive scaffolding (Clark 2003). For Clark, the mind "simply cannot be seen as bound and restricted by the biological skinbag" (4). He notes that whether it is simple pen and paper or the latest digital gadgets, our minds are built to create and take advantage of tools and technologies. Furthermore, as this process accelerates and our digital technologies become more pervasive and personalized, they are becoming part of us. Thus in a looping, recursive process humans make technologies which remake the human and its abilities to create new technologies, which in turn create more and better technologies, and so on. Clark offers copious examples from a wide range of technologies that he says are quickly enhancing are minds and reshaping our very nature. His notion that there is a certain inherent biological flexibility to being human which (under the right conditions) can open up certain cognitive possibilities are particularly relevant to the symbiogenic framework.

Many more scholars have made similar arguments to those discussed here. Some of these will be discussed in section 2.5, when autopoiesis and cybernetics — which can be seen as an extension or deeper analysis of a particular aspect of posthumanist thought — are established as an aspect of the symbiogenic framework. All argue in one form or another that we have always been intertwined with our technologies in varying degrees. Thus, the belief in a deep ontological divide between human and machine, though certainly still with us, seems weakened nevertheless. With the possible exception of Ihde however, none of these analyses specifically confront the nature of the direct experience of the human with intelligent technologies in this posthumanist world. This is where we will now turn.

2.4. Phenomenology and Human-Technology Relations

Following American philosopher John Dewey (1958), I am arguing in this dissertation that art, particularly interactive art, should be looked at from the perspective of experience rather than a focus on representation and the art object itself. For Dewey, art provides a heightened, intensified experience of meaning, with the roots of this experience arising from the common everyday occurrences of human life. At the centerpiece of Dewey's account of the phenomenology of artistic experience is a reestablishment of the connections between the refined aesthetics of artworks and the "raw" aesthetics of the everyday. He argues that understanding the latter is crucial if one is to understand the former. With this is mind and based upon the notion that artistic practice and lived experience and reflection are inextricably linked, I examine in this section the philosophy I feel most engages with direct lived experience and is therefore well suited for the analysis of interactive art: existentialist phenomenology, particularly that of Maurice Merleau-Ponty. Merleau-Ponty's embodied phenomenology is introduced here as framework from which to base descriptions and analyses of the highly subjective phenomenon I am calling symbiogenic experience. As I will show, a central feature of my proposed framework is an extension of the phenomenological model of **intentionality**, expanded to include its alteration by or adaptation to, the varied dynamics of human coupling with intelligent technologies. I draw significantly from Merleau-Ponty's model of intentionality, which focuses on embodied and preconscious aspects of perception and which he refers to as "motor intentionality" (Merleau-Ponty 2002, 127). This chapter provides a brief introduction to the key aspects of Merleau- Ponty's philosophy as well as those who have built upon and extended his work.

Until very recently, there has been little research relating interactive art with phenomenological methods. Diane Gromala used a phenomenological method based upon the writings of Merleau-Ponty for her doctoral thesis in interactive arts (Gromala 2007). The methodological approaches in her thesis were contextualized to particular interactive pieces. *The Meditation Chamber* for example, was a collaboration with scientists that focused on descriptive analysis combined with questionnaires and physiological data analysis. Meanwhile, *The Meatbook* was an interactive book made of meat and focused primarily on philosophical analysis and phenomenological reflection. Susan Kozel also draws significantly from Merleau-Ponty in her book *Closer: Performance, Technologies, Phenomenology* which combines first-person reflection with descriptive and philosophical analysis (Kozel 2007). Unlike Gromala, Kozel's method is more or less established a priori and applied to several pieces rather than being contextualized to a specific piece. Artist Jill Coffin provides a phenomenological interpretation of her interactive art project *Breeze*, a robotic maple tree that senses and responds to human presence and movement (Coffin 2008). Coffin focuses primarily on

Heidegerrian philosophy, differentiating it from Husserlian and outlining several of Heidegger's concepts relating to human action in the world and how they relate to *Breeze.* These include the most well known of Heidegger's neologisms such as *Dasein, present-at-hand* and *ready-to-hand.* Of particular note however is *Lichtung*, which Coffins defines as "a field of possibilities for interaction" (218), and which can more broadly be considered as the way something shows itself or becomes clear to us. Coffin argues that the open-ended responses available from *Breeze* create possibilities for emergent and unscripted interactions.

The incorporation of thee and other phenomenological methods of analysis in new media art research represents a different approach from the traditional art historical models based upon form and representation, which are ill-suited and insufficient for art that behaves, art that we interact with and establish varying kinds of relations of alterity. The shift in focus to embodiment and direct experience are but one example of what may be the beginnings of alternative models of analysis.

2.4.1. Overview of Phenomenology

Because both the symbiogenic experience and Merleau-Ponty's philosophy are part of larger questions relating to experience and corporeality, I begin here with a very brief overview of the phenomenological tradition as a whole. Phenomenology studies the structures of consciousness and the phenomena that appear to it from a subjective, first-person perspective. This includes aspects of experience such as perception, thought, memory, emotion, desire, bodily awareness, embodied action, and social activity. Phenomenology however, is not a single unified body of thought, but rather contains diverse and sometimes conflicting ideas.[5] Broadly speaking however, all share what I consider to be four key aspects:

- *A concern with subjective experience*. "Subjective" in the context of phenomenology does not mean made-up, imaginary or simply a personal

[5] The Encyclopedia of Phenomenology identifies 7 types of phenomenology: (1) transcendental, (2) naturalistic, (3) hermeneutic, (4) existential, (5) generative historicist, (6) genetic, and (7) realistic. For more see (Embree 1997).

inner world. Rather, it is a view that states that something exists only if there are subjects capable of perceiving and experiencing a particular phenomenon in a particular way.

- *A belief that all knowledge is (at least in part) subjective*. Knowledge is in part subjective, since it depends on individual observation and experience, and in part objective, since these subjective accounts are constrained by a body of regulated knowledge (Varela and Shear 1999).
- *A desire to study things not as they "truly" are, but rather how they are for us, in specific contexts*. All human endeavours, whether they be scientific, artistic or philosophical arise from a basis in direct human experience or in "the things themselves" as Husserl argued. Thus, they must be understood in those terms. Concepts such as scientific objectivity are derived from our direct experience, which is where they acquire their meaning. As Merleau-Ponty would say, we can understand geography scientifically only because we know what it is to experience a landscape (Matthews 2006, 16).
- *A belief that meaning arises from within connection to a "lifeworld".* The simple way to say this is that we are tightly coupled to our environment and our social-cultural world and that all meaning arises in relation to these.

Intentionality

A central concept in the phenomenological tradition is intentionality. Introduced into philosophy by Franz Brentano (1973), this refers to the notion that human consciousness is always directed towards things in the world. To see is always to see something. To feel is always to feel something. This intentional structure of consciousness is vital, serving as the foundational structure of experience. For the most part, lived experience is considered to be enacted consciously, which is to say that we are aware of most our actions. Some phenomenologists however, study those aspects of experience that we are not always overtly aware of. Martin Heidegger for example, examined everyday activities like hammering that sometimes fall out of immediate consciousness, only coming back when the object in question (the hammer) breaks (Heidegger 1978). Following Merleau-Ponty, Drew Leder discusses the ways in which the body displays a tendency to recede and disappear from awareness in daily life and certain activities, such as when playing sports (Leder 1990). An aspect of intentionality that we may also be less aware of but which is rarely discussed is its location: where, in reference to the human subject, it begins and ends. It is always assumed that the subject, whose consciousness is directed toward things in the world, is a bounded one; bounded by one's physical body. Yet as Edward Hutchins (1995) and Andy Clark (2003) have shown, cognition is not relegated to the brain but in fact exists in a tight coupling with its external cognitive scaffolding in the environment. Simple examples such as notepads and Internet bookmarks come to mind as ways that we extend our cognition beyond the boundaries of our skull. Thus, it may useful to think of intentionality as more diffuse. With regard to questions such as human-technology relations this may be problematic, especially when troublesome and thorny questions such as technological intentionality arise (Verbeek 2008). Since one of the pillars of the symbiogenic framework is founded upon an extension of the phenomenological model of intentionality, much of the analyses reviewed here will focus on this core aspect of experience as they provide a useful point of departure for my own analyses. Thus, a review of Merleau-Ponty's philosophy and his ideas regarding intentionality are warranted, as they help provide the context and ontological grounding from which to proceed.

2.4.2. The Existentialist Phenomenology of Maurice Merleau-Ponty

In *Phenomenology of Perception*, perhaps his most famous and most during work, Merleau-Ponty provides an account of the body's centrality to perception and its status as the root of consciousness (Merleau-Ponty 2002). Merleau-Ponty argues both in this work and in his first major work, *The Structure of Behavior* (Merleau-Ponty 1963), that perception is not merely a reaction to, or a causal artefact of, sensations, but rather arises from a dynamic engagement with sensory data and the environment, wherein stimuli are given a certain shape in consciousness. Central to this view of perception for Merleau-Ponty is the body, which he describes as "the vehicle of being in the world" and which he asserts, forges a deep reciprocal entailment with the environment (Merleau-Ponty 2002, 94). Our body is not merely an object in the world among other objects but the core of our very experience.

In Merleau-Ponty's interpretation of it, phenomenology is a philosophical view rather than a distinct system of philosophy. The goal of phenomenology as he sees it, is to lead us back to the world as we directly experience it in pre-reflective perception. To do this, we must set aside our "natural attitude" which consists of any preconceived ideas or assumptions, that for scientific and practical purposes, we normally make about the world and ourselves. This setting aside of theoretical preconceptions is known as epoché or bracketing, a method of phenomenological reduction. As mentioned in

Chapter 1, Merleau-Ponty accepts the idea of reduction, but argues that it is not a complete withdrawal from all engagement with the world. Merleau-Ponty wants us to describe experiences just as we find them in our direct embodied engagements with the world. If we analyze them and look for relationships between and among contingent features specific to that moment, our view of the world and our relationship to it may begin to shift. It may begin to appear less comfortable and defined, revealing itself as more indeterminate, as if in a continuously emergent flux.

This view follows from Merleau-Ponty's assertion that the world that we perceive in everyday experience (the world of perception) is largely unknown to us (Merleau-Ponty 2004). He asserts that scientific objectivity, while essential in most cases, offers representations or approximations of the world we experience. Thus, in order to get back to the world as perceived through lived experience, he suggests turning to modern art and philosophy, which he argues can "lay this world bare" and help us rediscover it (39). This provides insight into the relationship between perception and the arts and between the classical and (post) modern views of the world. Merleau-Ponty saw modern art as possessing a unique ability to get us back to things as we actually experience them in pre-reflective perception, thus fulfilling the same role as phenomenology (though through different means) (Matthews 2006, 135–151). He particularly focuses on the work of French post-impressionist painter Paul Cézanne (but also others such as Picasso and Braque) and how his paintings are born of a drive to "rediscover the world as we apprehend it in lived experience" (Merleau-Ponty 2004, 52) and how they can "lead us back to the things themselves" (93). Though Merleau-Ponty does not discuss technology very much and certainly not art and technology, his insights are particularly relevant today, for technological art is in a unique place to "lay bare" some of the inherently ambiguous ways that processes in the technological environment that are not consciously felt may still be "internally taken up... reconstituted and experienced" (Merleau-Ponty 2002, 380–381), or at least influence the contours of experience.[6]

[6] As mentioned earlier, Mark Hansen's work in updating Merlau-Ponty's philosophy within an interactive arts context is a notable an important aspect of this conceptual framework (Hansen 2006).

Merleau-Ponty's most unique and important contribution to Western philosophy is the importance he affords the body. Historically, few methodologies and philosophies have accounted for the lived experience of the body. While intellectual traditions in the humanities have analyzed the body in broad historical and cultural contexts, the material facticity and experience of the body has often been ignored. While there are certainly exceptions and this has begun to change in recent years,[7] phenomenology remains the primary philosophical and methodological tradition that studies direct lived experience seriously. And with regard to the body, Merleau-Ponty's work serves as a foundational text for understanding the body's role in perception. Thus, the existentialist phenomenology of Maurice Merleau-Ponty serves as the core philosophical and methodological approach in this dissertation as his ideas are directly relevant to the idea of an embodied felt sense of the symbiogenic experience.

For Merleau-Ponty the body is our "universal invariant", the locus point or grounding from which knowledge and experience arise. He argues that whatever we know, we know through the medium of our body. We invent concepts and models to make sense of our embodied experience of the world, but there is something that comes before the concepts, on which they are based, which is embodied engagement with that world. This Merleau-Ponty asserts, is the primordial form of knowing. Merleau-Ponty also describes how the body is constantly attuning itself to its environment in common everyday activities. Whether it be a simple matter of trying to attain the proper distance and positioning for reading a book or a more complex task such as learning a new skill, the body is led by the situation (outside of purely mental/cognitive processes) — in an active/dynamic process — to get into some sort of equilibrium with its environment (Dreyfus and Dreyfus 1999). Merleau-Ponty sees a tight connection between body and world. Via what he refers to as an intentional arc, Merleau-Ponty describes how as bodily skills are acquired they in effect alter the manner in which we respond to our environment and how objects and situations show up for us in consciousness. These ideas are crucial for the embodied felt sense of the symbiogenic experience as they aid

7 See (Dourish 2001; Dreyfus 1992; Varela, Thompson, and Rosch 1992) for important examples in the fields of human-computer interaction, artificial intelligence and cognitive science respectively.

in the analysis how the body and perception may be extended, and how interactive art can influence the body's attunement.

2.4.3. Human-Technology Relations After Merleau-Ponty

An important part of this dissertation lies in extending the Merleau-Ponty's model of intentionality. Shaun Gallagher has extended Merleau-Ponty's work in this area, arguing that certain preconscious factors of the body act to shape and constrain perception and experience (Gallagher 1995). Gallagher explores how certain preconscious or "prenoetic" factors "operate as constraining and enabling factors that limit and define the possibilities of intentional consciousness". In particular he notes how the "body schema" can shape the body's attunement to its environment by "limit[ing] and defin[ing] the possibilities of intentional consciousness" (239). Gallagher begins by delineating the difference between "body image" and "body schema". While he is careful to note the continuity between the two, emphasizing their operation as a single continuous system, he also outlines the important distinctions between them. Whereas the body image may involve partial representations of specific body parts that one is consciously aware of at any particular moment in time, the body schema functions as a holistic interconnected system of motor and postural activities and potentials. Most importantly with regard to symbiogenic experiences are the differences over what Gallagher refers to as "body ownership". The body image exercises control over body movements, since through it the body is experienced as an "owned body", one that belongs to the subject who is having the experience. The body schema, however, is not owned; it is anonymous and "subpersonal". Thus, control over movement, even though it is for the most part a conscious and wilful activity, is still subject to postural or other adjustments that are not under conscious control — for example, those adjustments necessary to maintain balance. Gallagher provides evidence from recent physiological studies to support his claims. Examples include studies that show how illnesses or diseases that effect motility, posture or physical abilities also impact (often negatively) perceptual and cognitive aspects of body image. Other studies show that changes in muscle tone often correlate to changes in bodily awareness and awareness of ones environment. Thus in extending Merleau-Ponty's ideas relating to the body schema and embodied intentionality, Gallagher develops an account of how bodily factors and processes that occur outside of or prior to cognitive experience shape the meaning that arises in conscious reflection. Part of the argument being presenting in this dissertation is that this shaping and control is subject to “outside” influence and that technics is the vehicle for that influence.

With regard to the body’s relationship to its environment, Gallagher once again draws from Merleau-Ponty to outline the various ways that the lived body (as opposed to the scientific or objective body) perceives, is perceived and escapes perception, and how this impacts lived experience (Gallagher 1986). His analysis culminates in the suggestion that what he calls the “lived body-environment” is close to Merleau-Ponty’s conception of “the flesh”, characterizing it as an “intertwining” or “communion” that ones body has with its surrounding environment. Gallagher identifies three types of experiences of the lived body in relation to its environment. *Present* refers to the lived body that is present to consciousness. *Ambiguously present* refers to the ambiguous, preconscious (or not immediately conscious) knowledge of the lived body; sometimes available to consciousness and sometimes absent to it. *Experientially absent* is where the body escapes consciousness altogether; for example, low level neural activity. Extending this third concept, Gallagher refers to an “absently available” body. This is where the body remains “in a mute and shadowy existence” while engaged in a given task but once something occurs that causes the body to lose equilibrium with its environment (pain, fatigue, etc.) it suddenly appears as “center stage” (152).

The symbiogenic framework being outlined in this dissertation analyzes our experience with intelligent technological art systems and draws significantly from the dynamics Gallagher describes. How and what aspects conscious experience and intentionality are or are not immediately available to consciousness are important aspects of these explorations. Still the question remains as to what roll technologies, particularly intelligent technologies, play in shaping intentional conscious and our relationship with the environment. Here we can turn to Don Ihde, who also draws upon Merleau-Ponty’s (as well as Heidegger’s) work to provide us with an analysis that helps to clarify some of the ways in which technology impacts the intentional domain (Ihde 1990). Ihde looks at a broad spectrum of technologies: from simple, everyday technologies such as clothes and eyeglasses to vast world-spanning technologies such as modern weaponry and nuclear energy, the immense power of which can have serious environmental and geological repercussions. Ihde identifies four different relationships and describes their structural features. First are *embodiment relations*, where the technics of a particular action or sense activity are located within the intentionality of that activity. This is a relation defined by incorporation. One sees for example, through a pair of glasses, which then become more or less transparent. In this relation, the technics of a particular action are “actively embodied”. Ihde describes technics in this context as “the symbiosis of artefact and user within a human action” (73). Next are “hermeneutic relations,” wherein technologies provide textual representations of reality that must be “read”, resulting in a sort of mimicking of sensory perception. An example is the reading of a thermometer that allows one to “know” the temperature without having to feel it. A third relation is where the technology is cast as “other”. Humans interact with it directly, almost as if it were another sentient, living entity. In this “alterity relation”, the world remains as context and background, while the technology emerges as the focus or terminal point of experience. An example of this relation could be a robot or a personal computer. The fourth relation is the background relation, which refers to functioning technologies that are not directly experienced but which themselves provide context for perception and experience. Examples include refrigerators or heating and cooling systems in buildings.

Peter-Paul Verbeek stresses the importance of approaching the analysis of human-technology relations with an even stronger emphasis on intentionality in order for his “radicalizations” to become visible (Verbeek 2008). Verbeek extends Ihde’s analysis by distinguishing among three types of “cyborg intentionalities”. Here, Ihde’s sets of relations are categorized as a subset of this cyborg intentionality, referred to as “mediated intentionality”. This is where the experience of the world is achieved through some kind of mediating technological device. Verbeek states that these devices either create a context for human experience or establish “new ways of accessing reality”, and thus amount to a type of cyborg intentionality, as the intentionality “is partly constituted by technology” (389-390).

Seeking to go beyond mediation, Verbeek discerns two more types of cyborg intentionality: “hybrid” and “composite”. Hybrid intentionality refers to the intentionality of human-machine hybrids. Here, the standard or “classic” conceptualization of the cyborg is offered as an example of an entity that is physically altered so as to become a new entity with ostensibly a new intentionality. The associated mediation that is provided the human by the technology no longer exists, as it has been subsumed or fully incorporated into the new entity. Pacemakers and implanted microchips for improving vision or hearing are given as examples. Composite intentionality refers to a “doubling” of the intentional domain. Here, “technological intentionalities” — that is, where technological artefacts themselves have a form of intentionality — cooperate with human intentionalities in directing action toward the world. As an example of this type of intentionality, Verbeek describes the photographic work of Wouter Hooijmans, who makes landscape photographs using shutter speeds of several hours in length. Verbeek describes this as an “extreme mechanical makeover of the intentionality of the human vision” [sic] (394).

A problematic aspect of Verbeek’s analysis is his use of the somewhat limiting metaphor of the cyborg. Rather than the superficial merging of silicon and flesh or bodies functioning with technological add-ons, a cyborg (if one were still insistent on using that word) in a more profound sense would be one whose processes are integrated, incorporated and shared with technology in a dynamic and constantly shifting evolutive flux. These shared, distributed process become part of each entities operationality, to the point that they cannot be removed and have it function. Notwithstanding this limiting definition of the cyborg — as well as the problematic notion of technological intentionality — Verbeek’s model serves as a useful starting point for explicating what is a foundational element of the symbiogenic framework: the notion of *distributed intentionality*. Discussed in greater detail in Chapter 4, distributed intentionality refers to a single intentionality, not locatable within a single entity at any single point in time, but one that exists in a blurry intentional zone. Intentionality here ceases to be confined to the self or human subject. It may consist of any number of systems (human and machine), each either ceding or co-constructing portions of their intentionalities as a result of their interactions.

2.4.4. Summary

With the possible exception of Hansen (2006), there has not been to my knowledge, a consideration of co-evolutionary experiences in the interactive arts done from a phenomenological perspective. Merleau-Ponty’s embodied phenomenology is introduced here as framework from which to base descriptions and analyses of the highly subjective phenomenon I am calling symbiogenic experience. Merleau-Ponty's phenomenological method is valuable and meaningful for this research precisely because it accounts for subjective or first-person experience, particularly mind-body experience. More specifically, this ambiguity of existence mentioned above, of simultaneously being part of the world but able to stand back from it, from being both subject and object, is crucial to Merleau-Ponty's ontology and serves as a basis for accounting for first-hand, creative experience and for an understanding of the symbiogenic experience.[8] Furthermore, Merleau-Ponty's focus on the material body as the locus point of knowledge and experience, of how the body is led by the particular situation (outside of purely mental/cognitive processes) to get into equilibrium with it's environment in an active, dynamic process, helps set the stage for my analysis of how the body and perception may be extended and how interactive art can influence the embodied subject's relationship to his or her environment.

2.5. Cybernetics

Theories and concepts from the sciences sometimes influence those in the humanities (and vice versa). Since I draw in this dissertation from cybernetic concepts and material practices in order to build up the notion of co-evolution, it is important to outline — at least in a provisional way — what cybernetics is and what its core ideas are. These ideas and theoretical references demonstrate the fundamental circularity and collective nature of what we usually consider individuality and autonomy, advancing ideas of embeddedness and co-emergence with a complex environment. My intent in marshalling cybernetics in the conceptual framework of this dissertation is to situate human-technology co-evolution as part of "natural" phenomena that these ideas point to. Thus, my goal will be to use these concepts, along with those from phenomenology and posthumanism, as the lens through which to see our relationship with this increasingly technologically intelligent environment. I will not cover the entire field of cybernetics here

[8] This is sometimes referred to as reversibility, but I wish to focus more on what Merleau-Ponty sees as reversibility's strange and ambiguous nature.

but rather those aspects of which are relevant to the concepts of co-evolution that I am building as part of the symbiogenic framework as well those that have influenced the artworks in this dissertation.

2.5.1. What is Cybernetics?

Cybernetics is a term that seems to mean different things to different people. Perhaps its most enduring image is of its connection to American post-war military command and control research. This authoritarian image is incomplete however, since it belies the breadth and complexity of this multi, trans and meta-disciplinary field. Derived from the Greek word *kybernetes*, or “steersman”, cybernetics is the study of systems, particularly goal-directed systems or systems that exhibit purposive behaviour. The term “cybernetics” itself can trace its origins to Antiquity and Plato as well as the 19th century mathematician and physicist André Marie Amperè (both of whom used the term in reference to politics and government) (Heylighen and Joslyn 2001). The concept was revived and elaborated by the mathematician and “father” of cybernetics Norbert Wiener. His seminal 1948 book, *Cybernetics: or Control and Communication in the Animal and the Machine* (Wiener 1961), a creature of wartime and post-war research into mechanical control systems for tasks such as artillery targeting systems, defined cybernetics within this regulatory and control framework.

From its very beginnings, cybernetics had been interested in investigating the similarities between autonomous living systems and machines. Gordon Pask defined cybernetics as the field concerned with information flows in all media (Hayles 2010). This definition works well within the context of interactive art and new media but also hints at what was an ambitions task for cybernetics: namely the task of developing a unified framework for studying such diverse phenomenon as information, cognition, human interactions and even life itself in abstract terms. Indeed, cybernetics starts from the bold yet simple declaration that systems exists and are all around us. This unifying framework transcends the long-held boundaries between many disciplines and more broadly between science and art, external reality and internal subjective experience. The most fundamental contribution of cybernetics is its explanation of purposiveness, or goal-directed behaviour — an essential characteristic of mind, life and intelligent systems — in terms of control, regulation and information (Heylighen and Joslyn 2001). Historically, cybernetics is generally separated into two distinct but overlapping phases. The original or first-order cybernetics was concerned with notions of regulation and homeostasis, while second-order cybernetics (sometimes called neocybernetics) was concerned with the observer as part of the system.[9] Whereas first-order was more mechanistic and engineering-centered, second-order cybernetics was more focused on autonomy, emergence, self-organization and the role of the observer in modelling a system. Henceforth, it appealed a great deal to psychologists, biologists and those interested in learning and cognition.

The cybernetic project can best be summarized via four distinct but interrelated categories: processes of circular causality, goal-directedness, relational concepts and constructivist epistemology.

- *Circular causality*, in contrast to the classical Newtonian model of linear cause and effect, is a process wherein effect feeds back into its cause. Cybernetics discovered that circularity, if modelled adequately, can help us understand fundamental phenomena such as self-organization, goal-directedness, identity, and life in a way that had escaped Newtonian science (Heylighen and Joslyn 2001).
- *Goal-directedness* is perhaps the central feature of autonomous and intelligent systems. A goal-directed system exhibits the ability to manage and regulate perturbations to its internal validity. All autonomous or autopoietic systems have the basic goal of survival, that is, maintenance of their essential organization.
- Cybernetics is *relational*. It looks at systems holistically, at interactions between components rather than the components themselves. While its material practices are important (as will be discussed in a moment) cybernetics is generally concerned with the relation between components of systems, independent of their concrete materiality. This is why high-level concepts such as closure, boundary, hierarchy, variety, control and complexity are used. As I will show in Chapter 3, these relations have a strong component of alterity to them when applied in an interactive arts context.
- Cybernetics features a *constructivist epistemology*. Cybernetic models are generally not passive reflections of reality, but active constructions by the subject. The cybernetic framework sees living systems as complex, adaptive

9 Second-order cybernetics or the "cybernetics of cybernetics" is also sometimes referred to as neocybernetics. For simplicity, and except in instances where highlighting the differences is deemed necessary and appropriate, I will these use the terms cybernetics, second-order cybernetics and neocybernetics more or less interchangeably with the understanding that they mean the same thing within the context of this dissertation.

and entwined in circular relations with their environments. Reality is in a sense co-constructed as way of dealing with perturbations and deviations from a goal state.

Overall, cybernetics can be credited for introducing ideas such as circularity, feedback and self-organization, whether the systems are biological, psychological, chemical, mechanical, social or cultural in nature. These in turn helped spawn or had a crucial influence on much of the work in artificial intelligence, robotics and artificial life. Many concepts central to these fields: complexity, self-organization, connectionism and autonomy, were first explored by cyberneticists during the 1940's and 1950's. Examples include von Neumann's computer architectures, game theory, and cellular automata; Ashby's and von Foerster's analysis of self-organization; Braitenberg's autonomous robots; and McCulloch's artificial neural nets, perceptrons, and classifiers (Heylighen and Joslyn 2001). Ideas from cybernetics are also used within the burgeoning field of complex adaptive systems and research in the natural sciences such as dynamical systems and catastrophe theory. Finally, as will be made clear later in this dissertation, cybernetics, with its focus on goal-directed, purposive behaviour, circular causality and emergence, is also well suited for the analysis of the emergent arts, as these works are essentially cybernetic art systems whose emergent relations unfold in complex patterns of purposive action and behaviour.[10]

2.5.2. The Cybernetic Ontology

The relationship of cybernetics to the emergent arts (and the arts in general) can perhaps best be understood via a consideration of the cybernetic ontology. There is much theoretical and highly abstract theorizing by both scientists and humanities scholars who utilize a cybernetic frame in their work (some of which have already been discussed and some which will be discussed as we move forward). These theories present us with a picture of the world that is always in dynamic flux, enacting varied forms of complexity and heterogeneity, a world to which we are deeply embedded. Yet, although they present us with a world far different from the one given to us by classical

[10] For expediency and simplicity I will often use the term “intelligent systems” or “autonomous systems” to describe more modern system implemetations that while deriving from cybernetic concepts are not strictly cybernetic per se (or at least not modeled as such).

Newtonian science — often by stressing the situated and embodied context of cognition and perception — they do so, for the most part, in a theoretical way. With notable exceptions (some of which are discussed later in this dissertation), abstract ideas are presented but rarely enacted and made relevant to everyday experience. As already mentioned, interactive arts helps to partially fulfill this role. Although the connection between cybernetics and interactive arts practice was briefly introduced in section 2.2, I would like to solidify it here with an overview of the cybernetic ontology.

I focus here on the work sociologist, philosopher and historian of science Andrew Pickering and his analysis of a particular strain of cybernetics. Far from the cold science of authoritarian control that seems to be its enduring image, cybernetics for Pickering presents a vision of the world far different from that of mainstream science and engineering. Pickering offers us an alternative cybernetics. His historical analysis of the work and life of six British cyberneticists details their far-reaching influences and how their work contrasts from mainstream science and AI (Pickering 2010). Pickering's interest is not so much on the ideas of cybernetics but its "ideas as engaged in practice" (4). His focus is on the often strange and captivating real-world projects created by these men; work that "document[s] what cybernetics looked like when people did it, rather than just thought it" (4). This sets up Pickering's core argument that cybernetics presents us with an ontology that is strange and very different from the one modern science presents. For Pickering, the ontology of cybernetics is a "nonmodern", "nondualist" one; nonmodern in that it understands science and the world through performative engagements rather than representations and nondualist in that it refuses to make a sharp distinction between people and things. Cybernetic projects function as what Pickering calls "ontological theater", staging a vision of the world as one of continuously interacting dynamic systems. The vision of cyberneticists such as Pask, Ross Ashby and Stafford Beer, is of manifesting concepts and theories through practice and through knowledge and meaning generation that is situated and contingent. This alternative cybernetics has resonance with interactive arts as described by Burnham and Ascott, as well as with phenomenology and with the interactive artworks featured in this dissertation.

2.5.3. Autopoiesis and Enaction

With this view of the cybernetic ontology as a backdrop we can now consider certain specific cybernetics-based ideas that lend weight to the framework proposed in this dissertation. A good place to begin is with the innovative and important work of Francisco Varela and the enactive view in cognitive science, as it has the most resonance with the references discussed here (Merleau-Ponty's phenomenology in particular). Varela and his collaborators have argued for a radical change in the way the cognitive sciences approach the study of mind (Varela, Thompson, and Rosch 1992). This is exemplified in their development of a framework that blends cognitive science and Buddhist meditative traditions, with an orientation founded on the writings of Merleau-Ponty. They argue for cognition to be understood as an emergent process that takes place via an organism's active engagement with the world. Their term "enaction" describes an embodied cognition where the nervous system links with the sensory and motor capabilities of the organism to connect that organism to its environment, a process (taken from autopoietic theory) called "structural coupling". This places physical action as the cornerstone of cognitive development. The mind is viewed as an emergent autonomous network whose existence and knowledge generation is inseparable from its body. Our capacity for understanding is thus rooted in our biological embodiment.

Thompson and Varela's work on "radical embodiment" (Thompson & Varela, 2001) extends the work on enaction by combining the tools of dynamical systems theory and phenomenology for understanding transient brain patterns. They argue that brain-body-world divisions are in essence nonexistent with regard to consciousness and thus cannot be understood as only occurring in the brain. Because of this deep enmeshment, they argue that conceptions of brain, body and environment should be viewed as "mutually embedded systems rather than as internally and externally located with respect to one another" (423-424). The establishment of links between direct subjective experience (phenomenology) and dynamical systems that Thompson and Varela offer (or at least hint at), suggests a rich set of theoretical tools from which to explicate the operative principles of experiences that enable a sense of the "enmeshment" of humans and intelligent technological systems. The concern here of course lies in establishing links with regard to artistic experience. This will be taken up in chapters 3 through 7.

Thompson and Varela's radical embodiment and much of the enactive paradigm can trace their origins to the concept of autopoiesis (Maturana and Varela 1980; Maturana and Varela 1992) — which Varela describes as "a characterization of the mechanisms which endow living systems with the property of being autonomous" (Varela 1981, 14). Autopoiesis or "self-production" defines living systems as self-contained, self-referencing and self-realizing autonomous entities that arise out of certain circular and reflexive processes. Cognition in turn is defined by the fact that the process of living is in fact a process of cognition. These processes are what account for the unique nature of living systems, or what Maturana and Varela call "autopoietic unities". Unlike other definitions of life that primarily propose a list of properties, living systems as defined by Maturana and Varela are essentially self-producing machines and life is defined as an emergent property of autopoietic systems. Structural coupling, a core concept within autopoietic theory, helps elucidate how living systems exhibit emergent properties such as autonomy via cooperative self-organizing actions with other living systems and with their surrounding environment. This aspect of the theory is particularly relevant to this research as it firmly establishes a non-dualist ontology; living systems are not separate and in essence influence and are implicated in one another's development. More specifically, coupling with an environment is not seen as a series of input/output relations (as digital computation suggests) but rather as an ongoing (re)organization of the system in response to environmental perturbations, which circle back and perturb aspects of the environment, which in turn cause new perturbations to the system, and so on.

Although autopoietic theory has been criticized for what some see as its overly self-referential and solipsistic nature (Swenson 1992), it nevertheless has been influential in a wide range of fields such as biology, systems theory, cultural theory, sociology and the arts.

2.5.4. System-Environment Hybrids

The concept of co-evolution offered in this dissertation draws significantly from theories of autopoiesis and neocybernetic emergence. Here we can look at human-machine coupling more specifically. Central here is Félix Guattari's call for a rethinking of the concept of autopoiesis itself (Guattari 2001). Presenting a posthumanist co-evolutionary view that centers around the notion of boundary — specifically what constitutes a topological boundary and how the notion can be understood, Guattari describes possible ways that cognitive functions may be shared between humans and machines. Echoing Francisco Varela's decoupling of closure from autopoiesis (Varela 1981), Guattari argues not for a vitalist conception of machine autonomy but one where we consider their "specific enunciative consistency" (39). For Guattari this necessitates a rethinking of autopoiesis to a conception where boundaries and closure are less stable, dynamic and evolutive. Guattari argues for autopoiesis to be rethought of in terms of a collective autonomy and agency arising from interactions with humans and other machines, which he describes as "entities that are evolutive and collective, and that sustain diverse kinds of relations of alterity, rather than being closed in upon themselves" (42). For Guattari machines need an ample supply of "abstract human vitality" in order to retain their autopoietic viability. Specifically referring to computers and artificial intelligence, Guattari characterizes human thought as part of "the essence of machinism".

Extending Guattari's analysis, Mark Hansen also calls for recognition of the agency wielded by an environment that is becoming increasingly technical and intelligent. He argues that this "complexification" forces us to think of a more provisional and less stable notion of autopoietic closure (Hansen 2009a). Like Guattari, Hansen is concerned with how we might understand notions of boundary, closure and autonomy within the context of a "highly technologized, 'posthumanist world'" (113). He argues for a flexible and adaptive understanding not only of autopoiesis and the concept of closure as originally developed by its authors, but also more broadly, for an understanding of the legacy of neocybernetics itself (which has never really questioned the idea of rigid operational closure). Hansen asserts that the technical sophistication and intensity of our environment has evolved to such a degree that we must pay closer attention to the agency wielded by it (through increasingly technical means). He asserts that the central concern when considering "contemporary environmental complexification" is the "technical distribution of cognition", which he argues is revolutionizing both cognitive science and human experience. Echoing Don Ihde's phenomenological concept of technologies that are experienced as hermeneutic and background relations, Hansen argues that simple day-to-day activities such as paying bills, sending e-mails or checking stock quotes occur against a backdrop of “complex computational infrastructures” (117). This ceding or co-mingling of human agency with a machinic environment, calls for a more provisional, dynamic and ultimately less stable notion of closure, wherein the environment can cross over blurred boundaries and effect change in the organism. Thus, instead of the organism selecting which aspects or perturbations of the environment are relevant to it (as in the more rigid operational closure of traditional autopoiesis), the environment itself can force or suggest certain changes in the organism. This has the effect of engendering a more collective form of agency and thus as a result “human beings must welcome the alterity of machines as a crucial source of connection to a world ever more difficult to grasp directly” (125). Hansen refers to this as a “system-environment hybrid”. The relevancy to interactive art here can best be summed up in Hansen’s assertion that this flexibility and dynamism can open up “new cognitive dimensions, but only when correlated with the most creative, culturally and technologically catalyzed interactional possibilities” (123-124).

2.6. Embodiment, Materiality and Intelligent Systems: Implications for Interactive Art

Many of the artworks discussed in this dissertation are inspired or can be seen as exemplars of this drive for “symbiotic intelligence” between humans and their increasingly technologized environments. Broadly speaking, they concern the coupling of human and machine, sometimes suggesting some sort of “enhancement” to some human faculty. They also employ research methods or are inspired by worldviews that resonate with the phenomenological view that holds that mind, body and world are inextricable. Some are based upon various Artificial Intelligence (AI), Artificial Life (A-life) or cybernetic approaches and techniques such as reinforcement learning (Kaelbling, Littman, and Moore 1996), and “bottom-up” robotics (Brooks 1986; Brooks 1990; Brooks 1991). Others draw from cybernetics, particularly the work of cyberneticist Gordon Pask (Cariani 1993; Pask 1971; Pickering 2007). Others still are based upon some form of direct contact with the body, such as the sensory substitution techniques pioneered by Paul Bach-Y-Rita (Bach-y-Rita 1972; Kaczmarek et al. 1991), particularly those that involve human-machine interfaces (Bach-y-Rita and Kercel 2003). While entire fields of intelligent systems or biomedical research are not covered here, this section outlines the practical and conceptual implications of these techniques and approaches for the artworks developed in this dissertation. After a brief historical overview of human-computer coupling research, this section is divided into two parts. The first discusses intelligent systems, while the second discusses specific techniques used in the construction of the interactive artworks featured in this dissertation. Collectively, they serve as the most important and relevant technological aspects of this research.

2.6.1. Human-Computer Coupling: Historical Context

The modern vision of human-computer coupling can be traced to Manfred Clynes and Nathan Kline's article "Cyborgs and Space" (Clynes and Kline 1995). Clynes and Kline discuss the challenges posed to human physiology by the demands of space travel and deploy the term "cyborg" or cybernetic organism. Through this term, they describe their vision of how humans merge with machines to create self-regulating human-machine systems that would be able to adapt and survive in outer space and extraterrestrial environments. They define cyborg as an "exogenously extended organizational complex functioning as an integrated homeostatic system unconsciously" (30) and go on to discuss physiological and psychological problems involved in space travel and how a cyborg may adapt to these potential problems better than a standard human. As a provisional example of a cyborg, Clynes and Kline point to an osmotic pressure pump developed by S. Rose that injects chemicals at a slow, persistent rate without any attention by the organism (a laboratory mouse).

Around the same time as Clynes and Kline's article, JR Licklider put forth a radical vision (at least by 1960 standards) of human-computer coupling. He describes his scenario as a "symbiotic partnership," where human cognitive functioning is shared with machines (Licklider 1960). The aim is for machines to aid humans in (1) formulating solutions to problems that are too difficult for humans to do alone and (2) trying to think in "real time" (this kind of computation of course being impossible in 1960). The hope for Licklider was that this would lead to greatly enhanced abilities in thinking and decision-making for both humans and their machine collaborators. He then provides suggestions as to requirements and prerequisites for making such a symbiosis a reality. Practical issues such as memory requirements and appropriate input/output and display equipment are discussed.

In a similar fashion, R.M. Page, in a short thought experiment, offered a vision of intelligent machines whose coupling with humans is so seamless that each would not only cooperate with the other, but would in a sense realize itself through the other, thus enabling better communication, both human-to-machine and human-to-human (Page 1962). A prelude to the fields of affective computing and HCI, this ability of the machine to "enhance human capabilities" would, in Page's view, take the form of communication via bodily gestures, breathing rate, skin resistance and the like. The machine would be able to discern the human's emotional states, thus enabling communication "beyond words and pictures".

While these beliefs in control theory or the ideas of the information theory strain of cybernetics as the "solutions" to enhancing human intellect and potential via machine integration have only been partly fruitful, they nevertheless serve as inspiration for continued experimentation and reflection on what our relationship to technology is or can be. They also signal the dawn of the posthummanist vision, where human beings are no longer the dominant species on the planet, but must share that honour with the intelligent machines they have created; a realization ballasted by the fact that intelligent machines are now superior to humans in their ability to manipulate and store information. Thus, the general concept of humans and machines working together to solve problems dynamically and interactively — in essence forming "symbiotic partnerships" — continues to be a powerful, seductive and frightening idea.

2.6.2. Intelligent Systems

Defining Intelligence

Intelligence is something of contested term. With regard to a symbiogenic experience, we must ask what the machine side of the cybernetic equation is. How do intelligent systems co-evolve with us? How does one account for machine "agency"? To answer these questions, I must first state that my operating assumption is that intelligence can only emerge from situated, "real world" interactions between complex systems (such as humans and machines) and their environment. Intelligence is not an innate property; rather it emerges from the autopoietic processes of a particular system. Thus, any "definition" must take into account this notion of intelligence as relative and contingent. These were once radical assertions in the artificial intelligence community, but are now more commonly accepted (Brooks 1986; Brooks 1990; Dreyfus 1992).

While artworks utilizing artificial intelligence, artificial-life and similar approaches play an important role in this dissertation, their context lies within larger practices of art and technology. Within that larger context is where we can understand the theme of this dissertation, which lies in the examination of artworks that provide a sense of embeddedness and co-determination with an increasingly intelligent technological environment. From a practical standpoint, an intelligent system that is part of or constitutes an artwork need only be understood as having some sort of ability to sense its environment and "know" when its internal states have changed in response to certain environment factors. It should also be capable of some sort of autonomous action. That is, its behaviour should be determined to a certain extent, by its own experience in the world (rather than being based completely on built-in rules or knowledge). Ambiguities or inconsistencies need not be a problem, and in fact in an art context are often assets. Art will do what it always does — exploit the shifting and sometimes contested nature of culture (particularly with regard to technology) to take one out of their customary zone of expectations.

Still, some basic working definition seems called for. While this will take form as I proceed through this dissertation, what I can say here is that I take the cybernetic conception of intelligence rather than that of mainstream artificial intelligence.[11] I argue that intelligence resides not in the formal manipulation of symbols but rather in complex observed interactions. Intelligent systems do not map external objects to internal states (i.e. what is commonly referred to as representations) but rather map through an environment that then feeds back onto the systems themselves — a dynamic of circular causality. Systems produce adaptive relationships rather than store information. Reality is in part constructed, and is not simply "out there", waiting to be recovered. This requires a certain level of cooperation, agreement and shared meaning that arises

[11] From a historical perspective AI is sometimes conflated with cybernetics. Paul Pangaro (2006), a student of Gordon Pask, eruditely explains how although AI may have borrowed some ideas from cybernetics the two arose from very different philosophical and methodological foundations. For more see http://www.pangaro.com/published/cyber-macmillan.html

through conversational interactions rather than from static elements stored and recalled from a computer. Intelligence then, resides in these conversational interactions. Following from this, what we call knowledge and objectivity arises from shared agreements about meaning. These are not commodities that can be symbolically stored inside of an "intelligent" machine.

Critiques of AI and A-life

These definitions of intelligence are part of a larger context of critiques of AI and A-life. From within the arts, artist Simon Penny argues that we must recognize that any intelligent system or intelligent agent is culturally situated (Penny 1997). Penny states, "it is a fallacy to assume that the characteristics of an agent are in the code and are limited to what is explicitly described in the code. In fact, the opposite is much closer to the truth" (105). There is no culturally neutral technology. Intelligent systems are cultural products that affect our perceptions. Phoebe Sengers and Allison Adam bring this into greater focus. Sengers notes how construction of the cyborg — a term she uses to vaguely refer to intelligent robots which she calls "the alter ego of the computer" — had its existence already circumscribed before it was even built (Sengers 1996). With regard to symbolic AI, Sengers argues that because of an over-reliance on scientific rationality, the cyborg was unable to function properly in the world, suffering from a kind of schizophrenia. With regard to A-life, Sengers argues that schizophrenia was built right into a-life agents and that their failure is due, not to an over-reliance on rationality but because of an overabundance of behavioural modules. Thus, Sengers claims that both methods share a "mode of breakdown" that stems from a shared methodology that is itself a product of the cultural context that both function in. In fact, she claims that both approaches are rooted in Taylorism and are merely a more contemporary instantiation of industrial rationalization. Adam, an expert in the field of AI, describes how gender is inscribed into AI systems and challenges the male-dominated forms of knowing present in the field (Adam 1998). Drawing significantly from feminist theory, she provides a brief history of symbolic AI and shows how these gendered forms of knowing were embedded in the field from the very beginning. Adam also explores how knowledge is represented in symbolic AI systems and how this reflects gendered patterns of rationality.

Perhaps the most famous critique of AI however is that of philosopher Hubert Dreyfus. Drawing from the writings of Heidegger and Merleau-Ponty, as well as research in linguistics and the neurosciences, Dreyfus describes how disembodied machines have an inherent inability to mimic the higher mental functions of human beings and why the attempts of AI researchers to build machines that would equal or surpass human intelligence will ultimately fail. Dreyfus shows how the field is riddled with assumptions about human intelligence such as assumptions about the brain as a device that process bits of information (with neuronal spikes being analogous to bits), to assumptions about knowledge itself can be rigidly formalized in to sets of rules that define and describe human behaviour. Dreyfus's work was widely scorned within the AI field initially (though secretly widely read as well). Today, it is credited with influencing or inspiring the rise of "Heiddegerian AI" and other forms of "embodied" AI that arose to take the place of the GOFAI (Good Old Fashioned AI) that Dreyfus was critiquing.

Intelligent Systems as Co-evolutionary Agents

The use of AI and a-life techniques in the arts has yielded a rich and diverse set of artworks since their earliest iterations in the 1950s. There is an inherent strangeness and ambiguity to these technological systems. They behave quite unlike any technological systems we are accustomed to, often exhibiting autonomy, life-like behaviour and at least the appearance of intelligence or sentience. In addition, from an artist's perspective, the utilization of intelligent systems in the services of creating artworks or artistic tools that are capable of intelligent and/or autonomous behaviour offer the artist virtually unparalleled freedom to explore creative space by granting the system a certain amount of agency over the form and evolution of the work. Many intelligent artworks explore varieties of emergence, as well as themes of co-evolution with technology. As this dissertation explores how humans and physically situated autonomous technological systems may co-construct and co-evolve with their environment through their interactions, this section will provide a brief overview of AI and a-life techniques I have explored in my research and artistic practice as well as themes and concepts of emergence and co-evolution within the field itself.

The notion of intelligent systems co-evolving with their environments is a relatively recent development, founded upon links between AI and the enactive paradigm in cognitive science. De Loor, Manac'H, & Tisseau (2009) survey both fields and offer critiques of how models and simulations of autopoiesis (the roots of the enactive paradigm) are often lacking key elements. Their central critique is that these research programs can benefit from approaches that focus more on the co-evolution of system and environment. With this as context, the authors propose their approach, which (like autopoiesis and enaction) calls for explicitly integrating — with a high degree of granularity — the evolution of the environment. They consider how this then influences the functioning of the system (causing it to adapt), which in turn influences the environment in new ways. The system and environment thus co-evolve. Their most significant proposal with regard to this dissertation is that for the artificial system to create relevant meaning, humans must be in the co-evolutionary loop, with meaning emerging (evolving) through cooperation and situated, embodied interactions with a human observer.

Although they do not consider the role of embodiment or subjectivity, Johnson et al (1998) argue that the interaction of humans and technology occurs within the same dynamical processes inherent in both the social and biological evolution of self-organizing systems, and suggest that a symbiotic relationship is developing between the two. Presented from an artificial life and complex systems perspective, they argue that the Internet is the primary vehicle for the next stage in our social evolution. This symbiotic social evolution is made possible, the authors say, through the combination of the unique capabilities of humans and their coupling with the Internet. The combined capabilities go beyond previous human-technology systems and can lead to a symbiotic form of knowledge development. Thus the central claim is that through the increased use of the Internet, the self-organizing social capabilities of humans will operate at a "significantly enhanced functionality".

Like Burnham the authors use the term "symbiotic intelligence" to describe their scenario. Their model draws somewhat from Pask's Conversation Theory.[12] The basic idea of knowledge as emergent and contingent upon interaction between "knowers" — coupled with the notion of systems that evolve in response to user activity — can be

[12] See (Rocha 2001, one of the co-authors of the Johnson, et al. paper) for an extension of Conversation Theory that can be described as system designed for "symbiotic intelligence".

seen as a sort of collective emergent and *symbiotic* form of knowledge development. Human interactions with intelligent systems, when looked at from a broader "meta-system" (e.g., humans and intelligent systems as one system) may be said to form a sort of "swarm intelligence". This of course could have enormous ramifications for the cognitive evolution of humans and thus is highly relevant to any theory of art and aesthetic experience or theories dealing with human-technology relations.

Though compelling Johnson et al's model does not account for the situatedness of human intelligence as does for example reinforcement learning and Rodney Brooks' subsumption architecture (Brooks 1986), and by extension certain cybernetic ideas.[13] Though he does not argue for the idea of human-machine co-evolution, Brooks critiques the heavy reliance on representations in AI research (representation in this context referring to the construction of a static, centralized, "pre-given" model of the environment). He asserts that this over reliance leads to brittle systems than are unable to adapt to a complex environment. For Brooks, intelligence is as a product of an agent's interaction with its environment. This approach and in particular the one advanced by De Loor, Manac'H, & Tisseau each have a natural resonance with art-making and phenomenology and therefore I believe, to any form of a symbiogenic experience.

2.6.3. Organic Alternatives to Digitally-based Intelligent Systems

Perhaps the first artificial intelligence system was not so "artificial". In the late 1950s, cyberneticist Gordon Pask constructed several electrochemical devices that were capable of growing their own sensors (Pask 1960; Cariani 1993). These systems, which Pask referred to as "organic computers" (in reference to their quasi-organic properties), possessed emergent properties that enabled them to develop their own "relevance criteria" (i.e. perceptual categories/features). In other words, they literally evolved their own sensors and effectors as a form adaptation to environmental conditions. Pask's assemblages consisted of sets of electrodes inserted into a dish of an aqueous metallic salt solution (i.e., ferrous sulphate or stannous chloride) and connected to a current-limited electrical source. By passing current through the electrode array, dendritic

[13] Rodney Brooks has stated that he found inspiration in cyberneticist Grey Walter's robotic "tortoises". See (Pickering 2010) for more.

metallic threads would form. These threads had low resistance relative to the solution and thus their growth was reinforced if current was continuously applied. The electrical potential of the electrodes were then modified by the formation, bifurcation and/or disintegration of threads. Pask experimented by sending the assemblage sound that was being picked by a microphone pointed outside of a window of his London flat. Within a few hours the assemblage had "grown an ear", meaning the threads had adaptively grown to become sensitive to sound (and magnetic fields):

> "We have made an ear and we have made a magnetic receptor. The ear can discriminate two frequencies, one of the order of 50 cycles per second and the other on the order of one hundred cycles per second...The ear incidentally, looks rather like an ear. It is a gap in the thread structure in which you have fibrils which resonate at the excitation frequency" (Pask 1960, 261).

Pask pointed out that since the thread growth can itself influence current densities throughout the solution, any thread structures present at a given point in time will influence the plasticity of the assemblage. Thus, the prior activity and configuration of the system affected how it handled changes in its environment. In essence the system had the capacity to learn.

This work was largely forgotten until 1993, when Peter Cariani published a very insightful essay as part of a festschrift for Pask (Cariani 1993). Pask of course was not the only one working on developing electrochemical devices (Barton and Bockris 1962). Although he was perhaps the only one concerned with their self-organizing properties. Pask's colleague and close friend Stafford Beer was also attempting something similar. His approach entailed using small organisms such as the water flea Daphnia and the single-celled Euglena (a type of protozoa) (Pickering 2010, 231ff.). As digital computing began to take hold, much of this work seems to have been forgotten. Still, we can see echoes of this today both in engineering and scientific research as well as interactive arts. We see it in robots that are controlled by slime mould (Tsuda, Artmann, and Zauner 2009; Tsuda 2009) or cultured rat neurons. *Biopoiesis* is based on Pask's electrochemical experiments but it is not the only one. Artists Roman Kirschner (2005) and Andy Webster (2010, 220ff.) have also reproduced Pask's electrochemical experiments to some degree. From an arts perspective, what we see in this "Paskian" approach is a means of understanding nature and our relationship to it by looking through the other end of the telescope as it were. Not by establishing elaborate rule-based systems and seeing which one is the way the world actually works, but by focusing on the unpredictable properties of the world that these rules-based systems attempt to model and realizing that the “rules” are perpetually in flux. This is what Andrew Pickering calls “ontological theatre” when referring to Pask’s work (and that of other cyberneticists) (Pickering 2010; Pickering 2007). They showcase a vision of the world as a “lively place of performatively interacting and endlessly emergent systems (of which we humans are just one sort)” (Pickering 2007). For Pickering Pask’s art projects and electrochemical experiments offer a vision of the world as arising from active, varying associations between autonomous dynamic systems — what Pickering calls “open-ended performative interactions”. Pask acts out this “nonmodern ontology” — performing it as it were — by letting it loose in the real world to enact its “dance of agency”. In *Biopoiesis*, system and environment co-evolve or are structurally coupled, implicated in each other’s development. Computation and self-organization is not abstracted from the world but is a quasi-organic process that is co-evolving and co-determined with its environment. One can understand it as an outside observer while still influencing it (what Pask calls a “participant-observer”). The work also has the experiential and pedagogical advantage of concreteness. It “grounds us in the realm of the sensuously apprehendable material world” (Cariani 1993, 30). We experience this system-environment co-determination in a very direct way. As I will argue later in this dissertation, sensuously apprehending and experiencing the self-organizing, emergent processes of the work grounds us in the material world and its ambiguous complexity, and may lead to shift in intentional awareness.

2.6.4. Electric Body Stimulation and Sensory Substitution

The pioneering sensory substitution work of Paul Bach-Y-Rita (1972) serves as a valuable reference and background for the design of one of one of the artworks in thesis dissertation *Protocol*. More broadly, sensory substitution (at least the way I am using it) can be seen as related to electric body stimulation, which has an established history within the arts (Elsenaar & Scha, 2002). Stelarc and Stahl Stenslie being two notable contemporary examples of artists who have used these techniques.[14] Sensory substitution is defined as the mapping of one sensory modality (e.g. vision) into another (e.g. touch). Most commonly utilized to help patients lacking a sensory modality, sensory substitution devices present visual or auditory information across the skin via electrical pulses or vibrations caused by motors or solenoids, thus enabling someone to “see” or “hear” with their skin (Kaczmarek et al. 1991). An early example of such a device was developed to help profoundly deaf children “feel” the sounds of their own speech (F. Saunders, Hill, and Franklin 1981). The device displays sound frequencies as touch patterns on a belt worn around the trunk. Dubbed the Teletactor, this device analyzes the frequency and amplitude of the speech sounds received and translates them into electrical patterns that the patient/user can feel and thus learn to associate with the sounds, in a sense learning the “feel” of the speech. This device, as well some of the electro-tactile techniques for transmitting information across the skin detailed by Saunders (1983), serve as inspiration for the tactile communication system in *Protocol*. Recent innovations in electrode technology has also allowed for the transmission of high-resolution visual (and other) information into an area as small as the tongue (Bach-y-Rita et al. 1998). In addition, more sophisticated human-computer interface techniques and technologies have also been developed that have presented new opportunities to develop systems with increased portability and flexibility (Bach-y-Rita and Kercel 2003).

2.6.5. Biofeedback and Physiological Monitoring

Many artworks, including two of my own experiments mentioned in this dissertation (*Body Daemon* and *Naos*), are based upon biofeedback or some sort of physiological monitoring. Most of these pieces require some form of interaction or participation. Here, the participant typically affects the visual or sonic elements via some form of novel interface such as motion or gesture. In *Biomorphic Typography* (Gromala 2003), Diane Gromala created a set of typographic fonts that continuously morph and evolve in real-time based on a participant’s physiological states. Font’s “throb” in response to heart rate and expand and contract as the participant breathes. *Divided By*

[14] See Stelarc’s *Ping Body/Amplified Body* performance events (1996) and Stahl Stenslie’s *inter_skin* (1994).

Resistance (Gilchrist and Bradley 1996), a performance/installation by Bruce Gilchrist and Jonny Bradley featured the real-time brain wave output of a sleeping performer. The signals were analyzed and used to “remix” videos and narrative text. Participants could also communicate with the performer by administering a series of codified questions and statements in the form of mild electrical stimulation. *Whisper[s]* is a collaborative project led by Thecla Schiphorst where physiological data is mapped to collective network visualization and sonification and physiological data is exchanged between participants (Schiphorst 2005). In the field of electronic music, David Rosenboom (1976) and Eduardo Reck Miranda (Miranda and Wanderley 2006) have investigated the use of physiological signals as musical interfaces. Miranda includes the use of machine learning techniques to analyze the bio-data.

Common measurements utilized in biofeedback and physiological monitoring contexts include heart rate, galvanic skin response, brain waves, facial tension and patterns of bodily movement. It must be understood that biofeedback-based artworks cannot be divorced from the scientific and medical fields from which they draw. Physiological monitoring has only become an established field of its own within the latter half of the 20th century. Its emergence as field is best understood as a convergence of numerous research areas including psychophysiological, behavioural medicine, cybernetics and many others (Schwartz and Olsen 2005). Human physiological processes and techniques for the proper monitoring and recording of them are well understood (R. M. Stern, Ray, and Quigley 2001). Their subjective correlates however are not. The field of Affective Computing (Picard 1997), attempts to develop systems and quantitative models for the recognition of human emotion, affect and other subjective factors. Typically, this involves some form statistical modeling and classification and measures various physiological parameters that often provide cues as to one’s emotional state. Generally, the goal of this field is to develop systems that can better serve humans by sensing how they are feeling at a particular moment, thus better anticipating their needs. While most biofeedback-based artworks also deal with subjective elements like emotion and affect, others (such as *BodyDaemon* and *Naos*) also raise questions about the legitimacy of the systematic and institutionalized use of these often intrusive technologies as well as critically exploring the body and its role in political agency and as a communications medium.

2.7. Summary: Conceptual Framework

This chapter has proposed a conceptual and critical framework for the development and evaluation of my theory of symbiogenic experiences. Beginning by defining co-evolution and symbiogenesis, and using it as a metaphor or point of departure, I have drawn from varied perspectives in order to weave an account of symbiogenic experiences in the interactive arts. Interactive Arts have often advanced themes of co-evolution, symbiosis or “structural coupling” with technology and this analysis constructed via the interlocking frames of interactive arts, existentialist phenomenology (particularly that of Maurice Merleau-Ponty), posthumanism, cybernetics and the cybernetic ontology of emergent becoming in order to weave an account of the range of experiences that I am calling symbiogenic. I also draw from various technical approaches in my art practice such as machine learning, sensory substitution and electrochemical computing. I have provided an overview of these techniques and their relevance to this research.

As will be further explicated as we proceed, these sources collectively encompass the foundation of what I describe as a co-emergent and co-evolutionary ontology and serve a framework for understanding emergent arts practices and their phenomenal impact for the embodied self and its intrinsic quality of embeddedness and intertwinement with in an increasingly complexified and technologically intelligent world. The proceeding chapters will show how aesthetic experience may serve as a means to expand awareness of our technologically-textured world so as to make this embeddedness and intertwinement perceptible to us on some level.

3. The Emergent Arts

This chapter introduces a taxonomical model that outlines a number of characteristics of new media and interactive arts practice that engage in processes that establish a foundation for the shifts in perceptual and embodied experience that I characterize as symbiogenic. The aim of this chapter lies in providing an overview of the field, and a context for evaluating individual artworks. The aim is not to delineate a broad, exhaustive survey or history of interactive/new media art but simply to propose some critical points of interest within the genre that I believe coincide with themes of reciprocal interplay (and co-evolution) of humans and intelligent systems and give an intuitive sense of connection or enmeshment with an increasingly intelligent technological environment. A number of examples will be selected to illustrate this drive for "symbiotic intelligence" between humans and their increasingly technologized environments that is characteristic of these arts practices. These works engage in similar processes and approaches to the artworks documented in Chapters 5-7 and form the basis for understanding symbiogenic experiences. I refer to this range of works collectively as the "emergent arts".

To further clarify what I mean by emergent arts, we must look at interactive art more broadly. What is it about interactive art in particular that can give rise to a heightened, transformative sense of co-evolution with an intelligent technological environment? While the general conception is that interactive art offers levels of gestural and immersive interface to technological systems heretofore unparalleled, others have given a more nuanced theoretical account of its uniqueness. From Pask's ambiguity of role to Burnham's symbiotic intelligence, to Hansen's embodied technicity and technogenesis — what these all have as a basis is a conception of interactive art as machines or systems that exhibit a certain level of agency, novel forms of animism, autonomy and even raw information processing power (which may sometimes be interpreted as form of agency or even intelligence).

The works discussed here are analyzed not so much according to their respective mediums or technologies. Rather from within a necocybernetic context — which can be characterized as relational and holistic — the focus will be on elucidating and examining the *relations* the works bring forth, as well the aspects of experience they emphasize, whether it is interaction, reflection on materials or the cybernetic processes themselves. As mentioned in section 2.5, cybernetics is characterized by a greater interest in relations among components over interest in the components themselves. However, cybernetic ideas are often bound up with concrete material practices that highlight what Andrew Pickering calls its "ontology of unknowability" (Pickering 2010). This picture of a world that is always in dynamic flux, enacting varied forms of complexity and heterogeneity, may best be sketched out, I argue, via the emergent arts practices outlined in this chapter.

These works then cannot be defined simply by listing a set of characteristics (and in fact works in one category may share many characteristics with those in other categories). Instead, they must be considered holistically, where global "top-down" patterns of relations provide context for the experience of sensorial or interactional modalities that may arise from "bottom-up" processes. Thus, an interactive sound piece that responds to ones presence and motion as in David Rokeby's *Very Nervous System* exhibits a quite different set of holistic patterns of relations than another interactive sound piece that responds to ones presence and motion: Usman Haque's *Evolving Sonic Environment*.

What is important here is thinking less in terms of what these works are and more on *what they do* (Greene 2010). This sense of agency and **autonomy** that these works engender and showcase is the foundational element to what I maintain is the most crucial aspect that distinguishes what I call the emergent arts from other interactive arts practices: the evolving sets of *emergent relations of agency and alterity* that unfold in these works — characterized here as co-evolutionary — that give rise to an experience that I describe as symbiogenic. These experiences are often ambiguous, requiring the exploration and evolution of shared meanings. I have referred to this elsewhere as an enacting of difference or "heterogenesis" (Castellanos, Gromala, and Pasquier 2010). This is where the emergent arts set themselves apart as a distinct form of interactive art experience. What is equally attractive and compelling in these works is not only the “systems approach to creation” that Ascott describes, nor their abilities to expand human consciousness and transform our experience of the world and of our being within it by encouraging us to enter into states of mutual influence with them. Rather, like 2nd-order cybernetics and its concern with observing systems, autonomy, **self-organization** and **emergence**, the emergent arts are reflexive and self-referential, as they often explore, examine or critique the very technologies used in their making. The emergent arts typically do not marshal interactive techniques in services of more “traditional” arts practice such as narrative, emotional evocation via raw sonic or visual power or some external subject matter (at least they do not *only* do that). Emergent art systems are on some level, about the systems themselves, often of their ability to exhibit a capacity to self-organize and to simply *be*, to exist and get on in the world. As such, they often thematize or are characterized by interactions and behaviours that give rise to co-evolutionary experiences. These works thematize a coupling with their environments, not simply through a series of input/output relations but as an ongoing (re)organization of the system in response to environmental perturbations, which circle back and perturb aspects of the environment, which in turn cause new perturbations to the system, and so on. Cybernetic indeed.[15]

It is also important to state that regardless of the **ontological** basis from which they derive, computational, intelligent and organic or quasi-organic systems, like art, create and engage in complex relationships between inside and outside, body and world, system and environment. They are not merely representations of an “outside” world but are part of that world and its phenomenal constitution. Thus, it should be said that these works are not cold detached representations of generative or complex process but instead materially encompass and generate those processes as a matter of their concrete configurations. Like phenomenology and enactive cognition, these works challenge traditional dualisms by fomenting a perceptual and conceptual self-organization that involves an integration of brain, body and environment. The material and embodied dynamism they exhibit helps to showcase the cybernetic-enactive idea

[15] Many of the works discussed here could simply be labeled as AI, a-life or generative art works. However, I maintain that it is more appropriate to rely on cybernetic and neocybernetic models and concepts as they are broader and encompass ideas closer to those explored by the artists, while not being tied to particular techniques or technologies.

that concepts (such as emergence, and **co-evolution**) are not merely cognitive, that is they are not simply stored in our heads as part of higher order process cut off from the world. Rather they exist as part of complex, interrelationships with bodily process and material anchors in the external world, forming what philosopher Andy Clark (2003) suggests is an extended cognition, a cognitive-technological scaffolding involving "loops and circuits that run outside the head and through the local environment" (Clark 1998, 206–07). These works not only function as aestheticized/amplified versions of those anchors, they help to phenomenally amplify the dynamics they, as anchors, are a part of. With this in mind we can say that merely simulating complex emergent process visually or sonically on a digital computer does not in and of itself constitute emergent art as I conceive it. Rather, it is differing relations of adaptation and unpredictability relative to complex and dynamic environmental conditions that form the conceptual dynamics that make up the experiential "DNA" of the emergent arts.

Extending these ideas we can also think of processes of conceptualization, production and contextualization of emergent artworks as self-reproductive processes, autopoietic (i.e. self-making) systems that necessarily depend upon artistic (inter)action in the broadest sense. Thus, discussing propositions of emergent artworks as potentially cybernetic and autopoietic hinge upon the depiction of their **boundaries**, **circularity**, autonomy and adaptability. This is why the emergent arts model proposed here is founded upon an approach to interactive arts analysis that draws significantly from cybernetic perspectives. Approaching analyses this way helps to account for the art produced, the ideas put forth, the processes by which the art and ideas were produced and the participating observers, which includes audience and artist.[16]

The analytical model of emergent arts practice presented here posits a concentration across four key areas. These areas also simultaneously function as taxonomical categories that describe the types emergent artworks. Thus, all emergent artworks can be analyzed across these four areas but can be said to loosely fall into one

[16] In conjunction with phenomenlogical analyses, this cybernetic approach will also be used in the next chapter to account not only for technical, aesthtetic and experiental aspects of the works but also for the work produced and the realtionship between observer-particpants, which includes the artist(s) in the act of making, experiencing, and observing the work. For more on this approach to interactive art see (Lautenschlaeger and Pratschke 2011).

these four areas as overlapping categories. This analysis simultaneously looks at how these pieces do what they do but also emphasizes that what is unique about them is that they all *do* specific things — some of course more than others — that warrants their taxonomical categorization. For example all works can be analyzed according to their organic and/or material properties but only certain works can be categorized as "organic", since they deploy their materials to such a degree or in such a novel way as to make that a focal point of the piece. With this in mind, the four areas/categories are:

- **Interaction/Conversation:** Emergent artworks engage in conversational interactions. The focus of analysis here is on how we interact and/or engage in conversation (in the Paskian/Cybernetic sense) with a piece. How each responds to the other.
- **Material/Organic:** Emergent artworks often deploy novel or untraditional uses of materials, often employing some kind of organic or quasi-organic complexity and dynamism. The focus here is on the material substrate(s) of the work, particularly in cases where this aspect of the work is at the forefront or is important in establishing a context for the experience of it. The material complexity and dynamism of a piece is the focus here.
- **Process/Emergent:** Emergent artworks, as the name implies, are emergent. They foreground emergent processes or thematize emergence in some way. Here, we focus less on the material instantiation or interactional modalities of a work and instead focus on the emergent processes they foreground.
- **Context/Inquiry:** Emergent artworks are often forms of reflexive inquiry or research and not simply a form of expression. Here we look at how a piece is contextualized with regard to its stated subject of inquiry.

It should be said that in most cases there is no doubt a considerable overlap between these categories. They are not mutually exclusive. Works can be placed into more than one (perhaps even all) categories depending on the conceptual framework employed.

3.1. Interaction/Conversation

Interaction in emergent artworks is, in a sense, about constructing and articulating the conditions for emergent relations of alterity. This brings up questions of what exactly is meant by "interaction". We saw in Chapter 2 that interaction may be seen as not only tied to notions and processes of emergence but also to those of conversation

— defined here (in the Paskian/Cybernetic sense) as action grounded constructions of shared meanings — as well as notions of “ambiguity of role” and relations of autonomy and **control**. While the technologies and interactional modalities deployed may differ, the overall experience of these works may be regarded as being continuously self-recreating throughout ones encounter(s) with the work. Experiences where there is novelty, in which no participant has formal control (in the vernacular sense) over the proceedings. Boundaries (in the autopoietic sense) are being dynamically negotiated and perhaps reconstructed. Structurally speaking, the interactive/conversational aspects of emergent artworks — that is, the circular relations between the system and its environment (which includes sensorial feedback loops with human observers) — must be taken into account if we are to understand what actually constitutes a work as interactive and emergent as such.

With this in mind we can begin to look a bit more at the specific implementations of these relations. Two general categories of interaction modalities have been identified:

> **Direct bodily:** Artworks that feature a directly physical or embodied form of interaction.
>
> **Perturbations:** Works that feature systems that operate and respond to environmental perturbations or disturbances. This is a more indirect form of interaction.

These characteristics can be seen as a continuum, with direct bodily relations at one end and perturbations at the other.

3.1.1. Direct Bodily Relations

Motion and action are the cornerstones of perception (Noe 2006; Varela, Thompson, and Rosch 1992, 172–180). Sound, visuals and other sensations are directly co-dependent on motion and embodied action. This ongoing sensorimotor cycle leaves behind perceptual and experiential residues and contributes to our history of **structural coupling** with the environment. When we are tightly, physically coupled with an interactive technological system we are often compelled into relations where we learn and interact not only by vision or sound but also by direct motile and affective patterning. Some interactive works are more concerned with how we move and physically feel, how a body relates to another object (e.g., another body, system or even a disembodied intelligent system). These works feature a directly physical or embodied form of interaction with some kind of intelligent technological system, sometimes involving physical contact with the participant's body. Participants directly perceive (though not necessarily control) the interaction. This often produces mirror-like transformations of participant's actions and choices. The systems also exhibit some perceived agency of their own, whether or not they are "intelligent" in a technical/computational sense. This agency may or not be a major driver of the interaction but it is nevertheless a part of the experience of the work (and thus the work does not function as simply an instrument that someone masters). These are perhaps the most apparently "interactive" works, as they engage a participant's sensorium in direct physical ways, whether via responsive sound, vision and tactility, or even direct inner body responses (e.g. biofeedback). What is stressed here is a direct physical interaction with a technological system with some agency: a sort of embodied alterity.

A good example of this embodied alterity is David Rokeby's *Very Nervous System* (1986-90, Figure 3.1). This series of interactive sound installations uses video image processing to detect participants' movements and generate synthesized sound in response. Participants interact by moving their bodies (sometimes erratically) in order to generate sound in real-time. The audience moves and is in turn moved by, the musical sounds. The motivation behind this work for Rokeby was to move beyond the predictability and constraining limitations of standard computer interfaces. The piece creates a technology that conforms to a more intuitive, physical, embodied and thus "natural" way of interacting with the world. Rokeby describes the interface as "invisible and very diffuse" and in a constant state of transformation, producing an experience that he describes as almost "shamanistic". This is an interface that is ambiguous, always seemingly being re-determined via circular relations of causality (the participant's embodied actions and the system's interpretation of them). The interactional space needs to be explored in order to be understood. According to Rokeby, through one's embodied interactions with the piece "the self expands (and loses itself) to fill the installation environment, and by implication the world" (Rokeby 1986-90). For Rokeby, much like Pask, "interactive" does not mean control but rather the instantiation of states of "mutual influence" where neither the human agent nor the technological system directs the experience (Wilson 2002, 731–732).

Figure 3.1 David Rokeby's *Very Nervous System* in Potsdam, Germany.

This sense of ambiguity, of something that is always in development, parallels in many ways both the ontology of Merleau-Ponty's embodied phenomenology and the ontology of cybernetics. Also important to consider here is how the notion of control becomes hazy, in essence becoming lost (thus becoming more like "control" in the Paskian sense). Due to the tight, movement-based coupling of participant and system, minute differences in a participant's gestures (many of which she may be unaware of) will influence how the system responds. Seemingly similar gestures may reproduce radically different sounds. This helps illustrates the notion of embodied alterity mentioned above. By losing this sense of control (in that the piece cannot simply be "played" as one plays a traditional musical instrument), one has to come to terms with the system as "other" and realize that how we interact (which in this case is closely tied to how we move) is really a form of entering into a conversation, with all of the unpredictability that that entails. We are tightly coupled with a sort of intelligent "other" and must reorient ourselves bodily and mentally in order navigate this conversation. My argument (not unlike Rokeby's) is that this form of interaction leaves a sort of residue that heightens our sense of being coupled to our increasingly intelligent environment.

Another form of unpredictability made possible by direct bodily coupling with an intelligent system can be seen in Norwegian artist Stahl Stenslie's "psychoplastic" wearable computing works. The *inter_skin* project (1994, Figure 3.2) features special sensor/stimulator suits worn by participants that are capable of both transmitting and receiving different sensory stimuli, particularly touch. Participants can send and receive tactile messages from one another. For example, by touching ones own body, that same touch is transmitted across the network to the other participant. The intensity of the touch on the receiving end is determined by the duration of the touch by the sender. Stenslie notes that the nature of the piece highlights certain phenomena such as autoerotic stimulation and a conception of bodies not as separate but as virtually shared.

Figure 3.2 Stahl Stenslie's *inter_skin* system

Many artists have engaged directly with the body by way of monitoring some of the body's physiological and autonomic process (e.g. heart rate, galvanic skin response, etc.). Mentioned in the previous chapter, *Biomorphic Typography* by Diane Gromala features a set of typographic fonts that continuously morph and evolve in real-time based on a participant's physiological states. Font's "throb" in response to heart rate and expand and contract as the participant breathes (Gromala 2003). *Whisper[s]* is a collaborative project led by Thecla Schiphorst where physiological data is mapped to collective network visualization and sonification and physiological data is exchanged between participants (Schiphorst 2005). In many instances, participants create “body networks” or otherwise share their affective states in some way. While in *inter_skin* and *Whisper[s]* the alterity may be between human interactors, with the technology serving as intermediary, it may also be useful to look at the technological systems as another participant and “shared other” of the two (or more) human interactors. In addition, Stelarc’s cyborg-inspired *PingBody/Amplified Body* (1990-98) performances directly thematize human-machine co-evolution (in perhaps a more confrontational or aggressive manner). These performances may be seen as explorations of potential or ongoing bodily struggles against obsolescence — vacillating uneasily between parasitic invasion and some sort of symbiosis — when faced with the challenges posed by modern technology (Goodall 2005).

What is stressed again, in all these works is a direct physical interaction with a technological system with some (at least perceived) agency. Via the complex dynamics of machine and human bodily agency, works with these kinds of direct, tactile and gestural, and intercorporeal connection with the body provide a unique form of “embodied” conversational interaction.

3.1.2. Perturbations

Some emergent artworks feature looser or altogether non-existent physical couplings with the interactive system. They demonstrate greater agency of their own. These works feature systems that operate and respond to environmental perturbations or disturbances and are often in some kind of cybernetic feedback loop with the whole environment and do not necessarily require human presence to react. As an example, consider Usman Haque’s and Robert Davis’s sound-based interactive work *Evolving Sonic Environment* (2005-07, Figure 3.3). Participants encountering this piece would be excused for not realizing initially (and perhaps not at all) that they were entering into a conversation of sorts, one that they were (inter)actively participating in the moment they entered the space. In a sense, human presence and movement disrupts an already ongoing conversation among a group of non-human computational agents. This disruption creates a new conversation with the human participants as part of it. The piece consists of a group of electronic devices that emit and respond to sound and cooperatively function as an analog neural network. The piece is constructed primarily of analog components and is thus not “programmed” in the conventional sense. According to Haque and Davis, the devices are completely autonomous and constantly signal each other via rhythmic “chirping” noises (the rate of chirping indicating their internal state). Collectively, the devices form a highly adaptive system that is able to respond to human participants, determining their presence or absence even though it was not specifically designed to do so. This is a neural network that participants can actually walk into and experience directly. However, the very act of doing so alters the network’s response by disrupting the transmission of sound from one device to the other, forcing the devices to adapt by altering their sonic output patterns (in fact the simple act of moving ones head again disrupts the direct transmission of sound from one device to the other and affects the way that they relate to one another).

Figure 3.3 *Evolving Sonic Environment*, by Usman Haque and Robert Davis. Left: the sonic “neurons” suspended in the gllery space. Center: close-up of the neurons. Right: Seperate room showing a vizualization of the sonic patterns generatied by the devices.

Both technically and conceptually, *Evolving Sonic Environment* is a direct descendent of Gordon Pask’s *Musicolour* (1953),[17] an adaptive light machine that would respond to a musician’s improvisational performance with patterns of multi-colored light. Aside from the analog nature of its circuitry (modeled on biological neurons), the behaviour of *Evolving Sonic Environment* is also reminiscent of *Musicolour.* Like Pask, Haque notes how his devices may become “bored” (i.e. go quiet) if they hear too much of one type of tone and will subsequently begin to modify they output. The network may also reach a point of equilibrium or sonic “contentedness” which “may get disrupted

[17] See (Pask 1971) for a discussion of *Musicolour*.

when humans enter and start making their own sounds", thus entering into the "conversation" that the devices are having. One's mere presence in the space influences the very dynamics they are observing. Thus, the appeal of the work may be seen as the tension it sets up between observing a continuously iterating "society" of sonic devices while simultaneously being part of that society.

Similarly, Simon Penny has experimented with systems that generate conditions for emergence, complexity and at least the appearance of intelligence or agency. Of particular note here is *Sympathetic Sentience* (1995, Figure 3.4). Realized in collaboration with Jamieson Schulte, this piece consists of a group of small wall-mounted electronic devices that generate a series of rhythmic chirps. The units communicate by sending their rhythmic patterns to the next unit in the chain via an infrared signal, with the data stream looping through the entire group. Each unit combines its own rhythms with the ones it receives from other units. Participants can interrupt this chain of communication by moving through the space and blocking the infrared beams, thus altering the rhythmic patterns.

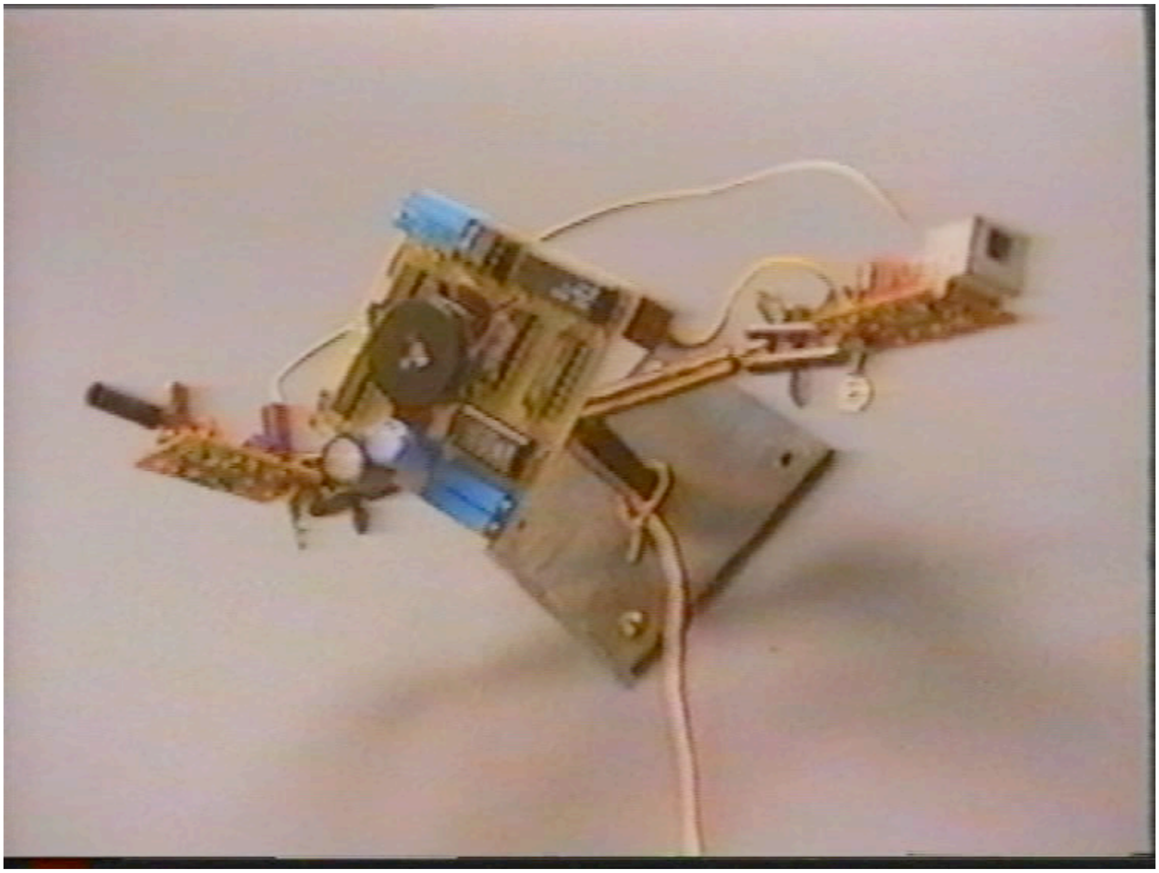


Figure 3.4 *Sympathetic Sentience*, by Simon Penny and Jamieson Schulte. One of twelve of the piece’s electronic units.

A piece that thematizes emergence and **autonomy** via complex interactions of sound, motion and human presence is Ken Rinaldo’s piece *The Flock* (1994. Figure 3.5) (Rinaldo 1998a). Realized in collaboration with Marc Grossman, this piece adds the element of movement (in particular the appearance of intentional movement by an artificial robotic agent). The piece consists of a group of interactive sound sculptures that exhibit collective autonomous behaviour similar to that of flocking birds. It is an assemblage of robotic arms constructed primarily from grapevines intertwined with an array of various electronics, including infrared sensors, microphones, motors and audio speakers. These “agents” or “creatures” communicate with one another via audible telephone tones which as Rinaldo notes, function as a “musical and positional language” to inform each other of their relative arm position as well as the presence and location of participants (Rinaldo 1998a, 405). The sculptures have a potent physical presence due their odd construction (sinuous organic materials mixed with metal and silicon), size (about 3m high), graceful motion and mode of interaction. Participants interact simply by walking between them. They are programmed to move in the direction of people's voices while at the same not getting too close. They move to and fro, slowly and unevenly, arching their tips towards and pulling back from participants as they approach. Thus, like *Evolving Sonic Environment*, *The Flock* can be seen as showcasing dynamic, emergent interactions between intelligent machines and between those machines and human participants. More broadly, this piece — and perturbation works more broadly — highlight a sort of co-emergent, co-evolutionary, milieu that may be said to exist between the organic and the technological.

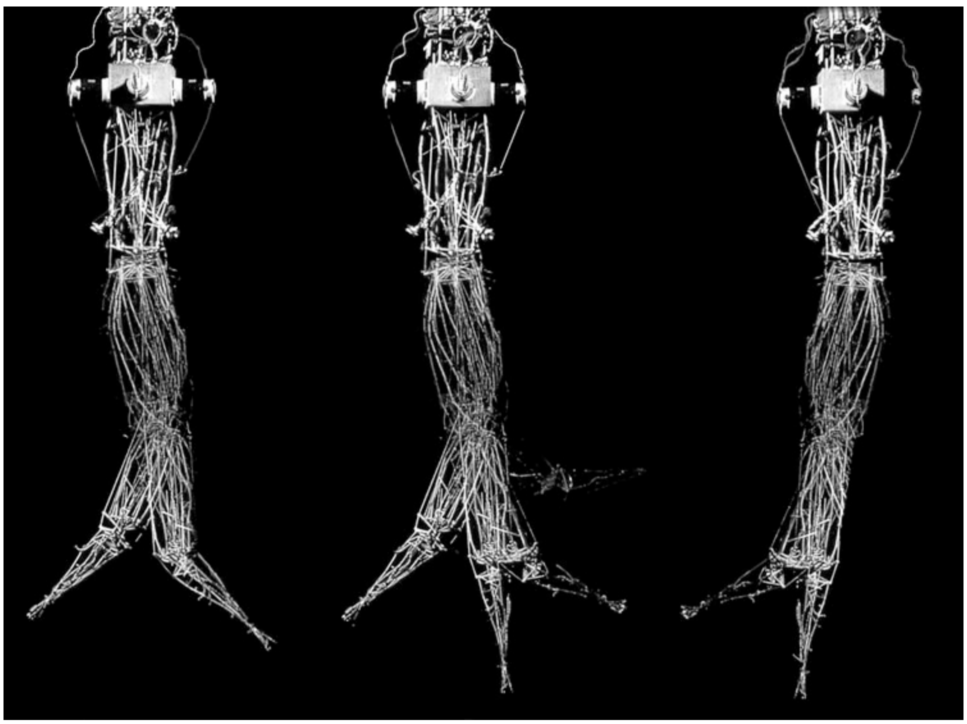


Figure 3.5 *The Flock*, by Ken Rinaldo (time lapse image)

3.2. Material/Organic

Many works that we refer to as "interactive" or "new media" are usually digital and electronic in nature. They are composed of sensors, motors, capacitors, computer visualizations, etc. These are the familiar modalities and mediums that we think of when we think of interactive, technology-based artworks. Others however offer unique material substrates, often mixed with the more traditional digital/electronic technologies. While these works can still be said to take a "systems approach to creation", some have a more direct focus on relations grounded in the unique complexity of the material(s) employed in the artefact/system. All emergent artworks can be analyzed from the perspective of their material instantiation. However for some works, the material substrate(s) that they are built upon function as the driver and locus point of experience. The participant is drawn to the strange and unusual material instantiation or substrate of the work (e.g. chemical solutions, biological systems, etc.), which sometimes combine with digital and/or intelligent technologies (or sometimes constituting that very technology). Here the very material form of the work adds a certain novel dimension of tactility or sensuous presence, sometimes even exhibiting a certain kind of agency. The often malleable and/or organic or quasi-organic material — and its context within and as a technological system — is where the work's aesthetic and conceptual valence lies. Some of these practices are related to "bio-art", others to artificial life. But they can more properly be described as quasi-organic cybernetic systems. They allow us to begin to apprehend (even if non-consciously) complex, emergent processes first-hand, merely by virtue of their growth or adaptation; and of their sheer materiality. They adumbrate an experience of the world that may be characterized as open-endedly ambiguous.

As an example, consider Andy Gracie's *fish, plant, rack* (2004, Figure 3.6). This piece features a robotic system that interprets electrical pulses from a virtually blind electric fish (*Gnathonemus petersi* or Elephantnose fish) and uses them as instructions to monitor the development of plants in a hydroponic system. The robot's AI system (designed by Brian Lee Dae Yung) gradually builds up an "understanding" of pulse patterns and continues to monitor and care for the plants in a manner increasingly influenced by the fish. The robot also expresses its 'feelings' about the conditions of the plants and its relationship with the fish through a series of sound and light signals and motions configured as the artists states, so as to "convey excitement, awe, anxiety and disappointment". The entire process is relayed back to the fish (which may or may not be influenced by it) via a screen near its tank from the robot's on-board micro-video camera.

Figure 3.6 Andy Gracie's *fish, plant rack*. Foreground/left: tank containing the elephant fish and video display. Background: hydroponic system monitored by an "intelligent" robot.

This piece contains no such confusion as to its interaction, as it is not "interactive" in the sense that human interaction is not required, nor does it influence the piece in any way. Nevertheless the quasi-symbiotic relations between intelligent technological and living biological systems resonate with human relations of the same type that are at play in works such as *The Flock*. Here, humans are merely observers to the ongoing quasi-symbiotic process. Nevertheless, the piece plays out complex emergent relations of alterity that while somewhat limited in a technical/cybernetic sense (as the robot is essentially a slave to the fish), are still mysterious, unpredictable and ambiguous.

Like *fish, plant, rack*, *Cybernetic Bacteria 2.0* (2009-2010, Figure 3.7), a collaborative piece by artist Anna Dumitriu, scientist Simon Park and philosopher Blay

Whitby, involves interspecies communication, more specifically relations between bacterial communication networks and human information networks. The artist team describes the work as "combin[ing], in real time, the raw network traffic taking place live around the gallery (including web traffic, mobile technology and Bluetooth) and data from a time-lapse film of bacterial communication occurring (involving two strains of genetically modified [GM] bacteria, which will indicate, by changing colour or glowing, the communication taking place). From those two sources a new cellular automata artificial life form based on Conway's 'Game of Life' was generated" (Dumitriu and Whitby 2011, 265). Dumitriu claims the volume and complexity of bacterial communication invokes a feeling of the sublime when compared to human communication technologies. But while the processes and relations brought forth in this piece do amplify the complexity and ambiguity of organic communication networks and may thus be considered to give a sublime experience, when these networks and processes are intermingled with human-constructed digital networks the work takes on slightly different character, one that can perhaps be better described as amplifying what Herbert Grabes calls the "aesthetic of the strange" (Grabes 2008).

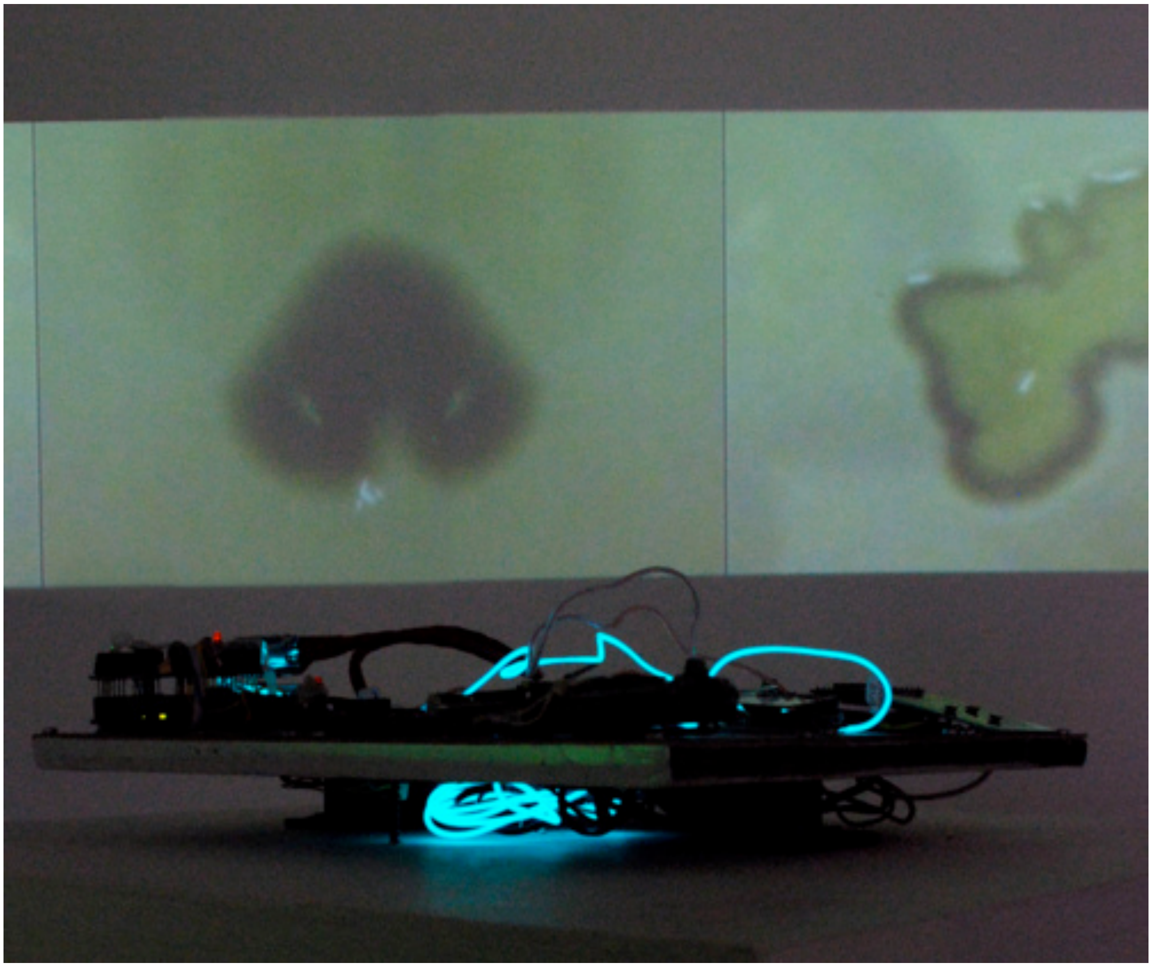


Figure 3.7 *Cybernetic Bacteria 2.0* by Anna Dumitriu, Simon Park and Blay Whitby

The substrate of the *fish, plant, rack* system, *Cybernetic Bacteria 2.0* and those of quasi-organic works such as Roman Kirschner's *Roots* (2005, Figure 3.8), which is partly based on the electrochemical computing experiments of Gordon Pask, can serve to redirect our attention to the very material forms of the works and how they add a certain dimension of materiality and sensuous presence that is often lacking in digital and even robotic works. The agency at play in these works can only come from these non-symbolic (i.e. non-digital), material forms grounded in processes of organic or quasi-organic growth and behaviour.

Figure 3.8 *Roots*, by Roman Kirschner

Of course the materials used in all emergent artworks play a role in its reception, interpretation and aesthetic valence. Taking the previous example of *Evolving Sonic Environment*, the simple commonplace looking materials of speakers, microphones and exposed electronic circuitry establishes a recognizable “tech aesthetic” that does not immediately give us a sense of alterity or agency. Thus we must focus on what these objects are doing, which at first glance may appear to be nothing but generating random high-pitched tones. Eventually we may discern some patterns, perhaps communication in the generated sounds: in other words, a kind of agency. None of this however is directly attributable to the material underpinnings of the work. And in fact it is the relatively common, recognizable materials that while not effaced in the gallery context require somewhat greater thought and critical judgment outside of immediate experience to get at their aesthetic and ontological status. The material takes somewhat of a back seat to the dynamics of communication and conversational interaction that the piece explores. While these processes are still grounded in materials, they are common materials without their own agency per se. They do however cast matter more generally, in a new light. Not as inert and simply there to do human bidding, but as capable — under the right conditions — of exhibiting emergent intelligence.

3.3. Process/Emergent

In the next two sections, instead of a direct focus on either the artwork/system's materiality, it's interaction modalities or its performative aspects, we want to look at how the mix of process and context influences a work's reception and understanding: how the conceptualization and construction of the work is approached by the artist(s) as well as how the piece is contextualized. Thus what we have is an abstraction away from the specific material instantiation of a work and instead a focus toward the processes they foreground and their relationship to the work's contextualization, while at the same time not forgetting that these processes are threaded through, and have relationship with, the materials through which they are created.

Interactive/new media art is often described as "process-based", referring to the fact that the creation of an artwork is often never at a standstill. Works often exist as iterations or modified versions of previous works. Thus, the static *objet d'art* is not the primary focus. With regard to the emergent arts however, "process" takes on a slightly different meaning. Here, in addition to the iterative nature of the artmaking process we have something of a unique aspect of many emergent artworks: the artwork itself *as a process*, or as a system that establishes conditions for processes that may be considered emergent. Works such as *Sympathetic Sentience* and *Evolving Sonic Environment* are obvious examples of works that thematize and explore emergent processes (at least in the computational sense). Organic works such as *Roots* and *fish, plant, rack* showcase emergent processes rooted in quasi-organic growth and symbiotic behaviour respectively. Some works may even feature processes that are outside any direct human perceived effect (at least immediate effect) but give a sense of longitudinal intertwining. These process establish almost a background context for understanding our relationship the world: such as things living/growing with us or otherwise linked to us in some way. The work may even engage us beyond the physical presence and experience of the gallery space. They may be said to establish complex conceptual-corporeal relations among abstract and theoretical ideas through their longitudinal processes. The concepts are in a sense borne out of the emergent process the works enact for, with and through us. In this sense, many of these works can be seen as relational. Thus, all emergent artworks can be analyzed and discussed from the perspective of the processes they explore and/or deploy and the conceptual-corporeal relations they implicate us in.

3.4. Context/Inquiry

While most art can be considered a form of inquiry, emergent artworks are often specifically contextualized as forms of inquiry rather than expressions of emotion. Many are often reflexive forms of inquiry into the nature of the systems that they themselves exist as. Interactive works investigating interactions, organic systems explore organic systems and so on. This inquiry includes the artmaking process and its role in the contextualization of the piece. The process of developing an artwork may often feed back and influence the actual artmaking process. While it is virtually impossible for anyone other than the artist(s) to be present and privy to all of the details of the entire system-building/artmaking process, the fact that an emergent artwork itself exists as a process in some sense, plays a role in our understanding and conceptualization of what is entailed in the *artmaking process* and thus plays a role in establishing context. Additionally, how the artist contextualizes the work in a gallery, describes it and writes about it in a journal or artist statement influences our own reading and experience of it. Thus, we must recognize the relations of mutual influence between the work as a form of inquiry, the artmaking process itself and how the piece is contextualized by the artist(s). The ways in which artists analyze and critique the work and apply that critique back to the work — its construction, description and further analysis — influences how the work is understood and discussed (by both artist and audience).

Emergent artworks may be seen as forms of ontological/metaphysical inquiry. They ask viewers/participants to think about larger questions such as emergence, co-evolution, our relationship to the planet's ecology, etc. As an example, we can look once again at *The Flock*. Rinaldo notes that he designed the software in *The Flock* to allow for a range of "learned and unpredictable behaviours, with an emphasis on cooperation to produce a group aesthetic" (Rinaldo 1998a, 406). The unpredictability here is more than programmed randomness. As in *Sympathetic Sentience*, the primary theme in this piece is emergence, which Rinaldo defines as "the coming together of systems with no central controller guiding their behavior" (ibid.). This behaviour arises in a "bottom up" fashion, where local interactions lead to global phenomena that cannot be explained by simply accounting for the local interactions. This is somewhat different to Penny's interpretation, which emphasizes holistic complexity rather than localized interactions by autonomous agents. Thus, where Penny seemingly valorizes the unpredictable (and perhaps the erratic, yet still coherent) qualities of emergence, Rinaldo is concerned with an elegant "coming together" of natural and technological materials. His conception of emergence is intertwined with a certain thematization of symbiosis. According to Rinaldo, his desire was to echo the forms and interactions of living systems and "[assert] the confluence and co-evolution of organic and technological cultures" (407). "If a technological and natural system... can fuse," says Rinaldo, "it will be the next step for our interdependent, co-evolving earth" (406).

What Rinaldo is telling us is that the conditions created by conversational, communal interaction between the creatures in *The Flock* and between the creatures and the human participants are the result of investigations that featured a careful back and forth process between hardware/software design, interaction design, material properties and the emergent processes that these elements collectively gave rise to when put in a gallery context, where they had to interact and respond to their environment. Furthermore, we as an audience understand the relations between these elements through the artwork's description as the result of artistic research into the creation of a pseudo-living entity of sorts. The aesthetic valence of this entity and its status as an artwork are grounded in a certain kind of human-technology-nature symbiosis and co-evolution. In contrast to *Evolving Sonic Environment*, which is contextualized more as a study of interaction itself, *The Flock* contextualizes its interaction design approach (which is not terribly unlike that of *Evolving Sonic Environment*) in the service of foregrounding these co-evolutionary themes. Thus, whether it is the elegant flowing motions of the hybrid tree/electronics armatures and their response to participants, the particulars of how the electronics were designed and how they function or the nature of the creatures' communication, these are all understood as elements of a co-evolutionary, emergent artwork that professes a certain flowing harmony between nature and technology.

3.5. Summary

All emergent artworks presented here stage performances that showcase aspects of a **lifeworld** textured with experiences of intertwinement with technology. They stand as exemplars of what Andrew Pickering calls “ontological icons”. This chapter has introduced both a taxonomy of emergent artworks and four key areas of that taxonomy most relevant to their analyses. As I have demonstrated, the emergent arts initiate what may be seen as cybernetic feedback loops of a kind of perceptual and conceptual self-organization. I argue that the emergent relations of agency and alterity that unfold in these works — via “loops and circuits that run outside the head and through the local environment” — amplify an embodied sense of embeddedness with the world via relations of circular causality that may give rise to a unique and heretofore unrecognized range of art experiences that I characterize as symbiogenic. Complex interactions between “stored” concepts and the materiality of the artwork/system/environment may alter these very concepts and the perceptions they are based on, or even give rise to new ones. In phenomenal terms, these experiences initiate the establishment of new sets of conceptual relations and thus reconfigure the perceptions that make up our lifeworld. The emergent arts may give rise to new networks of perceptual and conceptual complexity that may be thought of — in neocybernetic terms — as a self-organizing system with emergent properties being these lived experiences. Experiences that — via relations of circular causality — are constituted in part by the embodied perceptual associations that emerged from them. These experiences, starting from an amplification of the everyday (Dewey), are part of inchoate processes of perceptual connection to a technologically complexified world. In the next chapter, I turn my attention to an explication and analysis of these experiences directly.

4. The Symbiogenic Framework

This chapter sketches out the conceptual basis of the symbiogenic framework, allowing us to go deeper into examining the dynamics of what I call co-evolution by outlining four theoretical concepts that I consider to be the cornerstone of symbiogenic experiences in the emergent arts. As stated in Chapter 1, a symbiogenic experience in an interactive arts context may be defined as one where mind, body and an increasingly technologized environment interrelate to give rise to a sensory experience that arises from a dynamic wherein human conscious and pre-conscious processes can be thought of as locatable both within the traditional bounds of the subject and also dispersed without, in a myriad of intelligent technological structures. The symbiogenic framework rests on the argument that increasing technological change is bringing about an almost imperceptible historical shift in our embodied relationship with technology (which I characterized as co-evolutionary). The emergent arts can in many instances serve as a sort of advanced notice of this dynamic and this theoretical framework can help in discussing and analyzing it by developing a language and set of understandings. The approach taken here can be compared to the "horseless carriage" era of automobiles, where an unfamiliar technology is described and discussed in familiar terms (and its accompany impact on society arguably obscured) until a new set of languages and understandings are developed (Bolter and Grusin 2000). This framework may be also be seen as identifying a contextual change, perhaps a tipping point where technological sophistication and saturation (as exemplified by the proliferation of intelligent technologies) has reached a certain level where we can then start to sense a corresponding change in our embodied relationship to technology. The amplified experiences that the emergent arts (and the arts generally) provide may again help us become aware of this already existing dynamic that is nascent or incipient.

The core methodological approach outlined in this chapter lies in establishing the relevance of Merleau-Ponty's existentialist phenomenology to intelligent systems, neocybernetic theory and the material practices of cybernetics. Together, these constitute the theoretical lens through which I am viewing symbiogenic experience. What follows is a set of close readings of neocybernetic and Merleau-Pontian ideas from which four theoretical aspects have been derived. When combined with the analyses offered in the subsequent chapters, these aspects act as an adumbration of the symbiogenic framework from which further analyses of emergent arts practices can be undertaken.

4.1. The Phenomenological Context

The phenomenological lens applied to the analyses presented here employ elements of what are sometimes called *genetic* and *generative* phenomenology. Genetic phenomenology is concerned with how intentional structures and objects emerge over time. Symbiogenic experiences (as the name implies) occur over time. Genetic phenomenology recognizes that experience is not fixed but *emergent* (Thompson 2007, 29). Intentional structures are always in flux. Experience is viewed as sedimented and in relation to the lived body and phenomena such as affect, habit and emotion (ibid., 17). The guiding thread in the generative approach is the **lifeworld**, the cultural, social, historical and intersubjective/inter-corporeal constitution of the human world as directly experienced in the subjectivity of everyday life.

The analyses that encompass the symbiogenic framework cover what I see as three general subjective characteristics of experience: emergent, distributed and cultural-historical. To say that a symbiogenic experience is emergent or has the qualities of emergence is to say that it has a *genesis*, a point from which the experience, or certain qualities of it, grow, develop and change over time. Primordial phenomena such as **autonomy** and distributed **intentionality** are emergent processes that are in continual flux, responding and adapting. They are in some sense unknowable in all their complexity, except via the subjective contours of symbiogenic experience. An emergent artwork that can highlight this emergence and adaptation to a highly complex, intelligent technological environment may be said to amplify the emergent aspects of symbiogenic experience. Furthermore these interactions with the environment occur in reference to others (whether they be human or intelligent machine). As mentioned in Chapter 3, the key characteristic of the emergent arts is their “emergent relations of alterity”. Thus, to say that a symbiogenic experience is distributed is also to say that this relationality occurs in a lifeworld of accumulated components of experience for the subject. This necessarily leads one to focus on the correlational structure of intentionality, its relationship with a lifeworld that entails a history of lived bodily experience and dynamic coupling with intelligent technologies that influence the constitution of that lifeworld (whether directly or indirectly, active or passive). The cultural-historical characteristic of symbiogenic experience takes its stance from the focus in generative phenomenology to the generational and historical embeddedness of the subject (Thompson 2007, 33). Thus, the scope is widened, with respect to genetic phenomenology, to include a greater focus on the lifeworld itself, and its pregiven qualities that serve as the horizon of experience for the subject. Our lifeworld and its historical development influences and is influenced by ones participation in it. It is part of our everyday activities but we must recognize that these activities exist in a historical context that we all inherit and share. Emergent artworks arise from a historical lineage of art, technology, society, that we are all born into. I describe this experience as co-evolutionary to encapsulate a dynamic of longitudinal, dynamic co-emergence exemplified by all these concepts, while the term symbiogenic refers to the genesis and alterity of such an experience.

4.2. Notes on Temporality

All of this of course begs the question of what temporality is from a phenomenological perspective. As this research concerns felt experiences that may make us aware of what I refer to as our co-evolution with an increasingly intelligent, technologized environment, we must recognize that all mutual couplings between humans and technology occur in time. Thus, as a symbiogenic experience is at its core a diachronic and longitudinal phenomenon, it is important to discuss the phenomenon of time from within the existentialist phenomenological framework of this dissertation. Here, we can turn to Merleau-Ponty and his phenomenology of time. Merleau-Ponty provides us with a dynamic, forward-looking and non-objectivist account of temporal experience that helps us sketch out what a symbiogenic experience is and means and how this might play out in an emergent artwork. Thus, the focus here will be on laying out a phenomenological account of the temporal aspects of human-machine co-evolution.

Merleau-Ponty's account of time, it must be said, is subjective. This is not to say that it is "subjective" in the usual sense of the word. It is not imaginary or otherwise "unreal". What Merleau-Ponty is saying is that time — past, present, future — exists only for *subjects* that are capable of experiencing it in a particular way. For Merleau-Ponty, objectivist conceptions of time are rooted in those of embodied subjects who exist *in* time (or even *as* time), not separate from it. If we did not think of time from the perspective of someone who is in time, then we could not think of time at all. It would have no meaning for us. Time is always in the process of becoming, it is never "completely constituted". Merleau-Ponty argues that objectivist conceptions of time always presuppose a fully constituted time, which is not time itself but "the ultimate recording of time, the result of its passage" (Merleau-Ponty 2002, 482).

This emergent aspect of time is seen in everyday activities such as making coffee, opening a door or brushing ones teeth. The activities are purposive and non-reflective (i.e., we do them without really "thinking" about them). We also have the ability to adapt and respond to the breakdown of the otherwise coherent flow of these activities (e.g., the coffee machine breaks). Merleau-Ponty's embodied intentionality — what he calls "motor intentionality" — characterizes how the body is led by the particular situation (outside of purely mental/cognitive processes) to get into equilibrium with it's environment in an active, dynamic (temporal) process (Dreyfus and Dreyfus 1999). Thus, experience often does not have a subject/object structure, but is instead the phenomenal flow of one's coupling with the environment that is often pre-reflective (Thompson 2007, 314ff.). Objects of consciousness continually undergo change and transformation that we are sometimes not immediately aware of *consciously*, yet which we can discern over time, upon reflection (a generative and emergent phenomenological experience). This dimension of pre-reflective awareness is what Merleau-Ponty calls the "perceptual synthesis" of temporality, where the body "unites past, present and future…" and does not simply receive sensory data passively (Merleau-Ponty 2002, 278). This is how, for example, we can look at a tree from different angles as we walk around it and still experience it as belonging to one and the same tree. Or when we see the tree in the winter without leaves and imagine it with leaves in the spring. We remember past objects and anticipate future ones (Thompson 2007, 317ff.).

Perhaps Merleau-Ponty's greatest contribution to the phenomenology of time is his critique of Husserlian time-consciousness, or more specifically of the Husserlian conception of the seriality of temporal experience.[18] Shaun Gallagher notes how Merleau-Ponty identifies "a certain disruption of the serial flow" that is not accounted for in Husserl's analysis (Gallagher 2000). Merleau-Ponty shows how this orderly serial flow is only constituted and available to us after reflection. Gallagher characterizes this as a "frozen flux" of time that is constructed after the fact, where it is laid out in serial order. Merleau-Ponty then asks "whether a phenomenon that is essentially variation, change, flux can be eidetically reduced to its invariable unchanging contours" (ibid., 101). Gallagher goes on to show how Merleau-Ponty's radical conception of time is one where Husserlian serial order is disrupted, twisted, even reversed. He speaks of multiple "detached presents" and "diachronous individual nows" that exist not in themselves, but in relation to each other.

To make more sense of Merleau-Ponty's account of temporal experience and how it pertains to the symbiogenic experiences, it is also important to consider the temporal nature of intentionality, as it is at the heart of what Merleau-Ponty calls "being-in-the-world". This term (borrowed from Heidegger) is way of eliminating the split between subject and object, inside and outside, body and world; a way of getting us to understand that there is no consciousness or perception outside of the objects and phenomena that make up our world. Merleau-Ponty's model of motor intentionality as exhibiting preconscious or pre-reflective aspects that are rooted in the body's intertwinement with the world plays an important role in this disruption of the serial temporal order. Here again, we can turn to Shaun Gallagher and his analysis of these preconscious factors (Gallagher 1995). Gallagher's conception of the "body schema" and how it shapes the body's attunement to its environment and thus shapes and constrains intentional consciousness adds further weight to Merleau-Pointy's motor intentionality model. Thus for Merleau-Ponty, bodily processes (like intentionality) "unfold" in time. He speaks of how the "focusing movements" of the body "unite past, present and future, secrete time" and "project round the present a double horizon of past

[18] By extension, Merleau-Ponty's critique of seriality would also apply to empiricism (William James's "stream of consciousness comes to mind") and the cognitive sciences.

and future" (Merleau-Ponty 2002, 278). His model of embodied motor intentionality not only accounts for what occurs "out in front" of the noetic act (perception) but how these prenoetic factors might limit and define the possibilities of time for us, allowing for an imposition of serial order that is experienced "after the fact" of the passage of time. Intentionality then is not the clear straight line for Merleau-Ponty that it is for Husserl. It is not a clean break from the past but a taking up of it. Merleau-Ponty notes how the *stiftung* (translated here as "foundation") of a point in time can be "transmitted to other [points] without 'continuity' [or] fictitious 'support' in the psyche" (Merleau-Ponty 1968, 267). The past then, shapes our current and future intentional acts. "We not only retain the past, but *the past retains us*; it has a prenoetic effect on us..." (Gallagher 2000, 115). In this sense, intentionality involves more than consciousness; more than the present is operating within the horizon of experience and more than (or something other than) the serial order of time is presented to us pre-reflectively. "The phenomenal present is epiphenomenal; it only appears to maintain a structure" (ibid.). Merleau-Ponty asks us to look not only at the pre-reflective aspects of experiences that happen in time but also for distinctions among temporal events and their longitudinal effects, all of which arise from mind, body and world in specific and concrete contexts. Such an approach may reveal aspects of — and relations among — different levels of perception, sensation and affect. As I will now demonstrate, this can have an important impact on ones sense of human-machine co-evolution in an emergent artwork.

4.3. Ambiguity and Unknowability

In his historical analysis of six British cyberneticists, Andrew Pickering notes how cybernetics presents us with an "ontology of unknowability" (Pickering 2010). Instead of seeing the world as a fully knowable place, through the detached "view from nowhere" that forms the **ontology** of classical science and engineering, Pickering agues that cybernetics offers us a different way of looking at the world, one where the sharp Cartesian divide between people and things does not exists; where humans and their environment exist in a constant co-emergent interplay. For cyberneticists like Gordon Pask and Stafford Beer, the world is viewed as ultimately unknowable, a place to which we constantly adapt to through embodied action and performance of agency. The study of which was, according to Beer, the proper domain of cybernetics (Pickering 2010, 223). I want to argue that there is a connection here with Merleau-Ponty's concept of ambiguity.[19] A common thread running through Merleau-Ponty's philosophy, ambiguity refers anything that is undergoing development or is continuously open to determination. Experience has this quality, as it is composed of things that have dynamic and flexible, rather than fixed, essences. Since our perceiving bodies are not completely present to consciousness, we are incapable of detached, disembodied reflection upon our lived relations, thus engendering a certain sense of indeterminacy. Both Pickering and Merleau-Ponty valorize reciprocal couplings, rather than a dualist split, between people and things. As such, both of their views question the rational clarity of the classical ideal by eschewing a dualist ontology that separates people and things and by treating knowledge as provisional and contingent. Merleau-Ponty's ontology and Pickering's alternative cybernetics present us with a world of co-emergent, co-evolving systems too complex to fully apprehended or objectively explained. A world of contingencies that is in a perpetual state of becoming, characterized and brought forth via numerous and complex relations of alterity.

This complexity, in phenomenal terms, is amplified and brought into high relief via the direct experience of certain interactive or new media artworks. This range of works which I call the emergent arts provide us with distinct forms of interactive art experience that can be better understood by considering them via the lens of Merleau-Ponty's concept of ambiguity and its ontological resonance with cybernetics. There is an inherent strangeness and unpredictability in these works and the material practices employed in their construction that has not been fully appreciated. These works — many of which utilize nonhuman entities such as artificial life agents, living systems and quasi-organic materials — may be said to thematize a certain dynamic of co-emergent and co-evolutionary interaction with an exceedingly complex environment. The emergent relations that unfold in these works may serve as avenues of exploration of Merleau-Ponty's ideas and may also be useful as ontological grounding for (re)establishing a discourse between systems theory and the arts. In addition, reading neocybernetic emergence and the material practices of cybernetics through the lens of Merleau-Ponty's

[19] Merleau-Ponty is sometimes called "a philosopher of the ambiguous". But the term ambiguity has a specific technical meaning in his philosophy. See Sapontzis (1978) for a discussion of this concept and its function in Merleau-Ponty's philosophy.

philosophy, may guide our understanding of both the making and experiencing of these works.

4.3.1. Neocybernetic Emergence and the Merleau-Pontian Ontology

Neocybernetic emergence can be linked to what Merleau-Ponty calls "form". Introduced in his early (and underappreciated) work *The Structure of Behavior* (Merleau-Ponty 1963), form essentially refers to dynamic wholes which cannot be considered as separated from their individual components, as well as the **circular relations** between them. Form is a "total process" for Merleau-Ponty, whose properties are "not the sum of those which the isolated parts would possess" (Merleau-Ponty 1963, 47). Like Kant before him, Merleau-Ponty prefigures central concepts of cybernetics and systems theory when he states that "the relations between the organism and its milieu are not relations of linear causality but of circular causality" (Merleau-Ponty 1963, 15) and "the fate of an excitation is determined by its relation to the whole of the organic state and to the simultaneous or preceding excitations" (Merleau-Ponty 1963, 47).[20] Presaging neocybernetic thinking, he states that there is form "whenever the properties of a system are modified by every change brought about in a single one of its parts and, on the contrary, are conserved when they all change while maintaining the same relationship among themselves" (Merleau-Ponty 1963, 47). This recursive, co-emergent dynamic cannot be overemphasized. Merleau-Ponty shows how sensation and perceptions feedback upon one another and can give rise to new perceptions, again fostering an ambiguity that he states is "the essence of human existence and everything we live or think has always several meanings" (Merleau-Ponty 2002, 196).

In addition to organizational closure and relations of circular causality, neocybernetic theory also stresses the importance of structural autonomy if a system is to exhibit emergent behaviour. This entails the need for a system to have a capacity for initiating and evolving its own structural reconfigurations in response to environmental influences. This capacity for self-modification allows for the development of new

[20] See (Juarrero-Roqué 1985) for a discussion of Kant's prefiguring of autopoiesis and cybernetic theory.

informational linkages between the system and its environment, in effect creating a new system. The *Biopoeisis* project (discussed in Chapter 7) is an artistic recontextualization of the electrochemical experiments of cyberneticist Gordon Pask. The material practices of cybernetics most closely related to Merleau-Ponty's concept of ambiguity can perhaps best be exemplified by Pask's work on electrochemical control systems. In the 1950s, Pask experimented with the construction of electrochemical assemblages that were capable of adaptive **self-organization**. These systems, which he referred to as "organic computers" (due to their quasi-organic properties), possessed emergent properties such that they were capable of developing their own "relevance criteria" (i.e., perceptual categories) in response to environmental inputs. In essence, the system was able to grow its own sensors and effectors and was thus capable of adapting to changing environmental conditions, and in a circular fashion influence that environment accordingly. The system thus demonstrates a novel form of structural autonomy.[21] This is similar to Merleau-Ponty's notion of "structure" which, like form, concerns dynamic wholes whose components cannot be considered separately and also how these components self-organize in response to their "milieu" (environment), according to what Merleau-Ponty calls the organism's own "internal laws" (its autonomy) (Merleau-Ponty 1963, 161). In addition, Merleau-Ponty states that an organism "modifies its milieu according to the internal norms of its activity" (i.e. its operational closure) in order to "bring about the appearance in the world of a milieu in its own image" (ibid., 154); what Francisco Varela and his co-authors have called "shape[ing] a world into significance" (Varela and Bourgine 1992, xi) and enacting or bringing forth a world (Varela, Thompson, and Rosch 1992). This is in stark contrast to more traditional models of perception and cognition that posit that our minds simply represent a reality that is "out there".

In reading Pask's work and the material practices of other cyberneticists such as Stafford Beer — and his attempts to enlist leeches, euglena and mice (among other organisms) in the design of cybernetic control systems — through this Merleau-Pontian frame, we begin to get a sense of the ontological space they both occupy; what I like to call a philosophy of open-ended ambiguity. This also has, I argue, a certain resonance

[21] See (Cariani 1993) for an analysis of the importance of Pask's electrochemical experiments.

with artistic approaches and lends itself to artistic interventions. Pask's and systems theory's overall holistic approach, coupled with its philosophical resonance to Merleau-Ponty's phenomenology (at least with regard to autopoiesis and the enactive theory of cognition) and its constructivist epistemology gives it a natural resonance with the arts and with arts-based methodological approaches. **Structural coupling** for example (which helps to explain how cognition emerges when system and environment, through networked architectures, trigger and select in each other structural changes) helps elucidate how living systems (human or non-human) exhibit emergent properties such as autonomy via cooperative self-organizing actions with other living systems and with their surrounding environment. Autonomy then may be seen as emerging via these cooperative interactions.

4.3.2. Ambiguity as Method for Understanding the Exceedingly Complex

Pask's electrochemical system demonstrated the rudimentary capability of evolving its own relevance criteria in part because of its ability to compel an observer to interact with it. Both of these attributes are intimately bound up with its "ill-defined" nature. Pask provided no specification for components, construction details or connectivity for his electrochemical system (including the medium itself, for which an electrochemical solution was only one of many possible substrates). For Pask, the construction of such open-ended assemblages and the interaction with them was necessary for understanding complex phenomena such as learning, autonomy and intelligence. He notes that an assemblage like his "must force the observer to interact with it, in the sense that interaction yields benefits. It must be an assemblage for which the reference frame is badly specified" (Pask 1959, 892). The motivation for such an approach may have come from Beer himself, who was a close friend and colleague of Pask. Beer's notion of "exceedingly complex" systems such as brains, economies and pond ecosystems, were a special category of systems, ones that were not fully knowable or adequately predictable (Pickering 2010, 223). This category it should be said, did not include digital computers. We again get a sense here of the different ontological space within which Pask & Beer operated (and which Pickering sketches out). All of this brings us back to our notion of ambiguity. For artists who design systems that interact in dynamic and complex environments (e.g. gallery spaces, outdoor spaces) and are interested in emergent phenomena, working with such “unstable” mediums that grow unpredictably, and constructing systems with vaguely defined components, cannot help but spark ideas about possible avenues of exploration in ones artmaking process. Likewise, the evolution of sensors or relevance criteria that Pask’s assemblage demonstrated could only happen if the system was actually situated in a real-world context, with all the instability and variability that entails. Thus making an art gallery or a public space an almost ideal location and context for testing Paskian-like systems. For many years now, artists have experimented with different mediums, techniques and locations without knowing exactly what the results would be. Thus, to an artist, a “Paskian” approach might seem familiar and not that different from certain other artistic modes of experimentation.

4.3.3. Ambiguity and Co-evolution in New Media Art

In its vernacular meaning, the term ambiguity has of course a very lengthy tradition in the arts, along with surprise, wonder and metaphor. Jack Burnham’s vital insight on the impact of intelligent systems on the arts was more than simply identifying the emerging expansion of the art experience that these systems were helping to bring forth. Rather, it was his realization that these works expand our perceptual faculties in such a way that we approach ourselves and our technologically-textured environment as being bound up together. Burnham stated his belief that “the ‘aesthetics of intelligent systems’ could be considered a dialogue where two systems gather and exchange information so as *to change constantly the states of each other*” (Burnham 1970, 96, emphasis in original). This idea of an artwork as establishing a dynamic, emergent interplay with human participants is not only common today but is often the central concern of many interactive artists. In particular, concepts such as emergence, autonomy and self-organization that were not in the vernacular of the arts, or art theory and criticism in Burnham’s time — but which nevertheless resonate with Burnham’s ideas of a mutualistic and cybernetic art experience — are claimed by many contemporary artists who work in the area of artificial life (a-life) as one of the central concerns in their work. These concepts — concepts that are also of central concern to many cyberneticists and thus have a close relationship to the field’s “nonmodern” ontology — are threaded through the material practices of cyberneticists like Gordon Pask. Their work (both Pask's and many contemporary artists) functions as a way to bring these concepts "down to earth" so to speak, down to the level embodied experience. I propose that the strangeness and indeterminacy of the dynamic interactions present in these works — of which the emergent arts is really its aesthetic counterpart — evince and amplify a sense of incomplete knowledge of an increasingly complex world, full of interacting emergent systems; the totality of which is just beyond the grasp of our comprehension but which we nevertheless adapt to via constant interplay and shifting sets of perceptual relations. A phenomenology of emergent arts practice, when read through the lens of neocybernetic theory functions as a way of naming (in the sense of reifying as way of generating new concepts and modes of thinking, or updating old ones) the indeterminate complexity that concepts like emergence, autonomy and self-organization come from and may suggest conceptual markers from which to construct new models and modes of analysis. This strangeness is enhanced because it often depends upon our presence or how we move, react and respond rather than simply what we see or hear — or rather the shifting relations between these. These artworks thematize reciprocal interplay (and even co-evolution) of human and non-human systems and give an intuitive sense of connection or enmeshment with an increasingly intelligent technological environment and may be characterized by a drive for what Burnham called a "symbiotic intelligence" between humans and their increasingly technologized environments (Burnham 1970, 108). In addition, the often concrete or embodied nature of these works gives them a palpable presence, offering rich and complex experiences that have a resonance with phenomenological approaches. As Merleau-Ponty's notes, "our relationship to the world, as it is untiringly enunciated within us, is not a thing which can be any further clarified by analysis" (Merleau-Ponty 2002, xx). The emergent arts do not to clarify in the accepted sense, but instead establish contextual and contingent resonances with established perceptual patterns and in doing so may reveal an embodied sense — if only as an incipient, fleeting and ambiguously present shift in these established perceptual patterns — of co-emergence and co-determination with an increasingly complex technological environment.

4.4. Boundary Questions

In sketching out his framework for what can be called a co-evolutionary aesthetics of interactive art, Nathaniel Stern (2011) critiques previous theories — particularly those of Katherine Hayles (2002) and Mark Hansen (2006) — as incomplete for privileging technology. Stern argues that their analyses (1) treat the body as if it merely responds to technology and (2) that they view the body and technology as two “extant entities”, where technology acts as a catalyst on a more or less static body. Stern’s contrasting argument is that the body and technology are not “pre-formed” things and that interactive art “intervenes into entwined relationships that are always already emerging” (N. Stern 2011, 236). Yet in her discussion of artist Simony Penny’s interactive work *Traces*, Hayles states that embodiment emerges from dynamic interactions with the environment (Hayles 2002, 305ff.). How can a participant and an artwork be distinct (as Stern claims Hayles and Hansen consider it) when the participant's embodiment is realized only through relational, dynamic, co-emergent interactions with the environment that are always in flux? A priori co-emergence of body and artwork is implied (while not spelled out) here and Stern is right to point out this contradiction or ambiguity in Hayles’s analysis. We are, nevertheless, missing a larger question. There is some confusion regarding the body and embodied experience with regard to interactive art, a confusion that I believe stems from an undefined or incomplete notion of *boundary*. While Stern states that “[i]nteractive art… creates potentialized contexts that *amplify* the fundamentally relational process of embodiment” (N. Stern 2011, 236), the details of how this “relational process” comes about are vague, if present at all. If there are to be “relations” after all, must there not be some form of “other” to have relations with? As I argued in Chapter 3, the emergent arts are unique in that they bring forth “emergent relations of agency and alterity”. Thus, I share Stern’s assessment of embodiment and interactive art experience as relational and of the potential of interactive arts to catalyze and amplify these relations and even create new variations of them. But by definition, relations (or indeed interactions of any kind) require some form of border — even if abstract or liminal — for these relations to occur, especially among autonomous systems (such as human beings). Stern’s “entwined relationships that are always already emerging” is similar to Andrew Pickering’s characterization of cybernetics as showcasing an “emergent becoming” and dynamic interplay between humans and their environment (Pickering 2010). But the question remains: what are the mechanisms by which this emergent becoming occurs? If we take a systems view and concede that interactive art experiences are characterized by interactions between two or more systems, then we must decide what these constituent systems are, where one system ends and the other begins (even if, or arguably *especially* if, this is unclear). This necessarily involves defining a system's boundary.

Discussions of boundary with regard to interactive/new media art are altogether not uncommon in cultural studies. Though even here it is not deeply scrutinized as a concept. Stern largely avoids discussion of boundaries in his analysis (except to eschew the notion altogether). However, the extent to which an entity is or isn't "extant" with regard to another should be seen as a dynamic fluid continuum, not a rigid unchanging duality. Viewed in this way, boundaries are crucial for Stern's "entwined relationships" as they dictate what and how information and materials flow between boundaries and give rise to such relationships. In neocybernetic theory, concepts such as autonomy, emergence and self-organization all hinge upon notions of boundary. Boundaries in cybernetics and autopoietic theory are semi-permeable. The closely related concept of closure describes how a system establishes its own viability as a system (i.e. its autonomy) by adaptively selecting aspects of the environment to which it will respond. This paradoxical "openness from closure" principle states that a system's openness to alterity is intimately bound up with its autonomy. In other words, its boundary and closure are specifically what allows the system to become "entwined" with its environment, but not so entwined that it no longer exists as a discrete system. Boundary and closure are what help define autonomy.

While perhaps still privileging technology, Mark Hansen (2009a) offers at least a way out of this confusion by using the language of neocybernetics to argue for provisional and contingent boundaries. His notion of a "system-environment hybrid" — a conception founded upon the problematization of neocybernetic notions of boundary and closure — introduces a high degree of indeterminacy, contingency and subjectivity both to the process of selection of relevant environmental factors and of overall reduction of environmental complexity that is at the core of the autonomy of a system. Hansen argues for contingent and multiples levels of organizational closure, making a distinction between autopoietic closure and overall system closure more broadly. He delves deeply into theorizations of closure and autonomy and how we might understand them in a "highly technologized, 'posthumanist world'" (113) and argues for a more flexible and adaptive understanding of autopoiesis and the concept of closure as originally developed by Maturana and Varela.

Hansen's arguments draw significantly from Felix Guattari who also argues for a rethinking of closure and autopoiesis (Guattari 2001). Guattari argues for autopoiesis to be rethought of in terms of a collective autonomy and agency arising from interactions with humans and other machines, which he describes as "entities that are evolutive and collective, and that sustain diverse kinds of relations of alterity, rather than being closed in upon themselves" (42). For Guattari this necessitates a rethinking of autopoiesis to a conception where boundaries and closure are less stable and are instead dynamic and emergent. Echoing this call, Hansen asserts that the technical sophistication and intensity of our environment has evolved to such a degree that we must pay closer attention to the agency wielded by it (through increasingly technical means). This agency, calls for a more provisional, dynamic and ultimately less stable notion of closure, wherein the environment itself can cross blurred boundaries and effect change in the organism. Intelligent machines are for Hansen "mediators for human co-evolution with the environment" (Hansen 2009a, 125). Human-machine cooperation across system boundaries, and the complex alterity it entails is fundamentally, Hansen argues, altering human cognition. Thus, instead of the organism selecting which aspects or perturbations of the environment are relevant to it (as in traditional autopoiesis), the environment itself can suggest certain changes in the organism. This has the effect of engendering a more collective form of agency and thus allows us to see that "human beings must welcome the alterity of machines as a crucial source of connection to a world ever more difficult to grasp directly" (ibid.). Hansen characterizes such interactions across the system/environment divide as leading to a "system-environment hybrid". The high degree of indeterminacy and ambiguity this conception introduces, complicates the process of determining when the crossing of a (shifting and contingent) boundary has occurred and when and where boundaries between system and environment even get drawn, thus adding additional levels of uncertainty and subjectivity to the very notion of system. The relevancy to interactive art here can best be summed up in Hansen's assertion that this flexibility and dynamism can open up "new cognitive dimensions, but only when correlated with the most creative, culturally and technologically catalyzed interactional possibilities" (123–124). It may also help us see Stern's criticism of Hayles's analysis in a new light. An interactive artwork and a human can cooperatively enact a (blurry) "borderland" where the self "diffuse[s] into the immediate environment" without the artwork/technology and the human being a priori "extant entities". In effect, the entwinement is a matter of degree rather than of kind (i.e. the artwork/human interaction amplifies the entwinement that already exists between shifting and contingent boundaries). This introduction of "a high degree of indeterminacy, contingency and subjectivity" with regard to how a system constructs its boundaries and interacts with its environment also has strong correlations with Merleau-Ponty's philosophy of ambiguity and his notion of form.

4.5. Collectively Emergent Autonomy

Guattari argues for autopoiesis to be rethought of in terms of a collective autonomy and agency arising from interactions with humans and other machines. This view underscores that boundaries are in fact crucial for "entwining" interactive art experiences. But can we provide a more fine-grained analysis of this dynamic? Many of the emergent artworks discussed in Chapter 3 are good examples of systems that utilize simple techniques for generating emergent complexity. More importantly, we can discern in them a view of interacting emergent systems whose constitutive autonomy is seen as arising from situated, contingent and perhaps most importantly (and a bit counterintuitively) collective networked interactions with their surrounding environment. Emergent artworks instil in the human interlocutors a sense of being connected to a larger system or set of systems, whose complex interactions affect and are affected by human behaviour. The effect may be considered longitudinal as system and participants may flow in and out of emergent relations whose full impact may not be fully appreciated for some time and may require numerous interaction experiences. These works most closely resemble cybernetic models of conversational interactions between system and environment, where agents that stand out in their alterity and function as triggers or indirect forms of interaction and in doing so (and by triggering new sets of conceptual relations) foster a larger sense of embeddedness and complexity of interaction with other systems in a larger order fashion with the larger environment; in a sense a co-evolution of body, world and technology, a feeling that we are not separate from our technologies but like the environment, are continuous with it. What I propose is a model of analysis that seeks to highlight how the range of aesthetic experiences characteristic of the emergent arts may showcase how humans and physically situated autonomous technological systems may co-construct and co-evolve with their environment through their interactions. These experiences motivate a sense of being embedded and co-emergent with an "other" and more broadly, with an increasingly technological environment. These alterity relations (what I have termed heterogenesis) are a core element of the emergent arts. These works thematize and enact explorations of heterogeneous complexity, variety, cooperation and conversation. They often exhibit a sort of tension between observing a continuously fluctuating set of complex environmental patterns while simultaneously being part of them, thus influencing the very dynamics that one is observing. I refer to this as "collectively emergent autonomy".

The notion of intelligent systems co-evolving with their environments is a relatively recent development, founded upon links between artificial intelligence (AI) and the enactive paradigm in cognitive science (De Loor, Manac'H, and Tisseau 2009; Varela, Thompson, and Rosch 1992) but also having ties to neocybernetic thought (von Foerster 1960). This paradigm of "embodied cognition" describes the processes whereby the nervous system links with the sensory and motor capabilities of an organism to connect that organism to its physical environment. Rooted in the concept of autopoiesis — which Francisco Varela describes as "a characterization of the mechanisms which endow living systems with the property of being autonomous" (Varela 1981, 14) — enaction explains how cognition emerges when system and environment, through networked architectures, trigger and select in each other structural changes. This dimension of structural coupling helps elucidate how living systems exhibit emergent properties such as autonomy via complex interactions and other relations of circular causality with other living systems and with their surrounding environment. Enaction's overall holistic approach — coupled with its philosophical roots in embodied phenomenology[22] — provides a contrast to the traditional reductionist

[22] It is well-known that the concept of autopoiesis and enaction were influenced by the phenomenology of Merleau-Ponty. See (Varela, Thompson, and Rosch 1992; Thompson 2007) for more.

approaches of science and engineering and gives it a natural resonance with artistic approaches. Thus, when applied in an AI or A-life context, the environment — like any other agent — becomes a first-class actor and human sensorimotor interaction becomes an important co-evolutionary component. Autonomy then is constructed through these co-evolutionary interactions. The insight explored here is that the integration of these experiences — recurring longitudinally within the context of heightened aesthetic experiences that are characteristic of the arts and in particular the emergent arts practices I have outlined — may (for the human at least) lead to changes in perception and awareness. This echoes in many ways the drive for "symbiotic intelligence" between humans and their increasingly technologized environments and is an important feature of emergent artworks. Emergent artworks emphasize the ontological nature of autonomous systems. Their capacity to simply *be*, "to assert their existence" and — through their interactions with their environment — "shape a world into significance" (Varela and Bourgine 1992, xi). This model also recognizes that concepts such as emergence, autonomy and interaction have to be understood as being bound up with one another. Recognizing this may offer fertile conceptual ground for further theoretical and artistic investigations.

4.6. Distributed Intentionality

How can a subjective experience of collective autonomy and blurred boundaries with technological systems be described phenomenologically? This section attempts to do so by explicating the concept of distributed intentionality (first introduced in Chapter 2). This concept draws upon and extends the phenomenological model of intentionality to include its alteration by or adaptation to, the varied dynamics of a technologized lifeworld. As discussed in Chapter 2, intentionality is a central concept in phenomenology. For phenomenologists to say that consciousness is intentional is to say that it aims, is directed toward, or "intends" something beyond itself. Experiences of seeing, hearing, remembering and so on are experiences of seeing, hearing and remembering something. The intentional structure of consciousness is an intrinsic element of human experience.

Up to this point I have defined intentionality somewhat narrowly as primarily being about object-directedness. However, intentionality can also be considered a general openness to the world and to what is "other" (Thompson 2007, 22–23). In essence, intentionality is the phenomenal experience of alterity in varied forms. While object-directed experiences certainly include consciousness of elements that are distinct from us (and can thus be classified as "other"), there are many experiences that do not have this objected-directed quality. Experiences such as pain, exhaustion or euphoria are just a few examples of intentional experiences that are not "about" any specific object of consciousness. These experiences appear (at least on the surface) to be self-enclosed. Yet phenomenology sees all intentional experience as being based upon the idea of consciousness as *not* being self-enclosed (ibid.). While this may appear to be a contradiction, as Evan Thompson notes, these types of experiences "do qualify as intentional in the broader phenomenological sense of being open to what is other or having a world-involving character" (ibid., 23). Bodily feelings, internal moods and emotive patterns are not self-enclosed and in fact shape how we perceive and relate to the world as they "present things in a certain affective light or atmosphere…" (ibid.). Shaun Gallagher notes how this aspect of openness, which exists outside of or prior to conscious experience — via what he calls (following Merleau-Ponty) the "body schema" — acts to shape perception and consciousness (Gallagher 1995). This "world-involving character" of intentionality, of being open and amenable to alterity in a somewhat indistinct, dynamic and sometimes non-object-directed manner, is what I wish to focus on here.

Autopoiesis and the enactive approach to cognition use self-organization and autonomous dynamical systems as explanatory tools. Such systems bring forth or enact meaning via processes of co-determination between inner and outer, system and environment; what is sometimes referred to as an organism's history of structural coupling with its environment. As Evan Thompson notes, this form of self-organization echoes the correlational structure between subject and object that makes up the structure of intentionality (Thompson 2007, 26–27). Drawing from the work of Jean-Pierre Dupuy and his discussion of the "missed encounter" between cybernetics and phenomenology (Dupuy 2000, 104–105), Thompson argues that external events do not arrive to a system "already labeled" and are instead given shape, meaning and status *as* external events via the system's own internal dynamics (its autonomy). Thompson interprets Dupuy's analysis by arguing that this intentional meaning or significance corresponds to "an attractor of the systems dynamics (a recurrent pattern of activity toward which the system tends), which itself is an emergent product of that very dynamics" (Thompson 2007, 27). Echoing Merleau-Ponty's characterization of relations between a living system and its environment, Thompson sees the external world as constituted for a living system via emergent processes of circular causation such that the system's self-organizing activities and intentionality may be seen as arising out of these emergent processes of adaptation that bring forth a world for the organism. This co-emergence of a domain of interactions between system and environment leads to what Varela has called "sense-making": the organism's orientation toward that which is significant and valent in its environment. This significance and valence is not a pre-existent property that is "out there" but rather is enacted, brought forth by the system via the circular relations mentioned above (ibid., 158). These are the natural roots of intentionality. In neocybernetic language, we can say that intentionality arises out of the operation closure and interactive dynamics of autopoiesis (ibid., 159).

Broadly speaking, autopoiesis and intentionality may be viewed as a method of reducing environmental complexity and thus helping to define one's autonomy as a living system. It stands to reason then that increasing environmental complexity (via increasingly technological means that act as perturbations) may motivate system change and thus alter the shape and character of intentionality and the intentional experience that results, this change being necessary to maintain the system's autopoiesis (its autonomy and viability). Understood within the context of the phenomenology of human-technology relations, intentionality then is not only directed at technological objects directly, but may be seen as part of a "world-involving character" that achieves a heightened awareness of an already operating social-technical milieu that situates our very being within the midst of countless omnipresent technologies that shape and color the rhythms and cadences of life. In other words, it connects us to our technologized lifeworld. Furthermore, with neocybernetic notions of emergence and Hansen's notion of system-environment hybrids as conceptual backdrop, we can imagine distributed intentionality as a single intentionality that while referenced to a single individual is not locatable solely within that individual at any single point in time. Rather it exists in a blurry intentional zone. It may consist of any number of systems (human, non-human, machine), each either ceding or co-constructing a portion of their intentionalities as a result of their interactions. This ambiguous (in the Merleau-Pontian sense) and mercurial form of intentionality exhibits a metastability that continually coalesces and disperses as a result of fluctuations in the interactional dynamics.

Thus, as Guattari and Hansen do in rethinking autopoiesis via a rethinking of notions of closure and boundary in order to theorize how cognitive functions may be shared between humans and machines, we can posit that intentionality and its correlational and world-involving character is constructed through and across distributed interactions with a complex technologized environment. If the external world is constituted by virtue of its self-organizing activity (its autopoiesis) and this activity includes a highly technologized environment — with an increased agency that can influence or suggest changes in the organism — then it stands to reason that the system's intentionality would be dispersed somewhat in that environment. If intentionality is a form of self-organization, it follows that this new notion of system-environment hybrid includes a sort of hybrid intentionality, dispersed somewhat through this highly technologized environment. Distributed Intentionality then may be characterized as the phenomenal component of a system-environment hybrid.

It is important to note however, that this intentionality need not necessarily occur in full conscious awareness. As already mentioned, Shaun Gallagher advances the idea that certain preconscious factors of the body act as constraints on perception and experience. Gallagher's theory extends Merleau-Ponty's ideas relating to the body schema, which the French philosopher describes as "an experience of my body-in-the-world" (Merleau-Ponty 2002, 163–164). Merleau-Ponty stresses how the body schema modifies our impressions of incoming sensory impulses, to the point where some impulses may not even be perceived if the sensory organ is not attuned to them (86). Following Merleau-Ponty, Gallagher also stresses the body schema's role in relating the organism's sense experience to the environment, noting that the workings of the body schema are not possible without a relation to the environment (Gallagher 1986). Thus, just as embodied organism-environment coupling is central to Burnham's vision of a re-imagined aesthetic experience, so too is it central to Gallagher's and Merleau-Ponty's view of a human being's overall sense experience and world construction.

Gallagher's extension of Merleau-Ponty's model of the body schema and its "extraintentional operations" that exists outside of or prior to conscious experience but still influence experience and thus shape the meaning that arises in conscious reflection, shows us how a complexified, intelligent technological environment can influence how we experience and constitute our lifeworld. Still, in order to elicit the "embodied, felt sense" of a symbiogenic experience, it is necessary to reconcile the inherently preconscious function of distributed intentionality with the idea of a feeling body that is aware of the co-evolutionary processes in question. Perhaps it is useful to discuss what Brian Massumi calls the "incorporeal" dimensions of the body (Massumi 2002, 5ff.). Massumi describes the body as having a "charge of indeterminacy" which is not itself part of the physical body, yet is somehow still "material" (ibid.). Comparing this dynamic to that of matter and energy, both of which exist as "mutually convertible modes of the same reality," Massumi describes the incorporeal as something akin to a "phase shift of the body," a temporally indistinct "unfolding" (ibid.). This may have some relation to what Gallagher calls the "absently available" and "experientially unowned" dimensions of the lived body (Gallagher 1986, 147, 153ff.). Gallagher notes how the lived body (as opposed to the physiological or objective body), while partly a consciously felt body is nevertheless influenced by processes that are not consciously felt but may still influence the contours of experience. Furthermore, as Merleau-Ponty states, things are not simply given to us in perception but instead are "internally taken up... reconstituted and experienced... in so far as [they are] bound up with a world" (Merleau-Ponty 2002, 380–381). Thus, a symbiogenic experience and its location within a zone of distributed intentionality would necessarily leverage the inherent ambiguity and fluidity of this dynamic, perturbing one's extraintentional operations. This is a phenomenon that is brought forth from a diffuse and mercurial set of operations, located neither completely with the human nor with the machine — outside of immediate phenomenological reflection yet somehow still capable of being apprehended (if only for a moment) by tending to the shape it carves out in space and time.

4.7. Summary: Towards a Theory of Symbiogenic Experience

Symbiogenic experience is multi-faceted, always changing and co-emerging. There is not one kind of symbiogenic experience but many. Like shoots of a rhizome, they branch and intersect in multitude of ways. But aspects can still be teased out by first employing the primary phenomenological characteristics of emergence, distributedness and culture-history as a general context. With that context established, I have offered four theoretical concepts that begin to comprise a framework for analyzing emergent artworks and the unique experiences they bring forth. These concepts are not mutually exclusive and no doubt an experience can have aspects of more than one. Emergent artworks may provoke or enable an experience of embodied awareness of what I am calling co-evolution and what can be understood in neocybernetic terms as processes of crossing provisional boundaries, collective autonomy and distributed intentionality — within a dynamic that I have defined (following Merleau-Ponty) as ambiguous in character.

This proposed framework accounts for an awareness of an already existing co-evolutionary dynamic; awareness made possible by the heightened, intensified experiences characteristic of the arts. In other words, human-technology co-evolution already exists and the emergent arts — as sketched out in this framework — can make us more aware of it. The framework proposed here attempts to provide a microscope-like lens that examines the ways that emergent arts enable us to see elements of our relationship with technology that we otherwise would not see and in doing so may provide a different way of thinking about that relationship. The next three chapters will describe artworks developed for this dissertation and will discuss their experience with this framework in mind.

5. Precursor Artworks

This research combines theory and practice (Figure 5.1, reproduced from Chapter 1). The **circular** (in the cybernetic sense) relationships between them, as part of the same dynamic process of discovery, are an important aspect of this research. Making/doing/thinking/observing are all part of the same creative and hermeneutic process. Constructing interactive artworks then is, in a sense, part of theorizing (and vice versa). With this in mind, the next three chapters detail the development of four interactive artworks that comprise the tangible/practical component of this dissertation.

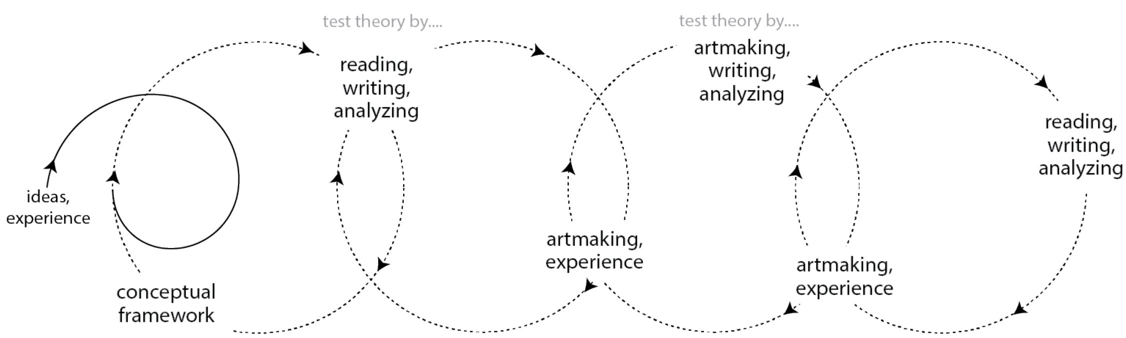


Figure 5.1 Art research process used in this dissertation, integrating a constructivist epistemology

This chapter gives a brief overview of two projects that I consider precursors. This research started informally with these two projects. I introduce them in order to highlight the progression that has taken place over the last few years in the thinking and making of this research. These projects were primarily concerned with internal embodied process, or an inner world. What I learned from these projects if nothing else was that there was a complicated relationship between technology and perception and that the body was at the center of this relationship. This pushed me toward exploring the phenomenology of Merleau-Ponty. With regard to my art practice, I learned that in order to answer the questions I was interested in asking I needed go beyond creative mapping or interpretation of bodily data. I needed to explore embodied and other non-symbolic forms of communication and interaction with intelligent technologies. This would eventually lead me to the sensory substation work of Paul Bach-Y-Rita that lead to *Protocol*. Chapters 6 and 7 describe the development of the conceptual, aesthetic and technical structures of *Protocol* and *Biopoiesis*, the two artworks that formally comprise the tangible/practical component of this dissertation, as well as the context within which each work was developed. It includes phenomenological descriptions and analyses of my own experiences with the works and analysis of the deeper conceptual connections to the symbiogenic framework.

This chapter however is concerned with *BodyDaemon* (2005-06) and *Naos* (2008-09). *BodyDaemon* represented the first informal inquiry into human-technology co-evolutionary experience. It approaches the problem in a very direct and obvious way: by directly engaging the body with a technological system in a way that makes the system dependant on the body to function and in so doing, extends or enhances the body in some way. *Naos* expands upon some of these ideas and takes a more critical stance by exploring possible future scenarios where the cognitive and emotional states of humans are monitored, profiled and classified. This research started informally with two projects and thus, they aid in establishing some context for understanding the overall research presented in this dissertation.

5.1. BodyDaemon

5.1.1. Introduction

BodyDaemon is a bio-responsive Internet server. Readings taken from a participant's physical states, as measured by custom biofeedback sensors, are used to launch and configure a fully functional Internet socket server. For example, more or fewer socket connections are made available based on heart rate, changes in galvanic skin response (GSR) can abruptly close sockets, and respiration amplitude can affect the rate at which data is sent to clients.

This project was realized as an installation/demonstration where participants were invited to put on the biosensors and connect themselves to the server (Figure 5.2). They (and others) could then watch as three client applications were displayed across the room as they mapped their bio/server data to sound and graphics. They could also see real-time server data on the command-line terminal display of the server machine itself (Figure 5.3). This prototype was exhibited at the *ISEA Festival and Symposium of Electronic Art* in August 2006.

Figure 5.2 Participant viewing the *BodyDaemon* server's output while connected to the system.

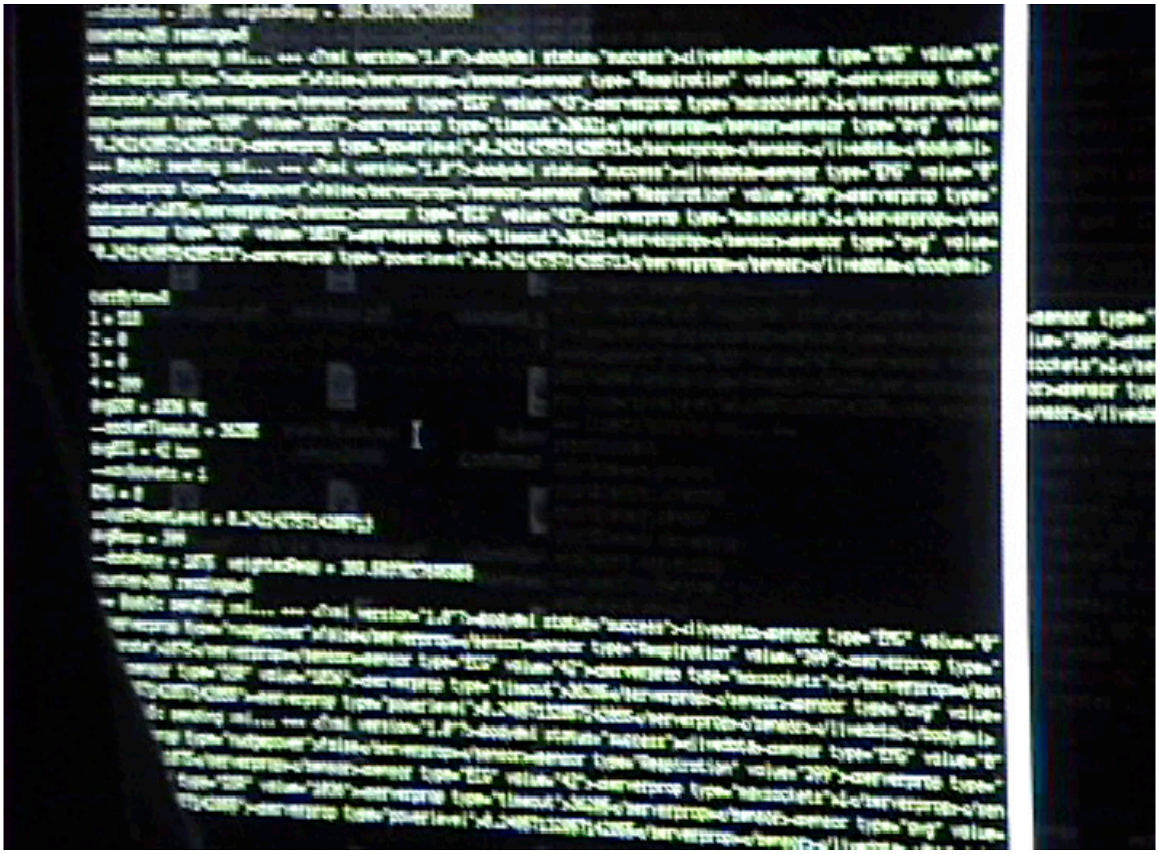


Figure 5.3 The BodyDaemon server's command-line display

5.1.2. System Overview

Aside from the physiological monitoring component, the system itself followed a standard client/server model (Figure 5.4). Communication takes place over a persistent network socket. Client applications can thus use the data to continuously visualize, sonify or otherwise render the live bio-data. The system consists of four different custom biosensors connected to a standard microcontroller. These include a heart rate monitor, a respiration sensor, a GSR sensor and an EMG (electromyography or muscle movement) sensor. The signals from these sensors are then sent to the microcontroller that is connected to a desktop computer via a standard RS-232 connection. This computer runs the *BodyDaemon* server application. Rather than measuring data in a scientific context, all data mappings strategies are arrived at intuitively.

The *BodyDaemon* server (as the name implies) runs as a daemon process, waiting for the appropriate conditions in which to spawn. In this case the "appropriate conditions" are not only client requests but also biosignals from a participant's body. When these signals collectively reach their selected thresholds, the server process is spawned, and the system is ready to accept requests. The server itself is essentially an XML (Extensible Markup Language) socket server, with messages between client and server taking the form of continuous XML streams.

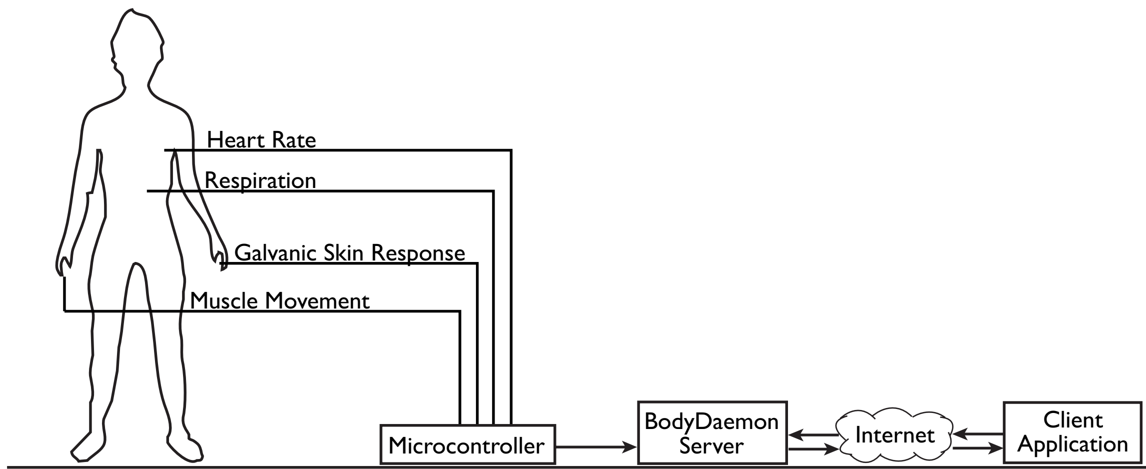


Figure 5.4 *BodyDaemon* system model

Once the server is running, it is configured in part by the participant's physiological readings. It does this by mapping the incoming physiological data to various server properties. Thus, instead of a standard configuration file, the system uses physiological data as its method of configuration

BodyDaemon also establishes a protocol for the transmission and retrieval of bio/server data from bio-responsive servers across the Internet. It takes the form of an XML schema that defines ***bodydml***, or BodyDaemon Markup Language. Client applications need only to implement this protocol by sending properly formatted xml messages to the server. Details on the protocol as well source code and examples of client applications can be can be accessed online at the *BodyDaemon* project web site.[23]

[23] http://ccastellanos.com/projects/bodydaemon/

5.1.3. Body as Protocological Agent

BodyDaemon is a conceptual piece based on a simple though often obscured idea: current views of culture are heavily influenced by technology, to the point where technological and computational paradigms are the prism through which we all view and understand ourselves. One of my motivations in conceptualizing and constructing the piece was to look for alternatives to this techno-centric view. The body currently occupies a contested space in this problem: effaced and under-represented in the world of traditional computer science and engineering research while simultaneously being engaged and made acquiescent in the world of biotechnology research. Although this has been gradually evolving over recent years, no coherent theoretical framework currently exists within technological design to deal with these issues. The approach taken to fill this gap is through a particular form of technology-based artistic inquiry. *BodyDaemon* attempts to shift our perspectives in these matters by positing that our technologies can be shaped or informed by our physiology, physical experiences and consciousness, rather than just the other way around. This is achieved by engaging the body with the world of computer networks and protocols, where the body itself functions as what I call a "protocological agent", and the computer (in this case a server) is informed and influenced by it. With *BodyDaemon* the body is represented as information patterns, and the physiological processes that generate the patterns reconfigure the computer system.

Networks are everywhere, quickly becoming the dominant organizing principle of industry and society at large (Galloway 2006). As the fields of health and medicine continue to merge with the fields of computer science and engineering (as evidenced by the rapidly growing field of biotechnology), the body's relationship to networks and network protocols needs to be examined more fully. *BodyDaemon* represents an alternate way of looking at body networks. It is a form of artistic inquiry that focuses on the context and meaning of the body within this emerging paradigm, a paradigm that I believe has the potential to fundamentally reconfigure our lived embodied human experience as well as our social and cultural lives.

A body network cannot exist without a body. Although self-evident, this runs contrary to the historical view of information as a disembodied entity that can pass through different material substrates unaltered (Hayles 1999). At the heart of most computer science research, this has historically acted as a potent force to continually efface the body and eliminate embodiment from digital technologies. The information of a body network is by its very nature *embodied,* and thus tends to complicate this paradigm. We do not believe that technology can erase the body. But it does present us with an altered one, or at least an altered relationship to it. Thus, the focus of *BodyDaemon* is in examining this relationship.

Like RM Page's prescient speculative essay on what we would today call affective computing (Page 1962), *BodyDaemon* was a speculative attempt at exploring human-machine symbiosis in a artistic-conceptual context and thus established a foundation for further investigations into what I would eventually call symbiogenic experience.

5.2. Naos

5.2.1. Introduction

Naos is an interactive art project that explores possible future scenarios where the cognitive and emotional states of humans are monitored, profiled and classified based on their physiological states. A collaboration between Carlos Castellanos and Luther Thie (Principal R & D) with Joseph Cori , Eyal Fried, Philippe Pasquier as collaborators/consultants, the project is contextualized as a research group dedicated to the investigation of automated biometric classification and the exploration of biometric architecture.

Building upon the success of the *Acclair* project,[24] of which it is an extension, *Naos* takes its inspiration from the various data mining and machine learning technologies that for example, attempt to determine categories of consumers, or to ascertain if one is a "security threat". The artistic motivation behind the project is centered not so much around researching new techniques for effective classification, but

[24] http://www.acclair.co.uk

with examining and exploring the very techniques themselves. The group is simultaneously fascinated by and sceptical of these types of psychological classifications, especially when an “intelligent” machine determines them. So here we offer an experience for people to investigate their own feelings about possible future uses of biometrics technology and psychological testing procedures. Our uncertainty regarding the validity and usefulness of such tests inspires us to create situations for others to experience and therefore be able to question the results based upon a direct experience. *Naos* creates a situation where an individual is interfaced with biometric technologies and confronted with the thorny issues related to biological data collection and security, thus making it a very real and tangible experience. The work seeks to examine similar, very real tests and situations that exist today and will likely become more prevalent as these technologies proliferate. From another perspective, we were also raising the broader question of what happens when the human body and its emotional and cognitive responses become part of a sophisticated information system. *Naos* was exhibited at Montalvo Arts Center in Saratoga, California in 2008 and Root Division Gallery in San Francisco in 2009.

5.2.2. Participant Experience

The installation consists of a capsule structure that serves as a biometrics service station where the user enters and is "hooked up" to the physiological monitoring (biometrics) equipment. A typical participant experience of the artwork is as follows: The participant approaches the service station where an attendant greets him or her and explains how the process works. After being safely secured within the capsule and having the physiological monitoring equipment attached, the user undergoes a test procedure while the biometrics data is recorded and stored in a database. After first gauging the user’s physiological data for five seconds in order to establish baseline readings, an image is projected onto the capsule’s ceiling. The participant's physiological response to the image is measured. Then via statistical classification — and depending on the specific test being administered — the participant is rated and placed into one of several possible categories. Another image whose data is closest to the measured physiological data is then shown. This loop continues in an attempt to achieve "equilibrium" — a point where the image’s expected physiological response and classification and the participant's actual response and classification are the same. Thus, in a circular relationship, the system influences the participant's body and brain that in turn influences the system (see Figure 5.5). Examples include being classified as "aggressive" or being given a "loyalty" rating of 0.5.

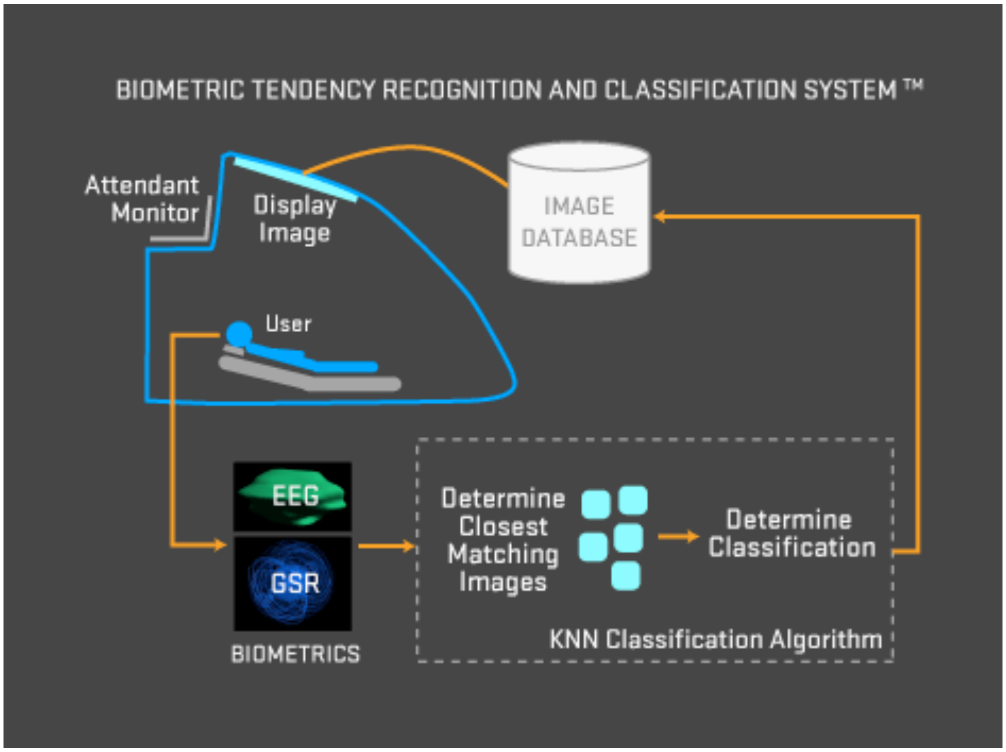


Figure 5.5 Diagram of *Naos*

5.2.3. System Overview

System-wise, the core of the *Naos* project was the development of the Naos Platform™, a biometrics and psychological testing system. The Naos Platform™ includes the Naos Biometrics Capsule, the Biometric Tendency Recognition and Classification System (BTRCS)™ and the Naos Adherence Index™. The current system implementation utilizes a Neurosky(TM) EEG brain-scanning headset, a Thought Technologies(TM) Galvanic Skin Response sensor, biometrics recording software, user profile and biometrics database, architectural capsule system and a psychological test example: the Naos Loyalty Test™. This test classifies individuals based on their reactions to people of other races in order to determine their level of prejudice. It serves as a very basic example, one of many that could be undertaken using the Naos Platform™.

Integral to the Naos Platform™ is the Naos Biometrics Capsule (Figure 5.6), an example of biometric architecture — an ergonomic brain-computer-architectural interface. Its design is influenced by recent research in the neurosciences and its impact on the design of living, work and therapeutic spaces. The intention is to explore the influence of architectural spaces on neural activity and emotive states.

Figure 5.6 The *Naos* Biometrics Capsule

The Biometric Tendency Recognition and Classification System (BTRCS)™ is a software application that continuously measures a participant's physiological responses to a given image and runs a statistical classification algorithm on the measured data that then classifies the participant into one of several predetermined categories. BTRCS forms the core of the *Naos* system. It includes a database of images that can be customized based upon the particular test being administrated. The classification is achieved using a K-nearest neighbour algorithm (Cover and Hart 1967). This machine-learning algorithm measures the distance between the participant's physiological responses to images and the responses that are in the database (what is known as the training data). With each new participant, new training data is continually being added to the system. For the two exhibitions we developed The Naos Loyalty Test™ as an example of the type of test that can be administered using our system. This test classifies individuals based on their reactions to images of people of different races coupled with questions intended to elicit emotional responses (Figure 5.7). The biometric reactions are then used to determine their level of prejudice on a "loyalty scale". The current system focuses on dividing the brain's activity into three distinct frequency bands (alpha, beta and theta). These bands are analyzed and used to discern the participant's levels of anxiety, attention and meditation. These levels are then mapped to 3-dimensional visualizations using NURBS, or Non-uniform rational B-splines. In addition, the GSR level is mapped to a 3-dimensional animating shape that increases in size as the GSR level increases. The test stimuli are also shown in correlation with the visualized biometric data (Figure 5.8).

Figure 5.7 The Naos Loyalty Test™: Images coupled with questions intended to elicit emotional responses

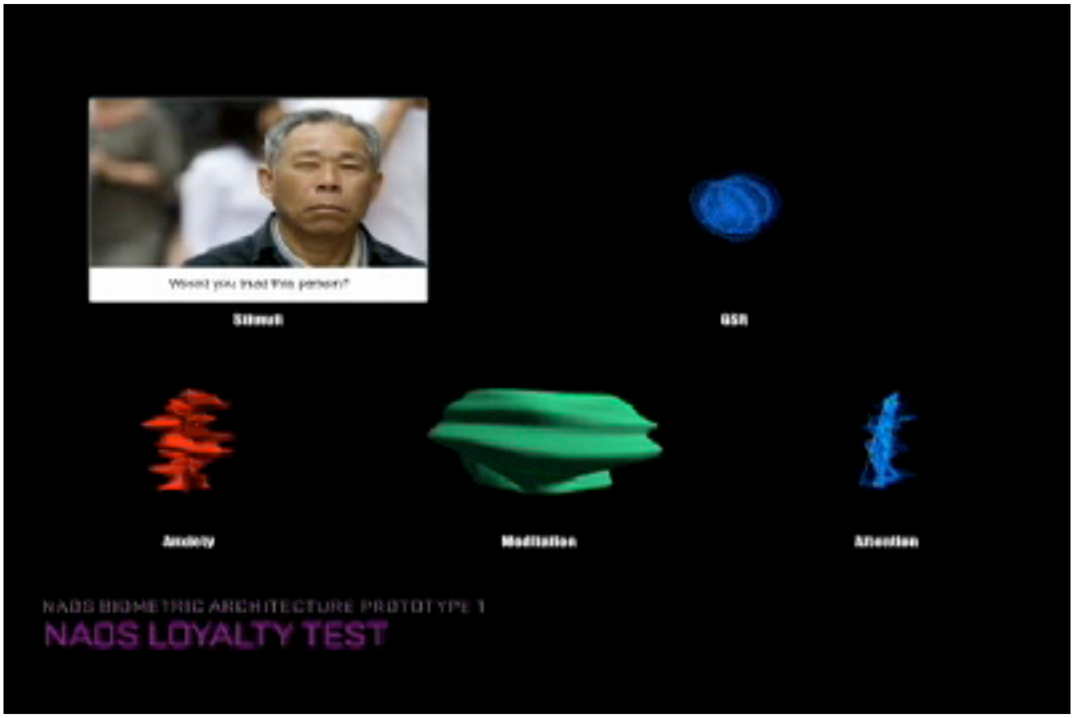


Figure 5.8 Screenshot of the Naos Loyalty Test™ showing the NURBS-based visualizations and the images and questions

5.3. Conclusions

Like *BodyDaemon*, *Naos* was constructed around the idea of directly interfacing the body and its physiological and cognitive processes directly with a sophisticated technological system. Whereas *BodyDaemon* was a protocological agent that directly engaged with computer networks and network protocols, *Naos* was about giving over part of oneself to a “thinking”, “reasoning” and ultimately “judging” machine, although it could be said that in the case of *BodyDaemon* there was a greater agency in doing so. In any case, both projects were concerned with the power and control relations involved and both were on some level about a sort of symbiotic relationship with technology (although at least in the case for *Naos* it could be seen more as a parasitic one). Although there was no direct research agenda toward exploring what I now call symbiogenic experiences, these projects explored the critical and political contexts under which such experiences could be considered. While *BodyDaemon* suggests a world of constant mutual influence of body and network in something like a biomedical context, *Naos* suggests a vision of an uneven power dynamic of mutual influence where one’s own (ostensibly private) physiological and cognitive processes are subject to use by state and corporate power structures as tools of control and regulation (something akin to Focault’s “biopower”). Although this critical aspect of what a symbiogenic experience may entail is not directly discussed in this dissertation, it nevertheless serves to highlight the multiplicities of experience that are possible. The rest of the projects in this dissertation are more concerned with outlining a framework for understanding the dynamics of these experiences as opposed to the particular political or emotional interpretations and contexts of specific experiences.

6. Protocol

Figure 6.1 Protocol

6.1. Introduction

Protocol was the first project that was formally part of my research into symbiogenic experience. I describe it as an interactive installation through which I attempt to realize a new form of human-machine symbiosis. It features a multi-modal interface and non-verbal communication system that networks and integrates a human participant with a group of intelligent digital agents that can “sense” and “communicate” with humans via sound, rhythmic patterns and electrical stimulation of the human participant's skin. Through their interactions, the agents and the human attempt to develop a human-machinic "understanding" or "equilibrium." The system is inspired and utilizes some of the tactile communication and sensory substitution techniques developed by Paul Bach-Y-Rita and others as well as "bottom-up" approaches to artificial intelligence such as reinforcement learning and subsumption architecture. Through *Protocol*, I seek to examine how a human and a physically situated, autonomous technological system can intertwine, interrelate and co-develop mutual shared meanings.

The agents in *Protocol* are conceptualized as quasi-intelligent beings that exist in electronic space (with the electronic here considered a property of matter or the environment). They are programmed to exhibit the ability to extend themselves via the human, and invite the human to reciprocate through them. The installation consists of a group of drums, one per agent, as well as a set of wearable electronic components that the participant puts on prior to interacting with the piece (discussed below). In addition to spatialized sound, these elements serve as the two-way communication interface between the human participant and the agents. The drums respond to agitation and concussive striking, and serve as the primary method by which the human communicates with the agent. The agents respond not only by processing the live, acoustic signals of the drums and generating their own sounds but also by electrically triggering muscle stimulation patterns in the participant. These patterns serve as a means for the entities to "touch" and manipulate the participant's body. In addition, the electrical stimulation patterns, along with the rhythmic patterns generated by the participant, constitute a sort of informal protocol that both human and machine co-develop and that each must learn and adapt to. I believe this motor-tactile protocol, while not always immediately discernible in its fullest sense, can nonetheless be incorporated into the subpersonal aspects of the body schema and thus influence the participant's pre-conscious movement, gesture and affective states, resulting in an alteration of the rhythmic communication patterns. Subtle changes in patterns that the participant may not be consciously aware of may serve to alter their body's attunement, or cause a "phase-shift" of bodily state. This may constitute a subtle yet important distribution of the intentional domain among the human-entity network, as the human is directing action toward the entities; yet the entities themselves may be engendering some sort of nonconscious effect on that very action (of which the participant may not be fully aware). This altering of the participant's and the machine's specific corporeal articulations could result in a shaping of the sonic, rhythmic and overall communicative dynamics that would not be possible in a non- symbiogenic state. Thus, while this is doubtless a highly subjective experience, filled with tension and ambiguity, I believe it to be one that simply cannot emerge from human or machine alone.

Protocol was developed using elements from a standard drum set. In this context, the participant can be seen as a drummer and the system as one that intertwines drums with drummer. However, it is important to note that *Protocol* is not an intelligent rhythm generation system.[25] It is not intended as a means of creating or inducing "musically interesting" rhythms. In fact, the system is not "interested" in creating any rhythm at all, as it has no concept of such things. It is merely a system that, depending on the situation, interprets being struck and communicates these interpretations to the human participant. Any machine intelligence that may or may not exist emerges from these corporeal interactions. The sounds, patterns and responses between human and machine could eventually blend, however chaotically and fleetingly, into a single, co-evolving state.

Protocol, like *Biopoiesis* (discussed in the following chapter) has both theoretical and practical aspects. In addition to the photographic and video documentation included here, I wrote notes and ideas at the end of every day that I worked on the conceptualization, design and construction of the piece. This took about a year at which point I stopped working on the piece almost entirely as I dedicated most of my time to *Biopoiesis*. By the time *Protocol* was exhibited, *Biopoiesis* was fairly well developed and the majority of my focus was there. This exhibition however, served as a useful transition point because it allowed me to observe both projects simultaneously. It helped me realize that what I was really trying to was explore complexity and heterogeneity. In part, it rekindled my interest in cybernetics, and in particular Gordon Pask's electrochemical experiments that formed the core of *Biopoiesis.* Although it may have been an awkward

[25] See for example, Arne Eigenfeldt's *Kinetic Engine* (Eigenfeldt 2006) or Andrew Brown's experiments with cellular automata and rhythm (Brown 2005) for examples of intelligent rhythm generation systems.

transition, *Protocol* nevertheless helped strengthen the link between complexity and related ideas such as emergence and **self-organization** and the experiencing of a phenomenological **lifeworld** as co-emergent and co-evolutionary by the simple fact that the techniques I was using were not giving me "real" complexity and novelty but only combinatoric variations within a predetermined state space.

6.2. Conceptual Foundations

Undergirding the development of *Protocol* was an interest in what might be called Paskian models of conversational interaction. These ideas of dynamic co-emergence and complexity would arise more prominently while working on *Biopoiesis*. Here however, they were still in a nascent stage. The focus, at least early on, was on developing my AI/machine learning "chops". Thus, the conceptual development of the piece was at first not a prominent concern, although the general themes of equilibrium and symbiosis were there. In some sense, *Protocol*, can perhaps be said to be in the mould of Stelarc's cyborg performances, as they thematize a certain brute struggle that is part of the body's adaptation to technology. However, I prefer to see *Protocol* more through the lens of conversation and exploration of understandings. Tension and struggle in the piece must be understood within that context.

6.3. Developmental Context

Most of the technical development details of *Protocol* are discussed in Sections 6.4 and 6.5. Here, I will briefly discuss the context within which the development of the piece emerged. As mentioned above, *Protocol* is the first work that was undertaken formally under the umbrella of my research into what I now refer to as symbiogenic experience. Prior to this, works like *Naos* and *BodyDaemon*, while they still touched on themes that might be described as symbiotic or co-evolutionary relationships with networks and intelligent systems, they were not undertaken within the context of a fully fleshed-out academic research agenda. I had an interest in continuing my explorations into art-based applications of AI and machine learning and more specifically I wanted to explore the idea of creating homeostatic relationships with intelligent systems that were symbolic (in that I was interested in developing a language of agreements and shared meanings) but were also based upon direct bodily relationships. In addition, while *Naos* and *BodyDaemon* utilized body sensing technologies such as EEG, GSR and heart rate, the responses of these systems were limited to visual and sonic patterns, displayed on a screen and/or played through headphones or speakers. I wanted to develop a system that delivered responses that could be felt as well as seen and heard. I also wanted to communicate via a method that can be easily and directly controlled (where intentions are perhaps clearer). In essence, I wanted a more visceral form of communication with intelligent systems. This led me to investigations of sensory substitution. It seemed a natural method for exploring the relationships between the symbolic and embodied aspects of communication. I also chose drumming for more or less the same reasons. Drumming is a primordial and ancient form of human communication and seemed an appropriate method or tool for communicating viscerally with an intelligent piece of software. There were also pragmatic reasons however. I am an experienced drummer and building a drum-based system would be reasonably simple, as I can easily get a system up and running and interact with it.

6.4. System Overview

Protocol consists of a group of drums and a belt equipped with electro-tactile stimulators that send electrical pulses to the participant's skin. These elements, in addition to spatialized sound, serve as the two-way communication interface between the human participant and the agents. The drums respond to touch, agitation and concussive striking, and serve as the primary method of communication. The agents respond not only by processing the live, acoustic signals of the drums and triggering MIDI sound events but also by electrically triggering muscle stimulation patterns in the participant. These patterns serve as a means for the agents to "touch" and manipulate the participant's body. Each drum is equipped with a microphone placed near the head that transmits the audio signal to a computer for processing whenever it is struck. As Figure 6.2 shows, the drums are patched into an audio interface (a MOTU 828 firewire interface was usually employed) that is connected to a Max/MSP program that processes the sounds for each drum Each drum in *Protocol* is also an intelligent software agent consisting of a reinforcement learning (RL) module and a subsumption module (both are discussed below). As each of the drums is being struck, the system continually analyzes the incoming performance data and responds by sending its response data back to the corresponding drum's RL and subsumption modules. This program is also responsible for generating the sounds and electrotactile stimulation patterns based upon what it is learning from the participant's drumming. As will be detailed below, the function of the subsumption module is to determine when a drum has been struck and if this event is a "positive" or "negative" event, where positive means "I like it" and negative meaning "I don't like it". Meanwhile, the RL module attempts to construct (along with the participant) the meaning of the reactions and responses (e.g. does a particular sound or tactile pattern correspond to positive or negative and is the participant responding accordingly).

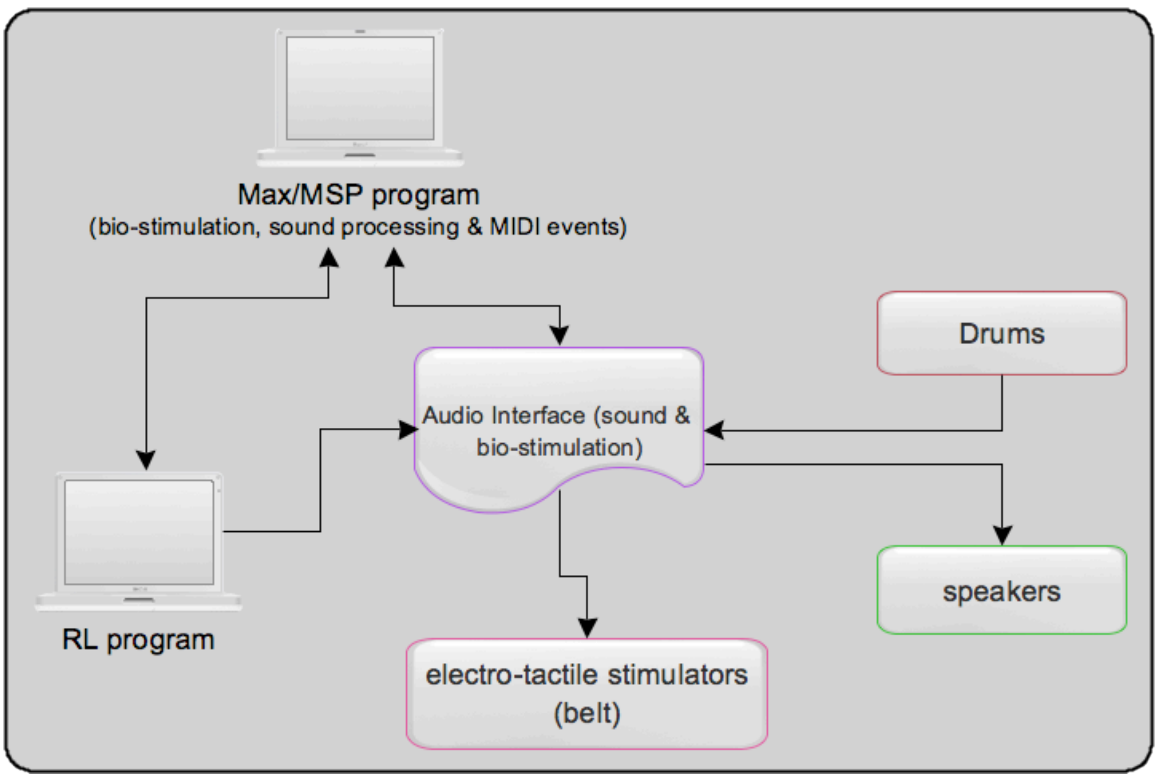


Figure 6.2 *Protocol* system diagram

6.4.1. *The Subsumption Module*

The subsumption architecture is an agent architecture developed by Rodney Brooks as a means of eliciting emergent, intelligent behaviour in robots (Brooks 1986).

Subsumption is often considered a category of behaviour-based or reactive agents since agents operate by simply reacting to their environment and carrying out simple behaviours on that environment without reasoning about it or drawing from elaborate pre-given representations of it (Wooldridge 2002, 90–91). Reactive agents are based upon the idea that intelligence and intelligent behaviour is an emergent property that is situated in the "real world" and can be better achieved without symbolic representations. An agent built using the subsumption approach is defined by two primary characteristics. The first is that an agent's decision-making behaviour is accomplished solely through the mapping of perceptual input (e.g., sensors collecting data from the environment) to a specified action that accomplishes a specified task. What are sometimes called *task-accomplishing behaviours.* The second is the organizing of behaviours into layers. This is known as a subsumption hierarchy since higher layers in the hierarchy are able to inhibit lower layers. The idea is that lower layers represent basic functions that an agent must always be able to do (e.g., a robot must avoid obstacles) while higher layers represent more complex abstract behaviours (e.g., picking up objects and delivering them somewhere). Like Russian matryoshka dolls, the higher layers can inhibit or subsume the lower layers, allowing for prioritization of agent actions (see Figure 6.3).

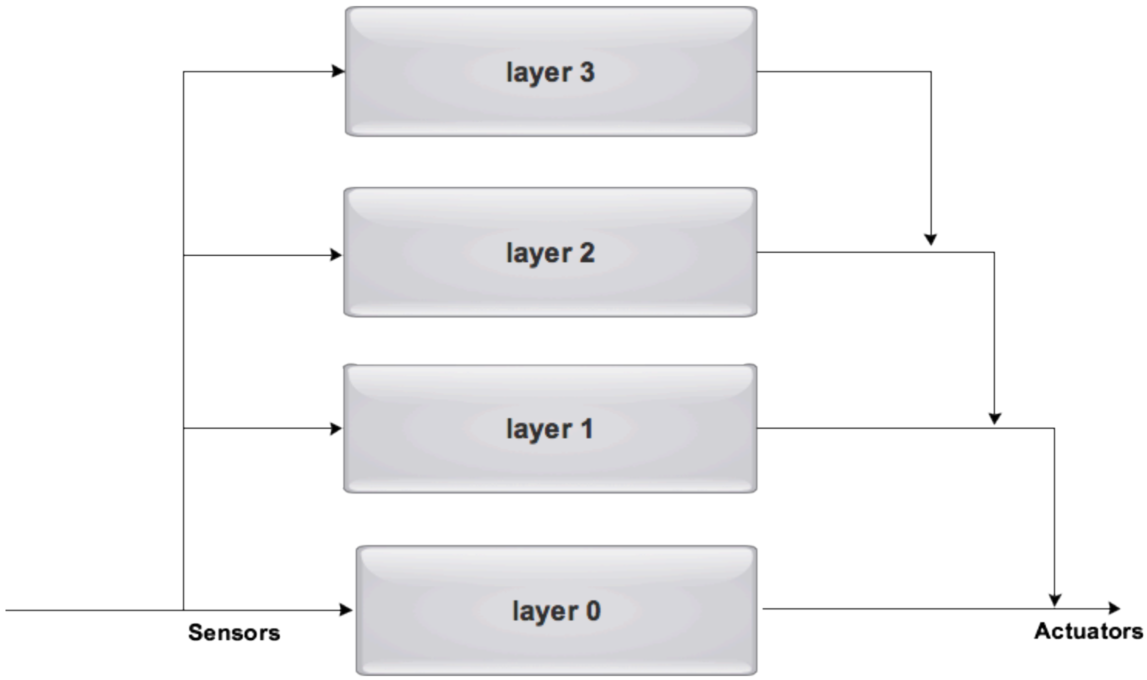


Figure 6.3 Subsumption architecture (adapted from (Brooks 1986)). Higher layers can subsume lower one when they wish to take control.

The subsumption module in *Protocol* is exceedingly simple, consisting of only two layers (see Figures 6.4 and 6.5). Layer 0 (the bottom layer) is triggered whenever a drum is struck while layer 1 is triggered whenever the drum's neighbour (a drum that is physically to the left or right of it) is struck. These layers are meant to work in conjunction with the reinforcement learning module and center around a measure of the *sensitivity* of the drum. The higher the rate and velocity with which a drum is struck, the higher the sensitivity of the drum. If one stops hitting the drum altogether the sensitivity will gradually fall to zero. The sensitivity parameter works in conjunction with the *sensitivity threshold* and *struck threshold* parameters. The former is a value, which if surpassed while the drum is being struck (or more accurately is in a struck state) will cause a layer to send a message that selects from a set of "negative" sound and electrotactile stimulation patterns, while a message to select from a set of "positive" patterns is sent if the threshold has not been surpassed. The latter value corresponds to a level at which the drum is considered to have been struck (thus filtering out mere touches of the drum or hits that are too soft for even the microphone to pick up). Implementation details of these behaviours, the sound and electrotactile patterns and all agent parameters are discussed in Section 6.5

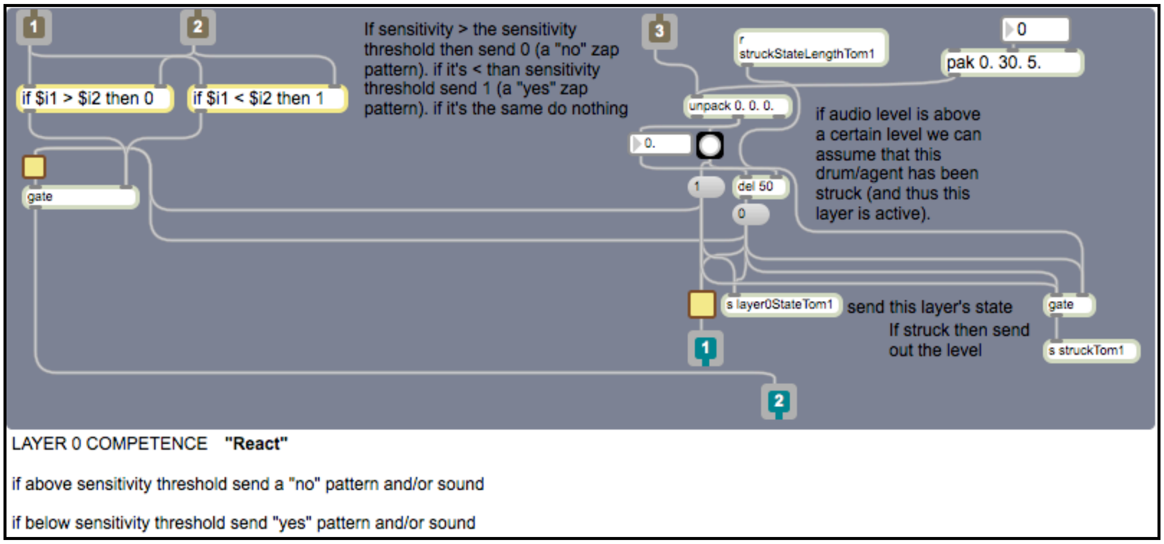


Figure 6.4 Subsumption Layer 0

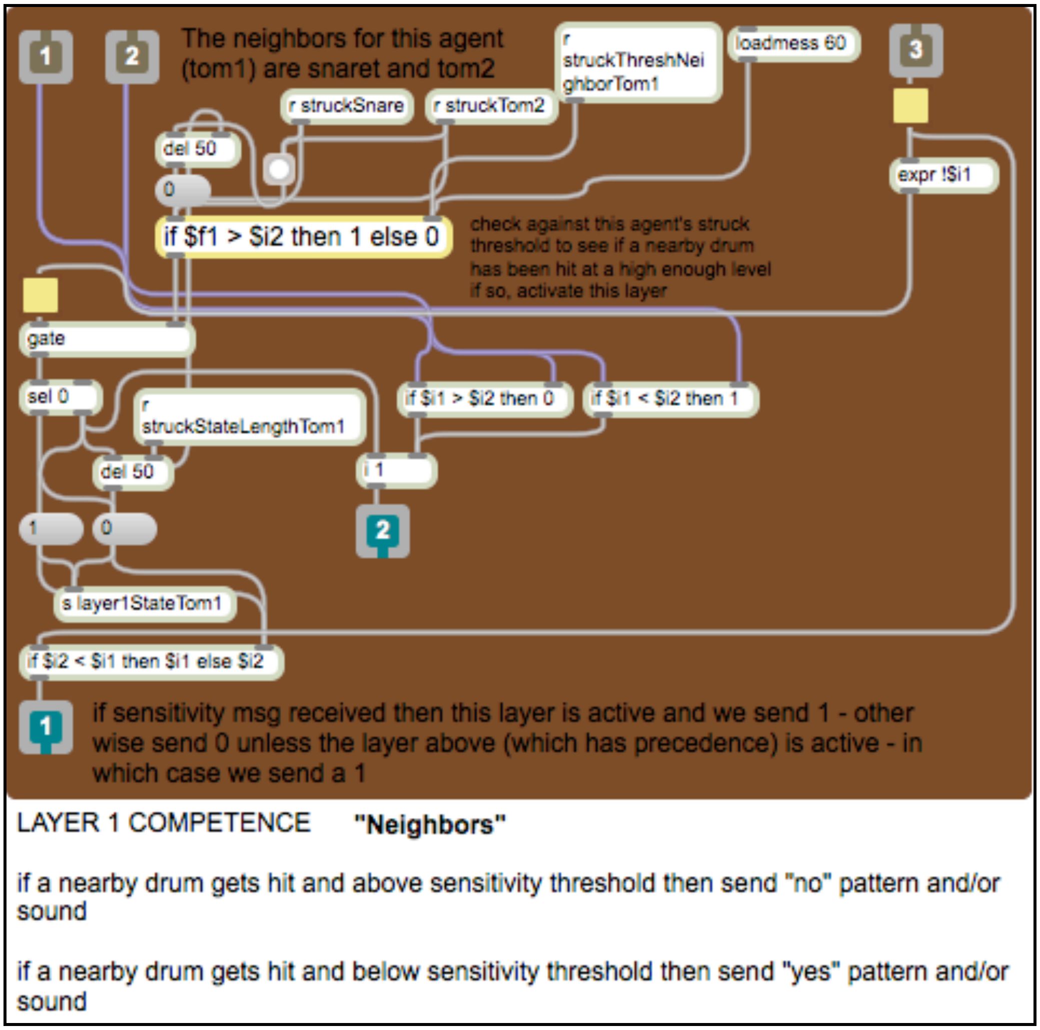


Figure 6.5 Subsumption Layer 1

6.4.2. The Reinforcement Learning Module

Reinforcement learning is a machine learning process wherein a computer program, software or hardware-based agent learns by interacting with its environment and observing the results of those interactions. The environmental features an agent is programmed to analyze and respond to are what constitute the RL agent's environment or its "world". Like the subsumption approach, RL procedures mimic (albeit very crudely) the fundamental way in which humans and animals learn: via direct, situated sensorimotor connections to the world. As humans we can perform actions and witness (most of) the results of these actions on the environment. Over time these experiences help us build up a sort of stored knowledge of our environment. The basic RL approach is composed of these trial and error interactions with a dynamic environment (Kaelbling, Littman, and Moore 1996, 237). A RL agent must explicitly explore its environment in order to learn from the consequences of its actions, rather than being explicitly taught. RL agents are not told *how* to achieve a given task or reach a certain goal but rather are programmed to simply receive rewards or punishments for their actions, to which they must adjust accordingly. Reinforcement learning then (like subsumption), is "model-free". A RL agent selects its actions on the basis of its past experiences (exploitation) and also by new choices (exploration). To successfully learn then, a RL agent must find a balance between exploration of what is unknown and exploitation of what has already been learned.

The basic reinforcement model is as follows:

- The agent observes an environmental state ***s***
- The agent determines an action ***a*** based upon some decision making function (known as a policy)
- The agent performs action ***a***
- This action changes the state ***s'*** of the environment and the agent receives a scalar reward or punishment signal ***r*** (sometimes called a positive or negative reinforcement) representing the value of this state transition
- The agent records information about the reward given for that state/action pair

Thus, the agent's actions are determined by a mapping of states to actions. This mapping is known as an action selection *policy* and its aim is to balance the trade-off between exploitation and exploration in order to maximize some long-run measure of reinforcement (Kaelbling, Littman, and Moore 1996, 239).

By performing actions and observing the resulting reward, the agent can improve the policy used to determine the best action for a given state. In theory, if enough episodes (iterations through the above loop) are made, the agent will have observed enough states that an optimal decision policy will be built up and the agent will perform optimally in that particular environment. Of course in an arts context the concerns are usually not those of optimization and achievement of pre-defined engineering goals. Computer music researchers studying RL applications in the development of real-time rhythmic agents have also experimented with more creative or contextually appropriate notions of reward (Collins 2008; Assayag et al. 2006). This includes positive rewards for the predictive accuracy of the system in anticipating the next state of the musical environment (Collins 2008) and positive rewards for paying extra attention to certain musical materials (Assayag et al. 2006). However, as mentioned above *Protocol* is not an intelligent rhythm generation system in the accepted sense. Therefore, I decided to do something a little different: to give the agent the ability to continually and indirectly influence the reward value for a given action. As will be discussed below, the RL agent's goal was to have the *sensitivity* and *sensitivity threshold* values be the same. Positive or negative reinforcement was determined by how much closer or further away these values were from each other. However, one of the actions the RL agent could perform was to change the *struck threshold* value of the subsumption module. This is a value that sets a minimum sound level at which a drum is considered to have been struck. Thus the same real world action by a participant (striking a drum at a given velocity) could (all other values being unchanged) result in a different interpretation of environmental state by the RL agent when the exact same action is repeated. While there may not be anything directly pertinent or useful in this approach from a rhythmic or musical standpoint, it does resonate with my (and Pask's) idea of learning and agreement: we are always trying to achieve goals and looking for new ones. Here, the goal state is never really achieved from a subjective perspective (though it quantitatively may be) as both system and participant are always responding to one another and trying to agree on what constitutes a drum hit or a drum hit that is too hard or soft or too many or too few drum hits, etc.; as in the real world the goals are always changing. This approach highlights the focus of *Protocol*, which is on developing a co-evolving language of shared meanings with an intelligent technological system.

States and Actions

Figure 6.6 shows the basic RL model employed in *Protocol.* The RL agents were programmed in Java and exchanged state/action data with the Max/MSP program (Figure 6.7). The goal of the system was quite simple: to have the *sensitivity* and *sensitivity threshold* values from the subsumption module be the same. Thus, a positive reward corresponded to a reduction in the difference between the *sensitivity* and *sensitivity threshold* values while a negative reward (punishment) reflected an increase in the difference.

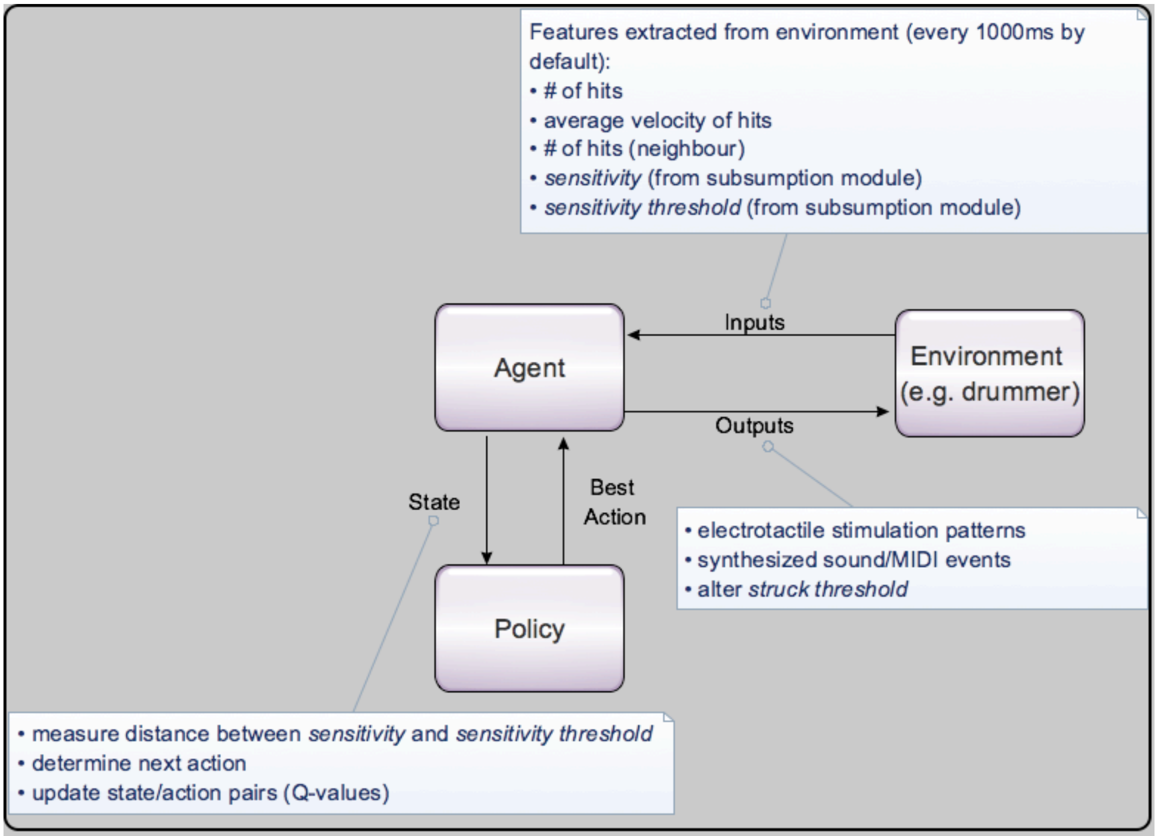


Figure 6.6 The reinforcement learning model implemented in *Protocol*

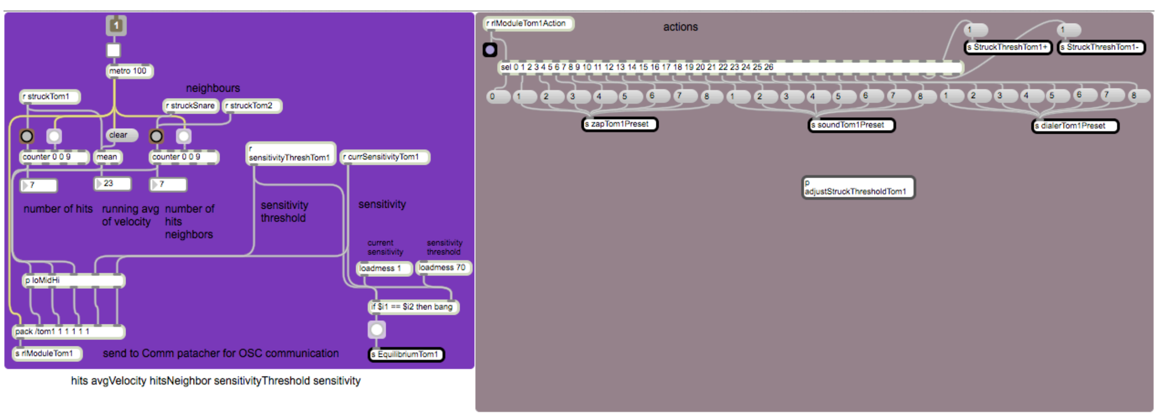


Figure 6.7 Subpatch in Max/MSP program that sends and received data to/from the RL Java program.

Table 6.1 shows the parameters associated with a state. These extracted features make up the RL agent's world. In order to reduce the memory and processing load of the RL application the number of possible states was reduced to a manageable level. Therefore all the parameters that comprise the RL agent's world were compressed into "low" and "medium" and "high". This was also an attempt to give it a more "human" feel, as it corresponds to human subjective measures.

Parameter	**Description**	**Values**
Number of Hits	Number of times drum was struck in one epoch	Varies: 0-2, corresponding to low medium and high
Average Velocity	The average velocity of the all the hits in one epoch	Varies: 0-2, corresponding to low medium and high
Number of Hits - neighbour	Number of times a neighbour drum was struck in one epoch	Varies: 0-2, corresponding to low medium and high
Sensitivity	How sensitive a drum/agent currently is (taken from subsumption module; correlates to number of hits)	Varies: 0-2, corresponding to low medium and high
Sensitivity Threshold	Level at which the agent is considered sensitive enough to react (taken from subsumption module)	Varies: 0-2, corresponding to low medium and high

Table 6.1 State data and features of the *Protocol* reinforcement learning module

Each RL agent's responses were taken from 27 predefined actions. These included eight actions corresponding to eight predefined electrotactile stimulation patterns in the Max/MSP program, sixteen different variations (eight variations each) of two synthesizer sound patterns and two actions that increased or decreased the *struck threshold* parameter. One action consisted of doing nothing. The sound and electrotactile patterns were similar but unique to each agent and were constructed in conjunction with the subsumption module. They functioned as follows: for each RL action corresponding to a sound or electrotactile pattern there were actually two versions of that pattern: the positive and negative version mentioned above. Thus, while the RL module would select say action 2, which corresponded to electrotactile preset 2, the subsumption module determined whether the positive or negative version of preset 2 was actually selected and thus heard and or felt by the participant. The way I like to describe this set-up is that the subsumption module determines whether a drum is being hit too little or too much (thus the "positive" and "negative" denotations) and the RL module attempts to determine what that means (e.g. should it send a message that it "hopes" the participant will interpret as a message to continue or stop what he/she is doing). Depending on how the participant reacts, the RL module will react so as to, in a sense, change the meanings of the patterns, causing the participant to in turn react and so in a continuing loop. For example, if a negative response (due to being above the *sensitivity threshold*) causes the participant to increase the velocity or amount of hits (and thus taking the RL module further from its goal, a negative reinforcement), that pattern may now be considered positive (even though it still one of the negative presets in Max/MSP program) and the agent will choose a different pattern that may yield better results (i.e. fewer and weaker hits). This constructing or "bootstrapping" of meaning was the core idea being explored in *Protocol*. Details of the sounds and electrotactile patterns are discussed in Section 6.5.

The Reinforcement Learning Algorithm

The RL agent learns by continually looping through an algorithm that gathers data on environmental states and performs actions in response to that data. A single iteration through the loop is referred to as an episode. The RL program in *Protocol* does not contain any pre-defined number of episodes that it will perform and typically continues until it is manually stopped (which is usually when the participant stops interacting with the system). The specific RL algorithm used in *Protocol* is known as the SARSA algorithm. The name SARSA is taken from the fact that the updates are done using the quintuple $Q(s,a,r,s',a')$ where s,a are the original state/action pair, r is the reward observed in the following state and s',a' are the new state/action pair. The pseudocode for this algorithm is as follows (taken from (Sutton and Barto 1998)):

```
Initialize Q(s,a) (values of state/action pairs)
arbitrarily

Repeat(for each episode):

   Initialize s

   Choose a from s using policy derived from Q(e.g. ε-
   greedy)

   Repeat (for each step of episode):

      Take action a, observe r, s′
```

```
    Choose a' from s' using policy derived from Q(e.g. ε-
    greedy)

    Q(s,a) ← Q(s,a) + α[r + γQ(s',a') - Q(s,a)] (update
    values of state/action pairs)

    s ← s'; a ← a'; (update state to new state and
    action to new action)

  until s is terminal
```

The **Q(*s*,*a*)** notation refers to a table of values that correspond to the value of state/action pairs (e.g. the value of taking an action ***a*** under state ***s***). This is often referred to as Q-values. The parameters used in updating the Q-values include the following:

- **α:** the learning rate. This is a floating-point number between 0 and 1 that determines how quickly the Q-values are updated. Higher numbers correspond to faster updating (but at the cost of accuracy).
- **γ:** discount factor. Also a floating-point number between 0 and 1, this models the fact that future rewards are worth less than immediate rewards.
- **ε-greedy:** the action selection policy. This method chooses the action with the highest estimated reward (hence the "greedy" denotation). Occasionally, with a small probability of **ε**, an action is selected at random. This is one of the more common policies. Others include **ε-soft** and **softmax.** Refer to (Sutton and Barto 1998) for more on these policies.

6.5. Iterations and Implementations

6.5.1. Drums/Hardware

Protocol went through several iterations and experimental implementations. In terms of the drumming hardware itself, the piece used a standard drum set (Figure 6.8). The drums themselves were not altered or "enhanced" in any way. There was one early attempt at implementing a behaviour wherein the drum/agent could sense when it was about to be hit and when the drum itself was being approached. This involved the use of capacitance and infrared proximity sensors (Figure 6.9). I also experimented with a piezoelectric sensor to measure vibration of the shells. All of these were eventually abandoned in favour of simplicity and also because the sensors could easily become loose or damaged with repeated striking. I also felt that their implementation did not really further the conceptual goals of the piece. Eventually the decision was made to only use microphones to measure the amount and intensity at which the drums were struck.

Figure 6.8 The drum set used in *Protocol* (a Pearl Export series set). In this photo only two drums/agent are being played.

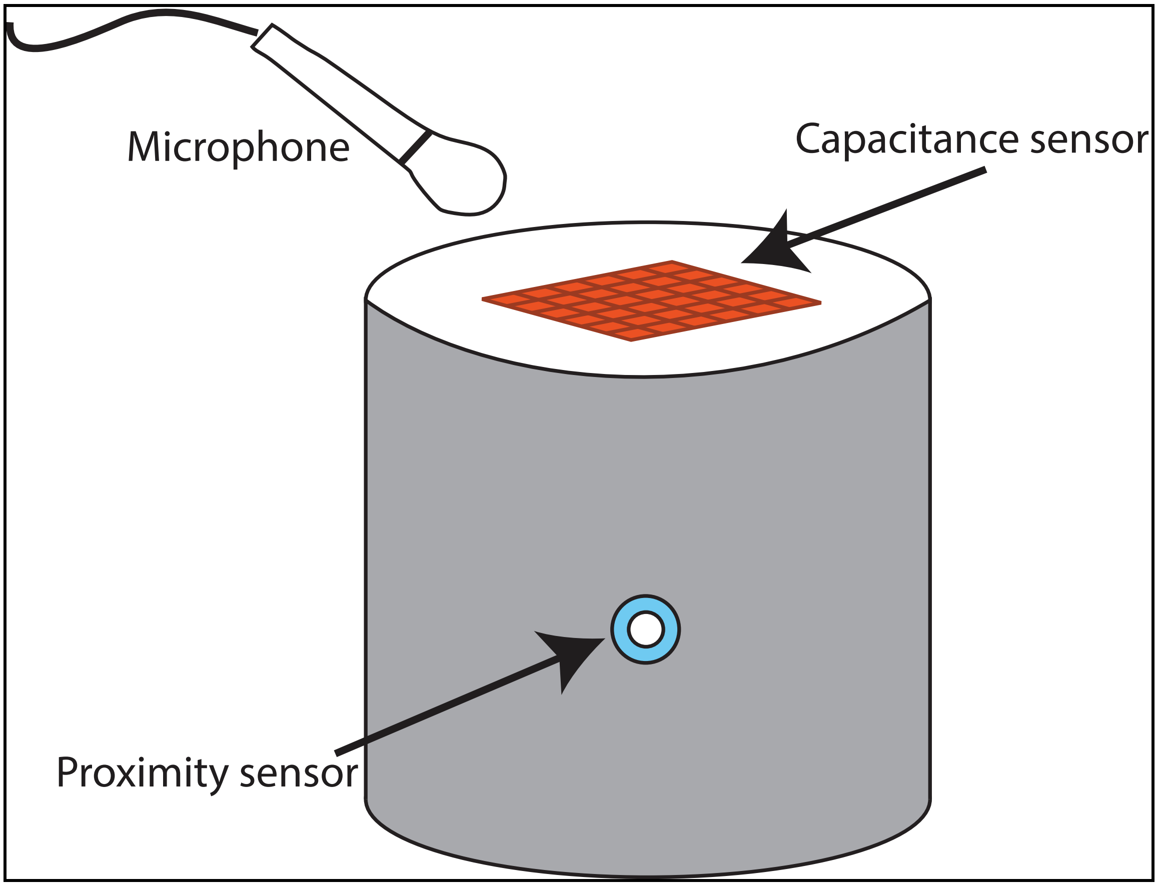


Figure 6.9 Early conceptualization of drum with capacitance and proximity sensors.

6.5.2. Sensors and Actuators

In regards to the participant/drummer, early experiments included the measuring of heart rate and arm motion (Figure 6.10). Some conceptualizations also included an EMG sensor to measure muscle movement and even robotic braces on the arms to as another method for the system to respond to the participant (i.e. as way for the system to control the participant's arm movements, see Figure 6.11). In addition to the electrotactile stimulation belt, this required a considerable amount equipment to be worn by the participant. Thinking that all of this would be too cumbersome and restraining for a participant (and with my rather limited knowledge of robotics and mechatronics with regard to the braces), it was decided have the belt with electrotactile stimulation as the only thing participants had to don.

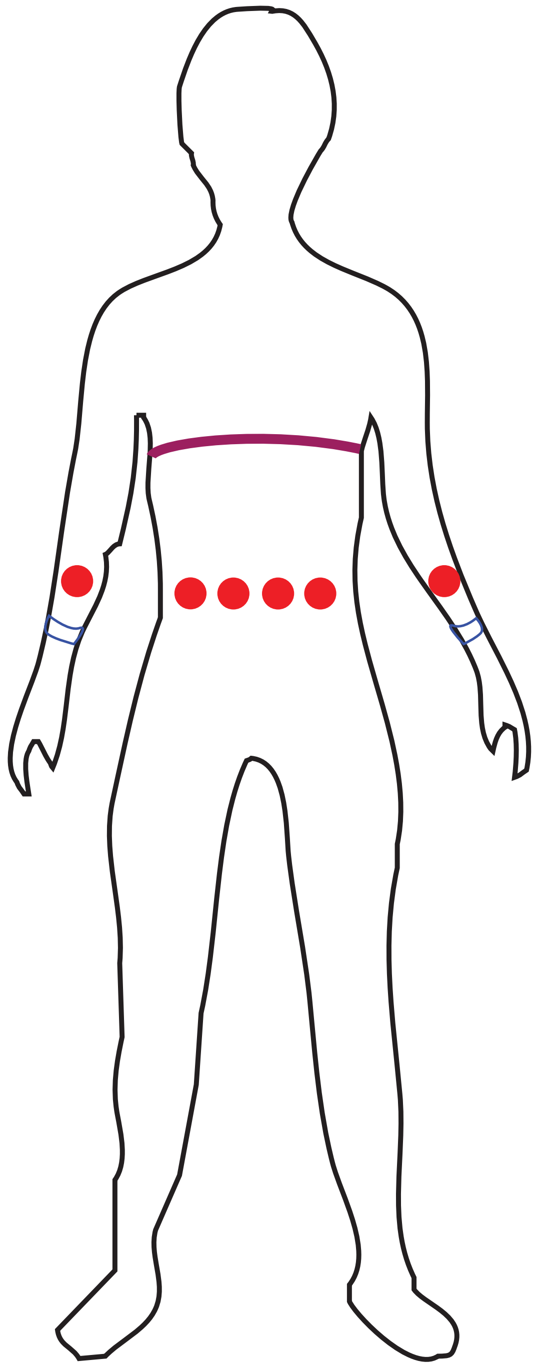


Figure 6.10 Early conceptualization of sensors and actuators in *Protocol*: accelerometers on the wrists, a chest-mounted wireless heart rate sensor and the electrotactile stimulators on the trunk and forearms.

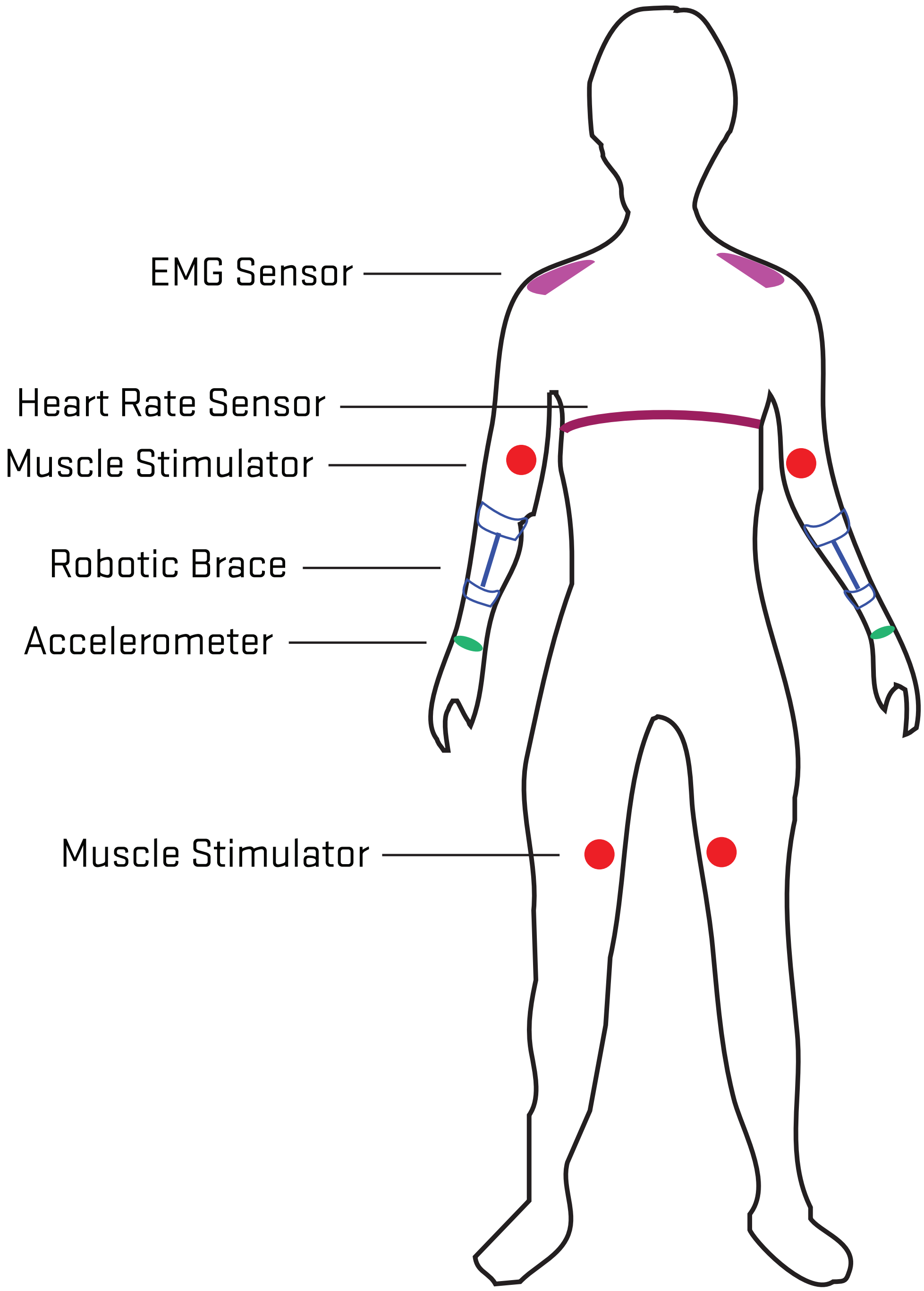


Figure 6.11 Another early conceptualization of sensors and actuators in *Protocol.*

The accelerometers were actually implemented and tested considerably with the system. One 3-axis accelerometer connected to an X-Bee wireless module that measured the output of the accelerometers and sent the data the Max/MSP program was placed on each wrist (Figure 6.12). The purpose of the accelerometers was to gauge the speed and location of the participant's arms, in part (as with the sensors on the drums mentioned earlier) to determine when a drum was about to be hit. This data would also be sent to both the RL and subsumption modules that would then influence the parameters of a granular synthesis effect (Figure 6.13). As mentioned earlier the accelerometers were scrapped in order to make the system less cumbersome for participants (and for me!). In addition, it had the added benefit of reduce the amount of data (state/action pairs) that the RL module would have to calculate.

Figure 6.12 Prototype for a wrist-mounted device to measure arm motion. Inside the container is a 3-axis accelerometer and an X-Bee wireless transmitted that transmits the data to laptop computer running Max/MSP.

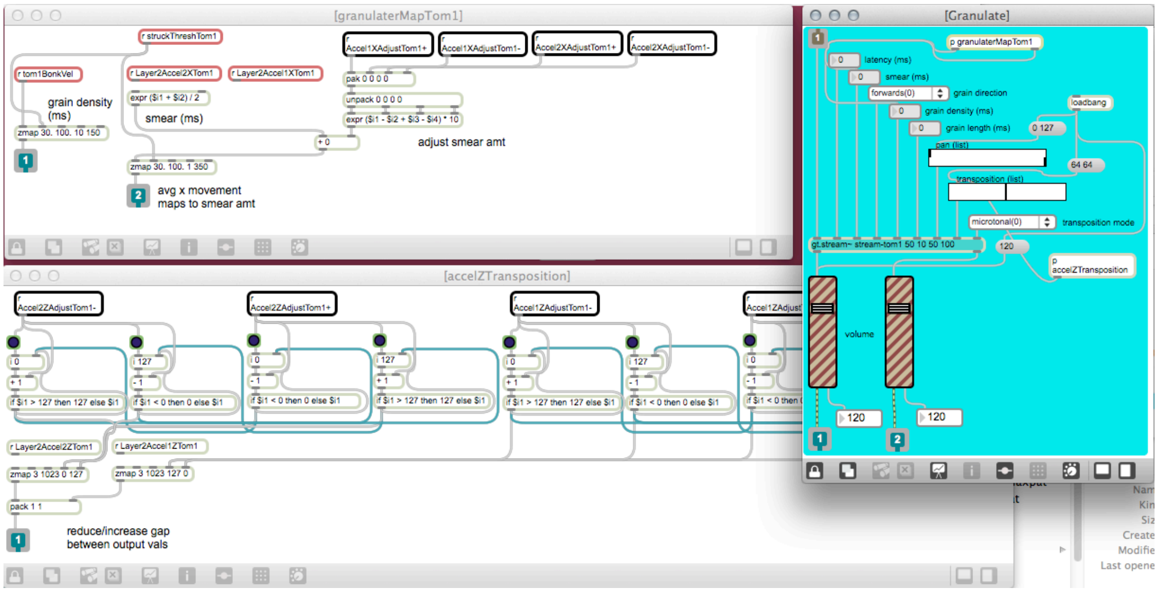


Figure 6.13 Granular synthesis subpatch(es) that worked in conjunction with the accelerometers. This was not implemented in the final version of *Protocol*.

In this desire to keep things simple, I decided to have the system respond in a very direct way and discernable way to a limited range of information. The final version of the system would only sensed data derived from the actual striking of the drums and responded with sound textures and electrotactile stimulation patterns that were clearly associated with a particular agent/drum. Spatially, each sound corresponded to the physical location of the drum (e.g. the sound associated with right most drum from a participant's perspective was be panned right). The sounds in *Protocol* were generated via two sources a: "dialer" patch (based upon an example patch that comes pre-installed with Max/MSP) that made telephone like beep sounds and atmospheric "hit" type sound effects generated in Reason, an electronic music production software suite. No overtly "musical" sounds were used.

Like the sound patterns, the electrotactile stimulation also associated a drum with a location on the body. Participants wore wear a belt (Figure 6.14) across their trunk that was fitted with four electrodes, one for each drum (enabling the system to have up to four agents/drums). When a particular drum was struck, its corresponding stimulator was activated. When a particular drum was struck its associated electrode would respond. This method of stimulation involves placing electrical current directly onto the skin. The inspiration for its use in *Protocol* came from my research into sensory substitution context. Sensory substitution works by transposing one sensory modality (e.g. vision) into another (e.g. touch). Most commonly utilized to help patients lacking a sensory modality, sensory substitution devices present visual or auditory information across the skin via electrical pulses or vibrations from motors or solenoids. Patients can then “see” or “hear” with their skin (Kaczmarek et al. 1991). The method that most directly inspired *Protocol* came from a device that was developed to help profoundly deaf children “feel” the sounds of their own speech (F. Saunders, Hill, and Franklin 1981). The device displays sound frequencies as touch patterns on a belt worn around the trunk. Dubbed the Teletactor, this device analyzes the frequency and amplitude of the speech sounds received and translates them into electrical patterns that the patient/user can feel and thus learn to associate with the sounds, in a sense learning the “feel” of the speech. I decided to use a variety of waveforms generated in Max/MSP as the source of the electrotactile stimulation in *Protocol.* These were relatively simple waveforms generated from an analog-style synthesizer (Figure 6.15). The patterns (along with the sounds) served as a sort of “proto-language” for the system.

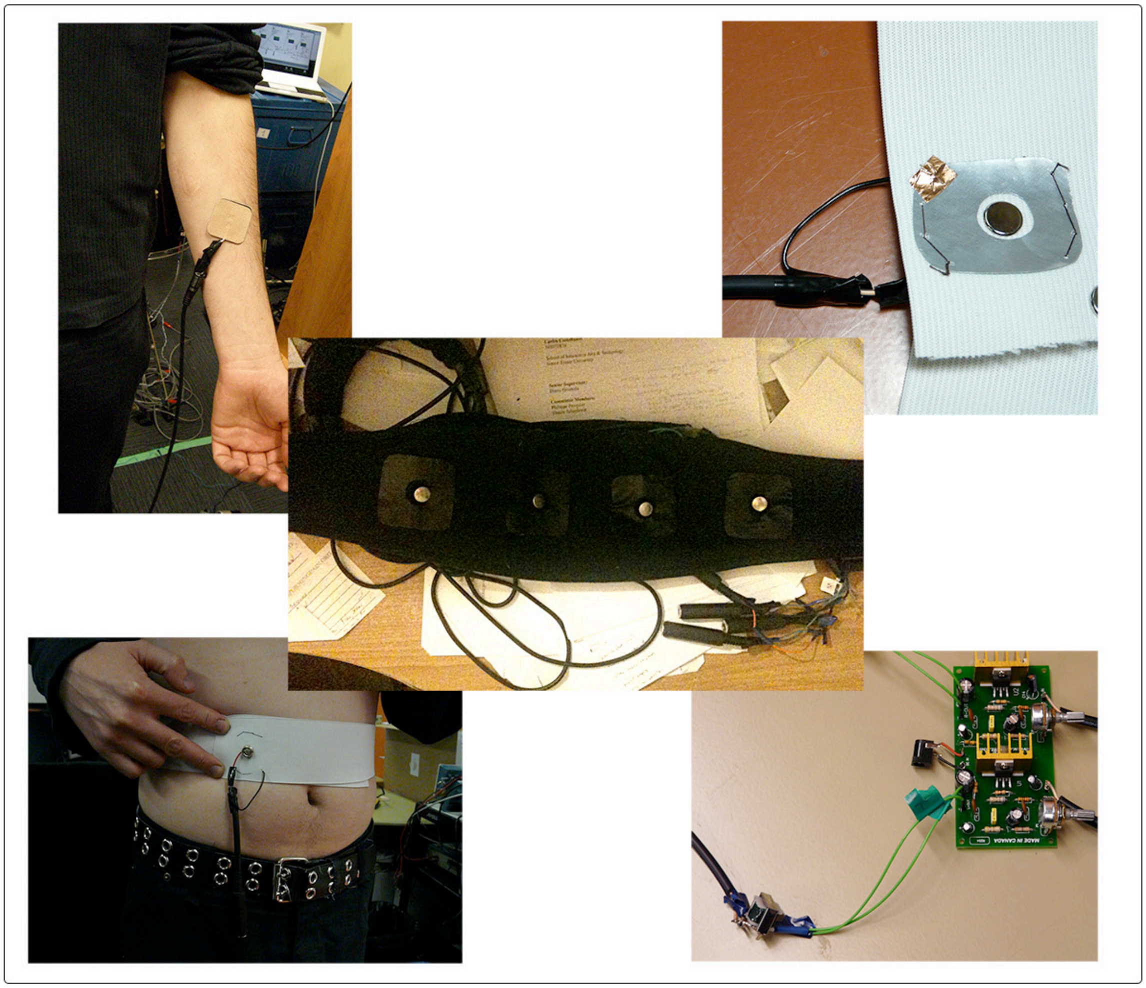


Figure 6.14 Electrotactile experiments. Top left, top right and bottom left: early prototypes of belt and electrode placement. Bottom right: amplifier with attached transformer used to boost the signal going to the electrodes. Center: final version of the belt, made from a modified TENS (Transcutaneous Electrical Nerve Stimulation) unit used for treating back pain. Velostat (a carbon impregnated black polyethylene film) surrounding each electrode was used for grounding.

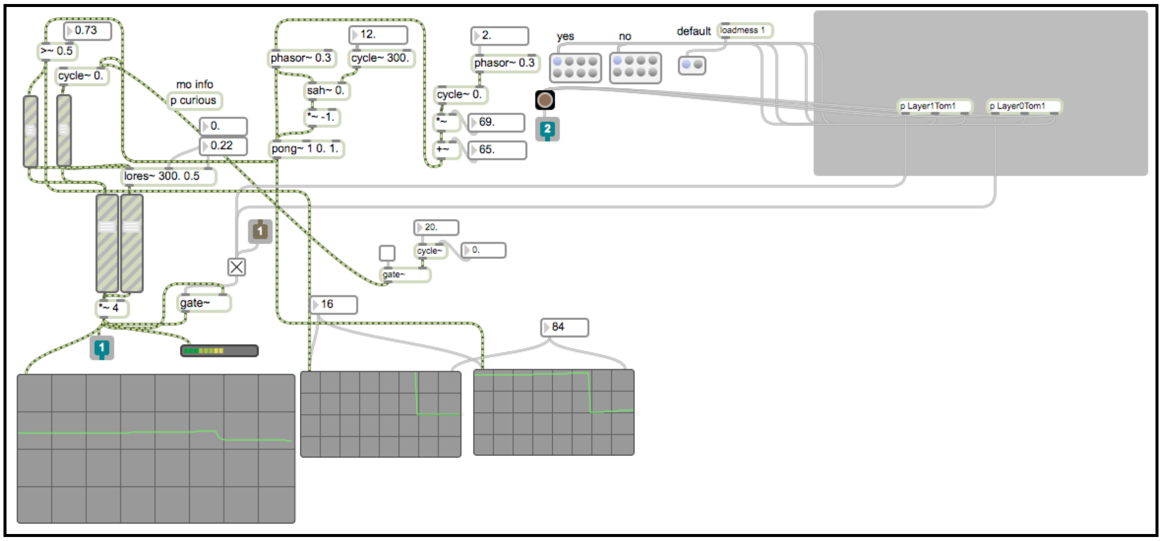


Figure 6.15 Portion of the Max/MSP program that generated the electrotactile stimulation patterns.

6.6. Exhibition, Analysis and Reflection

Protocol was exhibited at Gallery Gachet in Vancouver in June of 2012 as part of *Proof-of-Process*, a series of hybrid exhibitions, workshops and symposia. The basic idea behind *Proof-of-Process* was to allow gallery visitors to view, interact with and contribute to technology-based artworks and research projects as they were being built in the gallery space. Much of this exhibition was "open-source", in that visitors were invited to not only experience the works, but also go "behind the scenes" and learn how the systems worked and how they were constructed. Exhibiting *Protocol* in this context for an extended duration (five days) provided an opportunity not only to observe audience interaction but also to discuss the piece (both technically and conceptually) with visitors and participants. For this exhibition, two drums (and thus two agents) were used (Figure 6.16). Participants that approached the piece were given the belt and instructed on how to put it on. The system was then launched and the participant instructed to begin striking the drums. Other than informing them that the drums were "intelligent" and/or programmed to respond to striking by emitting sound and generating electrotactile stimulation, no other preparation or explanation was given. The results were interesting. I admit that up to this point, my own interactions with the piece felt somewhat random and unfruitful. I didn't really experience the piece as being an interaction or conversation with intelligent drums. But in the social context of the gallery (as opposed to the solitary context of the studio) this changed. I noticed many participants leaning in toward the drums or turning their heads as if to listen more closely (Figure 6.17). I also found myself doing the same thing on occasion. This is curious since the drums were quite loud, as were the synthesized sounds. It was as though participants were trying to "understand" what the system was trying to "say" to them. One participant referred to the drum/agents as "creatures" and that the system did an admirable job of mimicking something that was alive or endowed with some kind of awareness. Several participants also noted how the noises didn't just seem random or arbitrary, even though they were unpredictable. One participant — perhaps referring to the telephone dialer-like sounds of the system — remarked that the agents seemed to be communicating via some kind of "R2-D2" language (R2-D2 being the diminutive robot character from the Star Wars motion picture series that communicated via series of audible beeps and tones of varying pitch and envelope). This is despite the fact that the electrotactile stimulation stopped working about halfway through the exhibition. Thus the majority of the participants I spoke with did not even experience that portion of the piece. While none of the participants referred to the piece or their experience with it in terms such as "symbiosis", "equilibrium" or "co-evolution", they were — at least in the context of the social and collaborative atmosphere in which it was exhibited — anxious to engage in conversations related to intelligent systems and our relations with them. As Simon Penny remarked in reference to participant interactions with his robotic piece *Petit Mal* (Penny 1997) (an altogether different piece but one built with a similar "embodied" approach) participants would ascribe behaviours and understanding to *Protocol* that it did not have. This reiterated an idea I had all along about the technical implementation methods used in the piece to achieve "understandings" or "equilibrium" (in this case reinforcement learning and a crude subsumption method) had little or no correlation to the experience of participants and whether they thought of their experience in those terms. Participants interpreted *Protocol* through the lens of their own experience and their (intuitive and/or informal) conceptions of what constitutes intelligence or understanding. While I wouldn't go as far as to say that this would qualify the experience of *Protocol* as symbiogenic, it does nevertheless speak to the work's (and other emergent artworks more broadly) ability to reorient our perceptions so as to at least anticipate or entertain possibilities that such relations are possible. And as they say, perception is reality.

Figure 6.16 *Protocol* installed at Gallery Gachet.

Figure 6.17 Participant turning head to better listen.

My final impression of the piece and the exhibition was one of success in the broader research context, if not as good work of art. While my conception of terms like co-evolution, symbiosis or equilibrium were never Darwinian, working on *Protocol* helped crystalize what the meanings of these terms really were; or perhaps what they weren't. I realized I wanted to explore complex interactions between system and environment in a way that was more grounded in materiality and which can more easily be comprehended both by the audience and by myself as a way of stimulating ideas. In *Protocol*, most of the processes (and what I spent most of my time working on) were almost totally opaque to the participant. Other than showing them log files or command-line readouts, the symbolic processes of the system itself — though still grounded physically in the drums and still contributing to the work's alterity relations — was not part of the participant experience (and perhaps only marginally of my own). Though these still provided a context for their experience, I sometimes feel that perhaps it may have been a better idea to construct something more like Jean Tinguely self-destructing machines (such as *Homage to New York*), as way of attaining a less structured experience of human-machine understandings.[26]

Though the progress may have been a bit awkward, I realized through the entire process of constructing and exhibiting *Protocol*, that what I was really interested in was heterogeneous complexity — a complexity requiring a multitude of interactions across multiple temporal and spatial scales. The diversity and heterogeneity of our interactions with an intelligent technological environment may give rise to heterogeneous responses to the same stimuli (to say nothing of the variety of stimuli). Heterogeneity of interactions and feedback across scales give rise to an ambiguous, self-organizing and continually emergent experience of co-evolution that I am calling symbiogenic. *Protocol*, like *Biopoiesis* amplifies a narrow sliver of a particular aspect of such an experience and thus helped focus my research.

More specifically what I came to realize is that trying to create or induce a symbiogenic experience was not really the point. While, I was still thinking of active construction of shared meanings or states of mutual influence, it was now in a less direct way. Up until this point I had approached the problem of creating perpetual novelty and exploring co-evolutionary interactions through the lens of artificial intelligence and artificial life. The next chapter presents a shift in my approach. My thinking shifted to the natural environment and perhaps more day to day interactions of our technological lifeworld. I would now instead try to harness the existing complexity and emergent processes of nature instead of trying to implement them computationally.

Furthermore, abstract ideas such as circularity, conversation, emergence and self-organization that I was beginning to really think about deeply — through my immersion in the cybernetic literature — took on greater valence (with respect to the emergent arts and the symbiogenic framework) during the process of building and exhibiting *Protocol.* It did indeed function as an embodied-tool-to-think through these ideas and set the stage for the even deeper exploration of their relevance that would

[26] In a sense, that may be what *Biopoiesis* achieves, a sense of losing control.

occur during the development of my first “truly” cybernetic and emergent artwork: *Biopoiesis,* which I will now discuss.

7. Biopoiesis

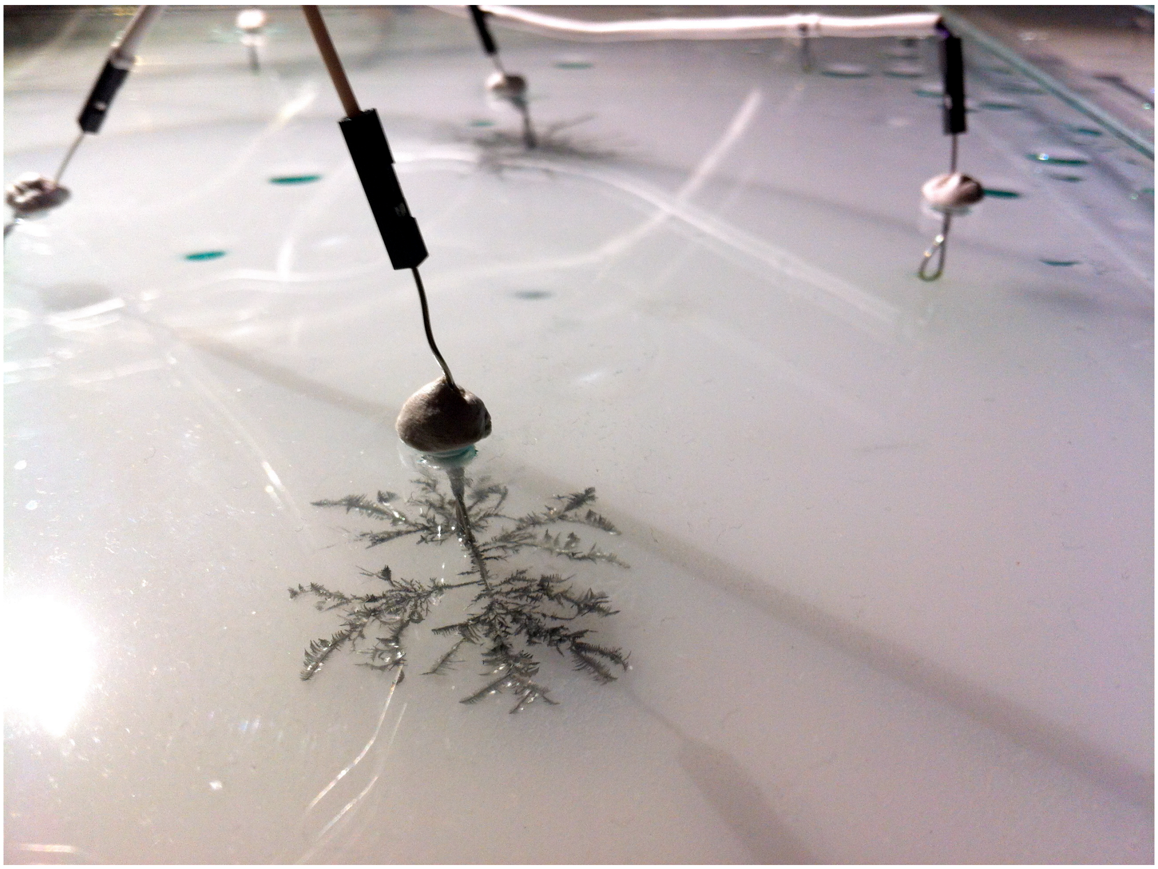


Figure 7.1 *Biopoiesis* at the SIGGRAPH 2012 Art Gallery

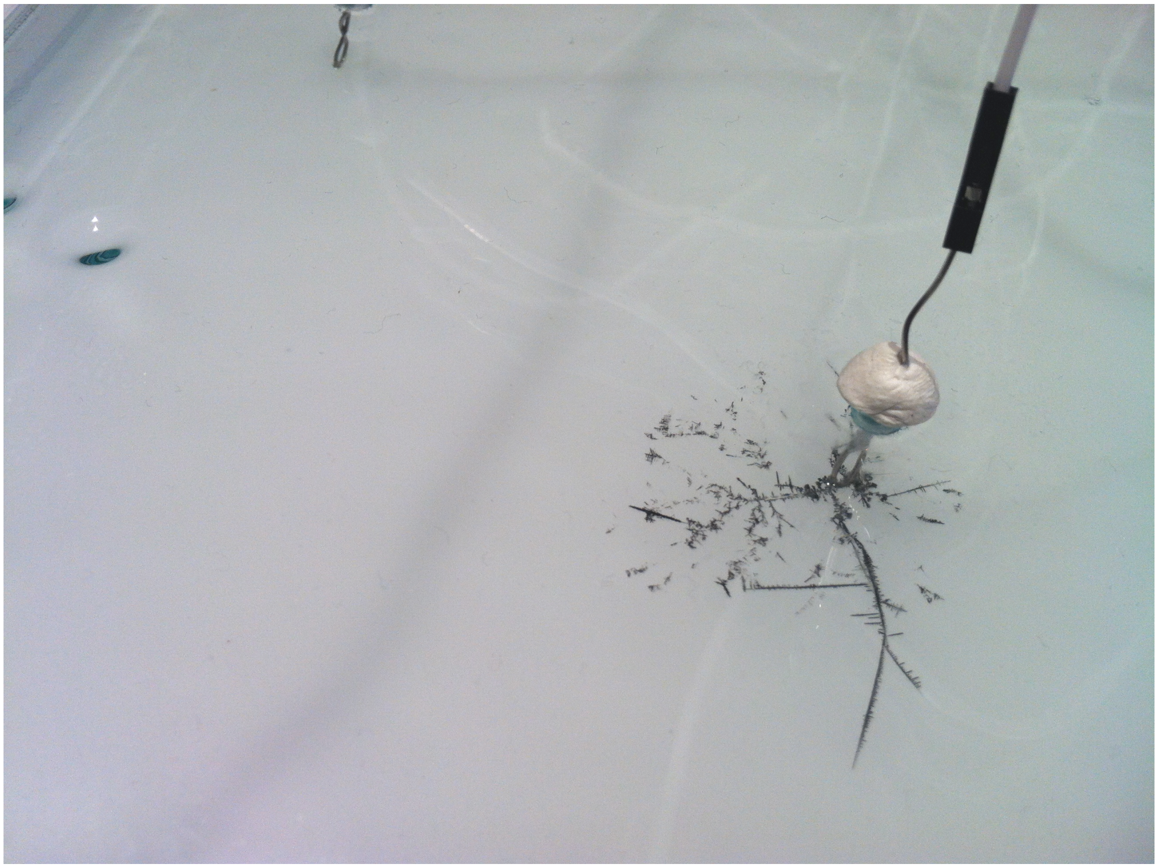


Figure 7.2 Electrochemical growth

7.1. Introduction

Biopoiesis is a series of experiments exploring the relationships between structure, matter, and **self-organization**, in what might be described as a computational "primordial soup". The piece entails the construction of several simple computational devices that are all based upon the process of electrochemical deposition. This work builds on cyberneticist Gordon Pask's research into electrochemical control systems that could adapt to certain aspects of their environment (Pask 1960; Pask 1959; Cariani 1993). The experiments presented here, undertaken by Carlos Castellanos and Steven Barnes, explore the artistic potential of Paskian-like systems. The work also examines the interactive and computational possibilities of natural processes and the potential for natural processes to serve as an alternative to the commonplace digital forms of computation, which might help (re)establish a dialogue between cybernetics, mainstream science, and the arts.

Biopoiesis, like this dissertation, is in part a theoretical work, but one that is threaded through practice. In addition to the photographic and video documentation included here, I wrote notes and ideas at the end of every day that I worked on the conceptualization, design, construction and exhibition of the piece, in order to get a clear idea of the process that led me to these final conclusions. *Biopoiesis* has provided a great deal for my research into subjective interpretations of self-organization, complexity, ambiguity and emergence as factors of co-evolutionary experience. The experience of developing the piece, from delving into Pask's research to reading papers on neocybernetic theory to brainstorming implementation strategies to constructing and exhibiting the system, dealing with the growth and dissolution was really an exercise in trying further develop abstract theoretical ideas related to symbiogenic experience, or at least aspects of it. Reading Merleau-Ponty's ideas on **circular causality** for example or thinking about his concept of ambiguity would perhaps have led me to different conclusions had I not been working on this project or had I been working on a different unrelated project. While working on *Biopoiesis*, I would occasionally be amused by simple, unexpected occurrences that the system would demonstrate, such as some unexpected growth trajectory or a change in the sound. Though I could not (and still cannot) make any direct causal connection to why these things occurred, I am still left with a sense of how these processes catalyzed in me modes of insight and of thinking about my **lifeworld**. One of the SIGGRAPH 2012 Art Gallery jurors remarked that the work was "cerebral" and said this in the context of describing the appeal of its slow, yet strangely purposive-looking growth. Several gallery participants were also intrigued and confused by what the piece actually was or how it functioned. Compared to the digital worldview that many of them (younger ones in particular) had grown up under the idea of a quasi-organic "computer" that "grows" as method of learning and adapting (and not one that learns by manipulating symbols) seemed quite odd. These experiences for me circle back to how this piece (and others like it) are grounded in certain relations of alterity, where humans and physically situated autonomous non-human systems co-construct and co-evolve aspects of their environment and deliver an aesthetic experience that motivates a sense of being embedded and co-emergent with the other and more broadly, with an increasingly technological environment.

As mentioned above, *Biopoiesis* is based upon the process of electrochemical deposition: when electrical current is passed through a metallic ion solution (e.g., ferrous sulphate, stannous chloride) metal is deposited on the electrode that is the source of electrons (i.e., the cathode). In our experiments, information (in the form of an electrical current) is fed to a chamber filled with a solution of stannous chloride and ethanol via an array of electrodes (Figure 7.3). The resultant electrochemical reaction includes the growth and/or dissolution of metallic dendritic threads in the metallic ion solution. These dendrites are fluid and unstable, bifurcating and dissolving in unpredictable ways. Thread bifurcation and dissolution, in turn, leads to resistance changes that modify the flow of information (current) through the network. This contributes to the emergence a dynamic pattern of complex electrical and physical growth activity across the entire system, thus constituting a continuously shifting and dynamic signal network (comparable to the plasticity observed in neuronal processes). If a subset of electrodes in the electrochemical solution receives input from an environmental sensor (or via some other method), and the electrochemical output can affect that sensor (or otherwise influence the growth of threads), then the network may move towards a dynamic equilibrium with its environment. The dendritic network also carries a decremental memory trace of its previous activities: when the environment changes, the system is perturbed but not immediately reset. Thus, the prior activity and configuration of the system affects how it handles a change in its environment. It can thus learn from its interactions. Furthermore, the system can be trained by providing reinforcement for certain sorts of conductance changes that are produced in response to a particular environmental perturbation (see section 7.4).

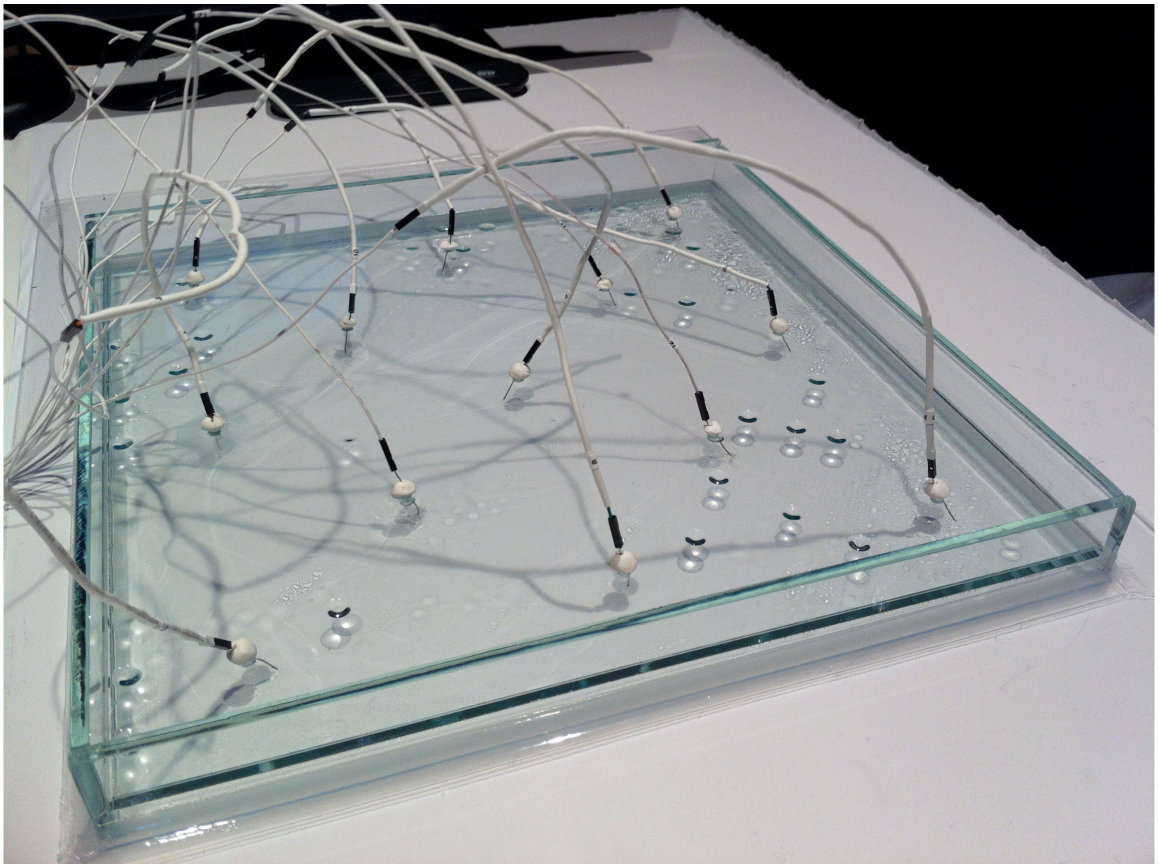


Figure 7.3 *Biopoiesis* tank containing a shallow bath of stannous chloride and ethanol solution. With electrodes attached.

7.2. Conceptual Foundations

In an art historical context *Biopoiesis* can trace its aesthetic and conceptual basis to the work of early systems artists such as Hans Haacke and his works exploring ecological systems. Exploring cycles of evaporation and condensation in response to temperature and barometric changes *Condensation Cubes* (1963-65) were hermetically sealed transparent plexiglass cubes that contained about 1cm of water. *Grass Grows* (1967-69) grew grass in dirt in the gallery space (often on top of transparent cubes similar to those of *Condensation Cubes*). One of the most well known conceptual artists of his time, Haacke, was strongly influenced by systems theory and cybernetics. In the present context however, *Biopoiesis* also represents an exploration into alternative models of interactive arts practice, as well as a (re)integration of cybernetic methods into artmaking.[27] Specifically, there is the exploration of the underlying mediums employed in the interactive arts. Few would dispute that digital computation has pervaded most aspects of our existence and transformed our very thought processes. New media artists sometimes make the implicit assumption that digital forms are the only avenues for exploration. The digital is often taken as a given. Rarely is the underlying paradigm embedded in the very material substrate on which the digital work exists ever seriously questioned. Seen in this context, *Biopoiesis* represents an experimental approach to re-imagining cultural production with non-traditional (non-digital) computational methods as a medium and exploring alternative models of electronic arts practice. One of the appeals of interactivity and digital computation in the arts is the inclusion of the participant as co-creator of the work. In addition, computational techniques such as genetic algorithms, evolutionary robotics and stochastic searches also have broad appeal (in both science and the arts) precisely because they seem to relax the (often rigid) engineering constraints inherent in traditional computational technologies. Of course the implementation of randomness and indeterminacy in the arts predate digital technology, as exemplified by John Cage's chance operations and the event scores of the Fluxus artists.

Biopoiesis and Pask's electrochemical assemblages both serve to redirect our attention to the very material forms of the works and how they add a certain dimension of materiality and tangible presence that is often lacking in digital and even robotic works. The work displays at least a hint of a certain kind of agency that can only come from non-symbolic (i.e. non-digital) material forms grounded in processes of organic or quasi-organic growth. Works inspired by Pask's electrochemical experiments, such as Roman Kirchner's Roots (2005-2006) and Andy Webster's System Generated by the Sound of its Own Making (2007) and Tuning Pask's Ear (2002), may be loosely related

[27] For artists employing cybernetic concepts and methods in their work see See Roy Ascott, Telematic Embrace: Visionary Theories of Art, Technology,and Consciousness, ed. Edward Shanken (Berkeley: University of California Press, 2003); Jack Burnham, "Systems Esthetics," Artforum 7, no. 1 (1968): 30–35; Jack Burnham, "The Aesthetics of Intelligent Systems," in On the Future of Art (New York: Viking Press, 1970), 95–122., as well as the early work of Joel Slayton and C5, <http://www.c5corp.com>.

to “bio-art” but can more properly be described as quasi-organic cybernetic systems. Along with *Biopoiesis*, these works allow us to directly apprehend and experience self-organizing, emergent processes by virtue of their growth and their sheer materiality.

In studying the growth and adaptation of an “inorganic” system, *Biopoiesis* also serves to question the traditional dichotomies of organic vs. inorganic and biological vs. non-biological. By standard scientific definitions, the *Biopoiesis* system is inorganic. Yet, we have commonly observed patterns of bifurcated growth and dissolution that have qualities classically reserved for organic biological systems. Accordingly, we wanted to test the boundaries of the inorganic and organic, the non-biological and the biological, by attempting to show that our “inorganic non-biological” system could manifest properties comparable to those associated with a biological system that is learning about aspects of its environment (e.g., neuronal and glial plasticity, or long-term potentiation/depression of synaptic communication). We feel that this may open up new ways of thinking about sensing, intelligence (environmental, collective; not just cognitive), and memory (mutable electrochemical traces).

7.3. Developmental Context

Biopoiesis was the first project developed under the auspices of DPrime Research. This is an organization founded by Steven Barnes and myself (with Tyler Fox joining very soon afterwards) that itself is a sort of conceptual art project. DPrime specializes in cultural production informed by the intersection of technology, research and the arts and was founded by our mutual interest in art-science collaboration and — specifically relevant to this dissertation — as way of exploring concepts of such as emergence, self-organization and the **ontological** aspects of these concepts and science and technology research more broadly bring to bear — all from within an arts context. The following from the DPrime web site explains our rationale:

> Standard theoretical models arising from within particular cultural contexts are often characterized by poly-reductive methodologies that radiate and diffuse paradigmatic approaches, thus favoring static and linear ontological worldviews. Nevertheless, concurrent and interrelated inquiry into the dynamics of uncertainty suggests alternatives to prevailing attitudes. DPrime positions itself in an autonomous zone of research

where alternatives to the over-reliance on purely reductionist and representational models of computation, natural systems and cognitive phenomena can be explored. Inquiries into adaptive and exceedingly complex information systems (e.g. brains, bacterial colonies, companies) guide our research, exemplifying fundamental principles that can be used for strategic operations and analyses involving new forms of social and cultural organization.

Part research and development think tank, part science and technology start-up and part cultural and community organization, DPrime is an ensemble of artists and academics that collectively embody the classical institutional identity, thus enabling experimental research and development endeavors characterized by aggressive transdisciplinarity and a continuously shifting, heterogeneous structure. Phenomena such as complexity, self-organization, emergence, autonomy and ambiguity are common areas of inquiry. Solutions are informed by collaborative expertise, including implementations of artificial intelligence, machine learning, systems theory, biocomputing, dynamical systems, cognitive psychology, phenomenology, cultural theory and art.[28]

This project was developed by Barnes and myself and involved much trial and error experimentation with different solutions, technical configurations and research implementation strategies. We feel that this project serves very well to highlight the goals and "spirit" of what DPrime is or aims to be. For myself, after *Protocol* I was looking for interactive and computational strategies that better fit my research goals of experimental with co-evolutionary concepts (e.g. emergence, autopoiesis) that were more "analog" and "material" in nature; that did not go through the "representational detour" that digital computation did. Instead of looking to code and pre-design electronics for these things I wanted to look more at the physical world.

The first few months of the project consisted primarily of experimentation with different solutions (primarily ferrous sulphate and stannous chloride), sketching out and brainstorming system configurations and deciding what exactly we wanted to send to and receive from the system (e.g. sound, motion, etc.) (see Figure 7.4). Several tanks have been constructed to house the electrochemical solution. Each has been made of either clear glass or acrylic of differing dimensions (typically between 10x10 and 21x21 inches; see Figure 7.3 for an example of a tank). Some tanks have accommodated 11

[28] DPrime Research web site: http://dprime.org/synopsis/

electrodes, whereas others have allowed for up to thirteen. In a typical setup, 8 or 9 of the electrodes serve as anodes while the remaining electrodes serve as cathodes. Although the construction of the tanks or electronics was not directly related to any particular implementation or exhibition, exhibiting was part of our trial and error process. Thus, observing how a tank or a particular technical configuration performed in a public gallery setting allowed us to refine our designs so as to better serve the implementations.

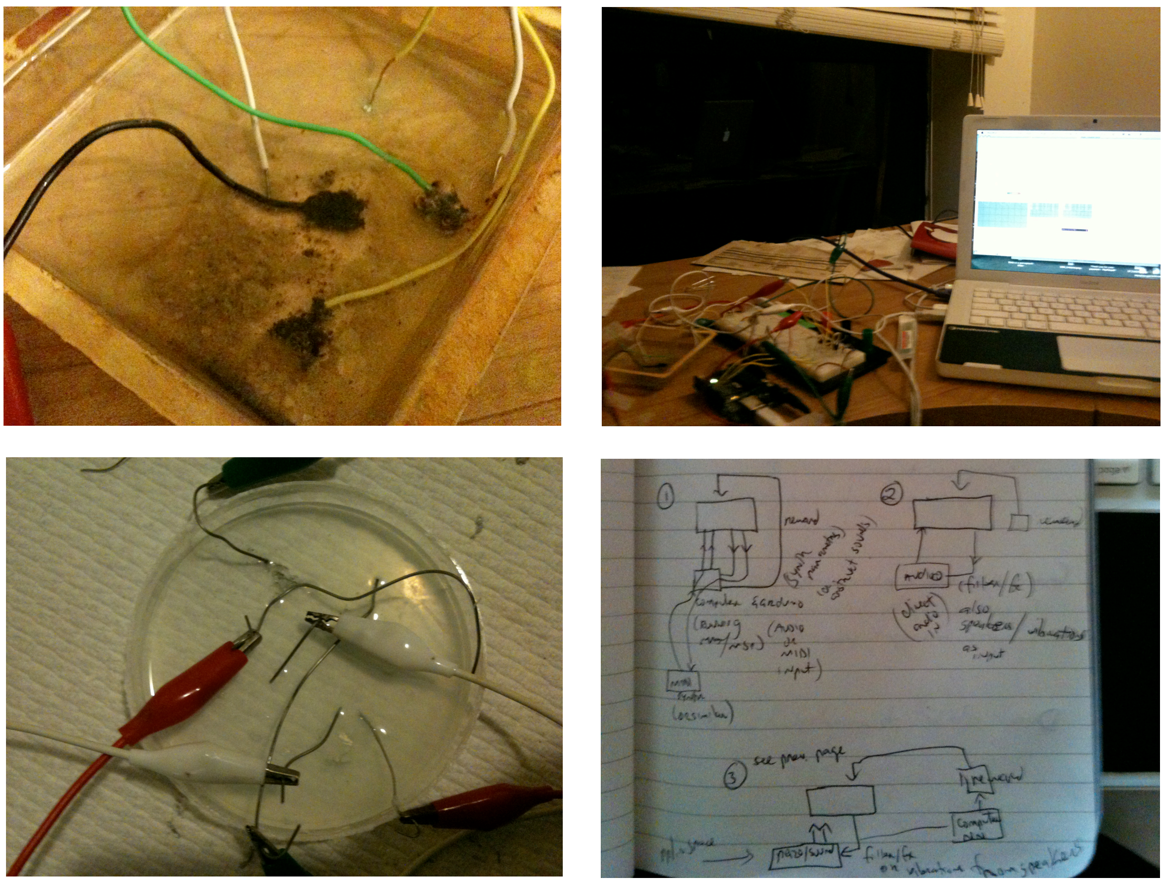


Figure 7.4 *Biopoiesis*, early experiments. Top left: ferrous sulfate growing in small plastic dish. Top right: PC running sound synthesis software connected to Arduino microntroller used to converted paramters of sound synthesizer to electrical pulses in the solution. Bottom left: alcohol saturated stannous chloride growin in small petri dish. Bottom right: early sketches of implementation ideas

7.4. System Overview

As shown in Figure 7.5, the general *Biopoiesis* system consists of one or more input electrodes carrying information (in the form of electrical current) from an environmental sensor (e.g., a microphone, a video camera) into the electrochemical solution. The subsequent effects of that information on dendritic growth in the electrochemical solution can be fed back to the environment in any of several different ways. For example, several of our installations have focused on passing ongoing sound captured via a microphone from the environment through the system and then back out to the environment through a speaker. In this way, the system affects the growth and/or dissolution of dendritic threads (which he often refer to as “plasticity”) as well as the sound environment in which it is situated; a typical cybernetic feedback loop. Furthermore, as the figure shows, the system can be trained by “rewarding” certain conductance changes produced in response to particular environmental perturbations (Cariani 1993; Pask 1960). This is accomplished by increasing the current or voltage going into the solution when a desired or novel output occurs.

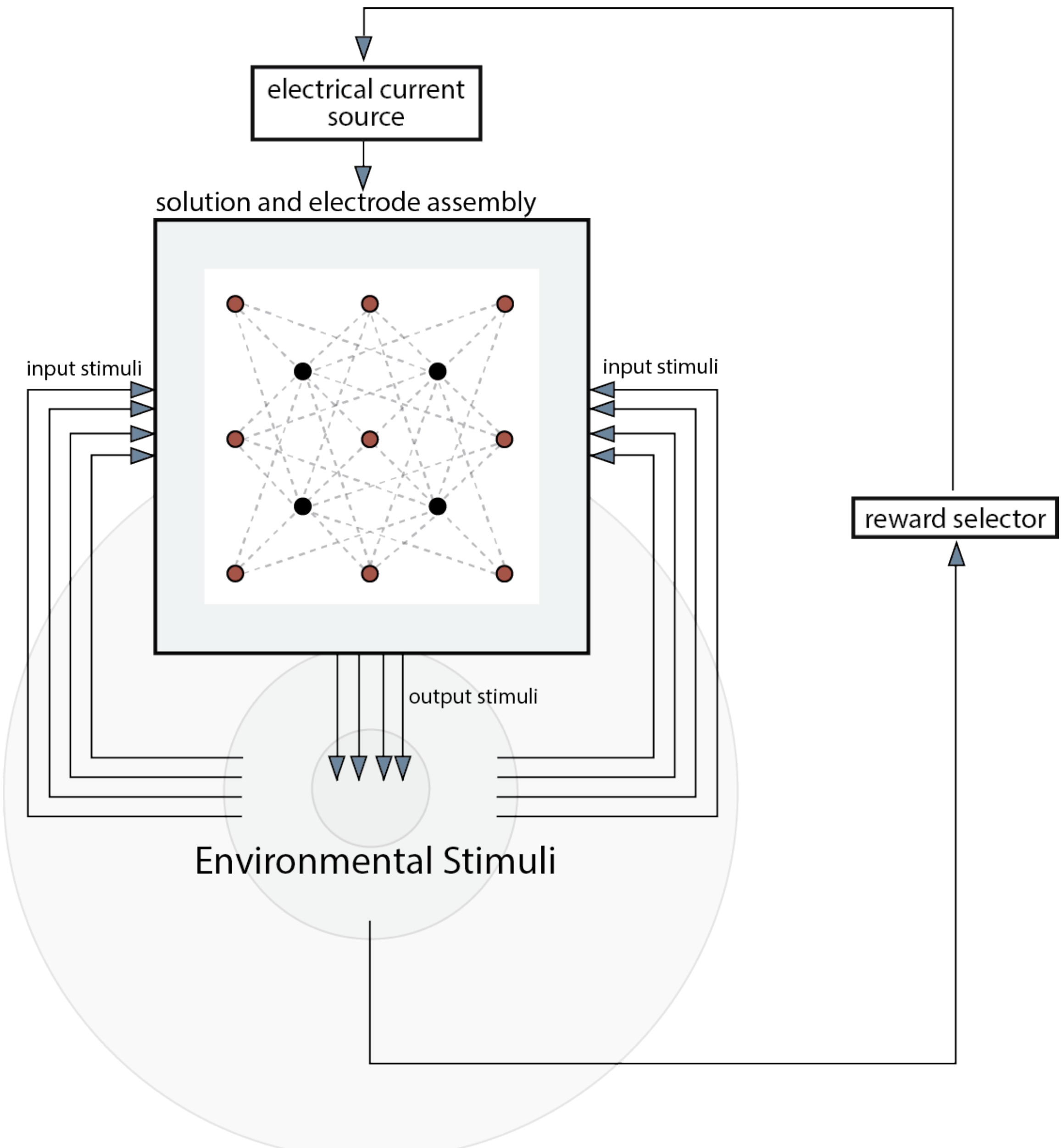


Figure 7.5 The general characteristics of a *Biopoiesis* system. Information from the environment is fed into the stannous chloride solution, thus affecting growth of dendritic threads, which in turn, affect any outputs to the environment — a typical cybernetic feedback loop. In this system diagram, 13 electrodes (4 cathodes (black dots) and 9 anodes (red dots)) are placed in the stannous chloride solution.

Figure 7.6 (left and middle panels in particular) shows a basic system configuration. Here, one or more input electrodes carry electrical signals from an environmental sensor (e.g., from a video motion tracker) into the electrochemical solution. The effect on the electrochemical dendrites is captured with a video camera, and turned into an output capable of altering the environment (and thus the sensor) in some way; the result of which is fed back to the solution to stimulate new growth.

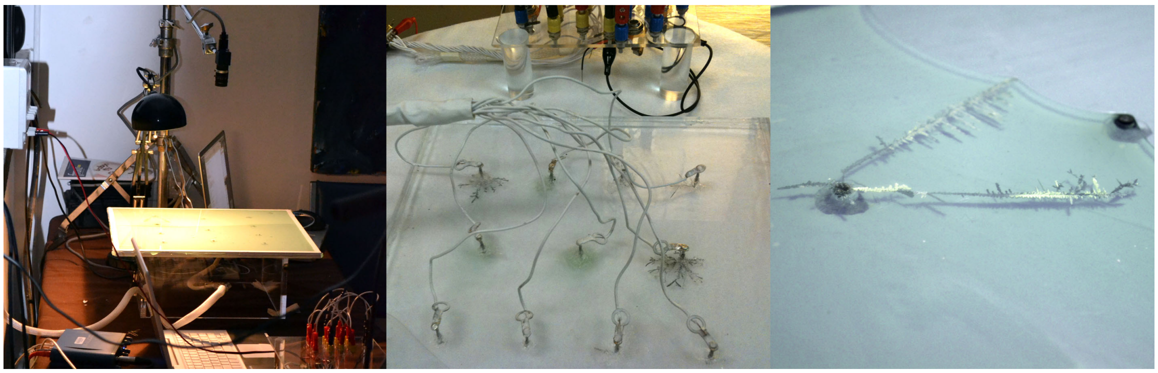


Figure 7.6 *Biopoiesis* System Setup: (left) overall system set-up, (center) electrodes carrying electrical signals and demonstrating thread growth and (right) growth and bifurcation from a single electrode

A notable strength of the project is the potential of the system, including its many potential sensors and effectors, to be easily "re-patched" and reconfigured, thus allowing for a wide variety of implementations and interaction modalities. For example, as an "open jam session": several participants are given the opportunity to simultaneously "patch" into the electrochemical network via a microcontroller to transform sound, video, computer graphics, or any other information source they want to provide, into an electrochemical reaction. Electrical output from that reaction can then affect the participants' data sources — and the feedback loop continues.

The general approach taken shown here can be employed in countless ways and with many different media. For example, dendritic patterns might be applied to the transformation of vertex data in computer graphics or gesture recognition in video tracking. The re-patchable nature of this project allows both artists and participants to explore the computational possibilities of natural processes that might serve as an alternative to more commonplace digital forms of computational processing, while the malleable nature of the medium allows for the exploration of virtually unbounded search spaces and implementation of open-ended evolutionary designs.

7.5. Implementation Strategies

Currently, two implementations of *Biopoiesis* have been developed. The first, dubbed “Emergent Relations” uses a relatively unmodulated feedback loop. It can be considered the “default” system since it has served as the template from which other implementations have been built. A second implementation, called “Organic Learning,” has been used to explore the electrochemical system’s ability to display properties of biological learning.

Emergent Relations. In this implementation, a PC runs a simple Max/MSP sound synthesizer patch. Various parameters from this synthesizer patch, such as oscillator frequencies and modulation data, are sent to a microcontroller where they are transformed into lengths of electrical pulses and sent to the anodes in the tank. The cathodes are connected directly to the negative terminal of the electrical current source (which is typically set to between 5-9 volts DC). The length and variety of the electrical pulses (patterns of current gating) ultimately lead to a shifting pattern of plasticity and bifurcation. Currents at the cathodes are then measured by the microcontroller and used to alter the parameters of the sound synthesizer patch, thus completing the feedback loop. A simple variant of this system involves inserting the signal from a microphone directly into the solution. The dendritic threads that form can then affect a sonic output from a set of speakers. The sound from the speakers, as well as their vibrations and any other local environmental phenomena establish a continuous feedback loop that serves to affect ongoing dendritic plasticity.

One variant of this system set-up, involves the use of a digital microscope along with video motion tracking software to measure the plasticity of the dendritic threads. Any plasticity of dendritic threads is captured by the motion tracker, which in turn changes the electrical pulse patterns — stimulating and influencing the pattern of ongoing dendritic plasticity in the solution.

Organic Learning. This experiment that explored the extent to which the electrochemical solution and electrode assembly could manifest features of associative learning (Balsam, Drew, and Gallistel 2010). Features of a gallery environment controlled the gating of current through each of the individual electrodes. Each of nine electrodes (the anodes) was gated by motion in one zone near the test apparatus, while each of the remaining four electrodes (the cathodes) was gated by the presence of sound within a particular frequency range (i.e., low, low-mid, high-mid, and high range) in the gallery (see Figure 7.7). In short, the circuit through the stannous chloride solution would only close when at least one anode and one cathode were active at the same time. This setup allowed us to explore if and how dendritic thread plasticity might serve as a coincidence detector (Stuart and Häusser 2001). If our system does have such a capability, then it should manifest itself in the network as both plasticity of the dendritic processes and as a long-term potentiation or depression of current flow between the respective anode and cathode (Abraham and Robins 2005). Thus, if there were sufficient simultaneous activation of motion-gated anodes and sound-gated cathodes any resulting plasticity and current fluctuations would constitute a bioelectrical record of sensory-sensory learning.

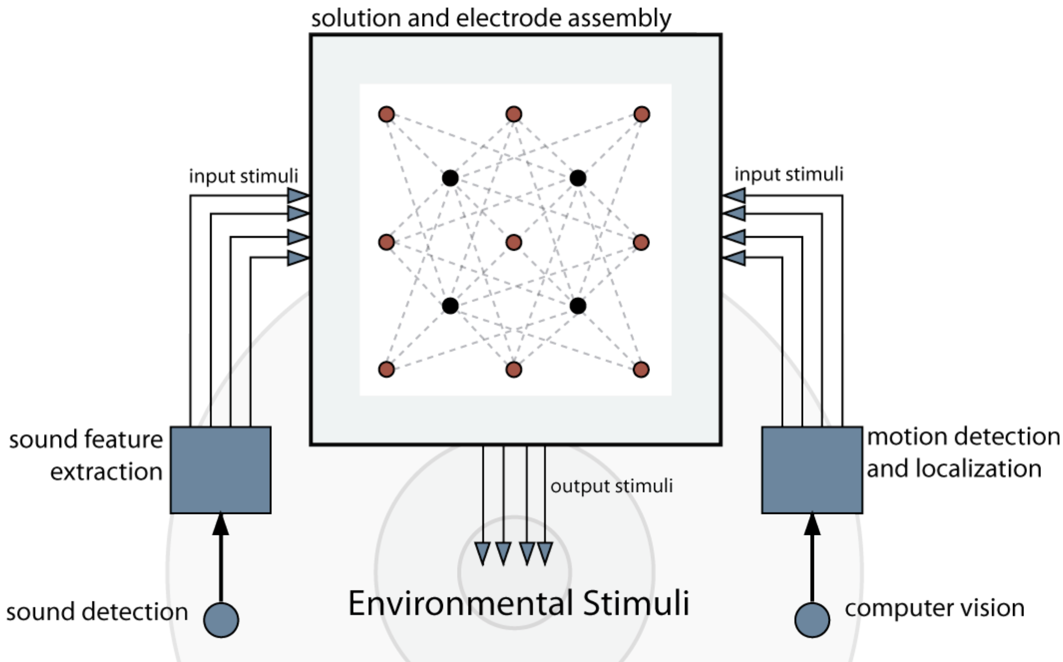


Figure 7.7 The *Organic Learning* setup. Coincident sound and motion information was fed into the electrochemical solution.

The purpose of this particular experiment wasn't merely to demonstrate the presence of associative sensory learning in our system. The more general goal was to explore the classic dichotomies of inorganic vs. organic and non-biological vs. non-biological. Our system is, by standard scientific definitions, inorganic. Yet, we have commonly observed patterns of bifurcated growth and dissolution that have qualities classically reserved for organic biological systems. Accordingly, we wanted to test the boundaries of the inorganic and organic, the non-biological and the biological, by attempting to show that this "inorganic non-biological" system could manifest properties comparable to those associated with a biological system that is learning about aspects of its environment (e.g., neuronal and glial plasticity, or long-term potentiation/depression of synaptic communication).

7.6. Construction and Exhibition

Thus far *Biopoiesis* has been exhibited five times: twice in Vancouver, BC at Gallery Gachet, at SIGGRAPH 2012 in Los Angeles, CA, ISEA 2012 in Albuquerque, NM and most recently at the Scarfone/Hartley Gallery in Tampa, FL. The first iteration of the piece was exhibited at Gallery Gachet in July 2011. For this exhibition, a square glass tank, approximately 19in x 19in was constructed (Figure 7.8). Two sheets of glass, each 6mm thick were glued together, leaving a small (approximately 5mm) gap in between for the solution. This shallow bath, coupled with the nearly clear solution and clear glass made the growth easily visible. The electrodes were glued to holes drilled into the bottom of the tank and sealed with clear epoxy. Small spigots were also drilled to the bottom to allow for insertion and removal of solution via a funnel. We also constructed a roughly 6in high acrylic platform to mount the tank onto.

Figure 7.8 First iteration of the *Biopoiesis* tank used to house the electrochemical solution and electrodes

This initial exhibition utilized what we would eventually consider our default configuration. We titled it "Emergent Relations" as the overall impetus was to study in a very direct and physical way what emergence and self-organization might look like. The goal for me was to bring these abstract and esoteric ideas down to earth, to the level of aesthetic and embodied experience. Specifically, the goal was to better understand — through experience and material practice (i.e. making the piece) — how relations between observer-participants, the environment, and the system's particular material instantiation are each contingent and in sense co-determinant with each other.

As shown in Figure 7.9, this exhibition consisted of the tank, a video camera mounted above the tank connected to custom motion tracking software (built in OpenCV), custom electronics (primarily relays and an Arduino microcontroller) and a computer running custom sound synthesizer software (built in Max/MSP). In this laboratory-esque set-up, various sonic parameters (e.g. oscillator frequencies) from the sound synthesizer were converted into lengths of electrical pulses that were fed into the solution. The resulting electrochemical growth (and resulting change in conductance) was measured and used to alter the parameters of the synthesizer, whose parameters were again fed into the solution in the form of electrical pulses. In addition, motion from the video tracking system was also converted into lengths of electrical pulses and fed into the solution. Since the camera was pointed directly at the tank it was the growth itself that was being tracked (i.e. being used as output and subsequent input). More growth picked up by the tracking software would (at least in theory) result in more and longer electrical pulses, which would in turn result in more growth and so on. Data from both the sound synthesizer and the motion tracker were connected to, and interacted with, the solution in this circular fashion. An additional component used in this exhibition was a patch bay of sorts. This was a patching interface that allowed for the real-time reconnection of environmental input to electrode placement. Thus, for example motion tracking data that was connected to an electrode on the lower left of the tank could instantly be swapped with an electrode on from the upper right that was getting its input from the sound synthesizer. Participants were invited to reconfigure these connections, in effect changing the configuration of the system.

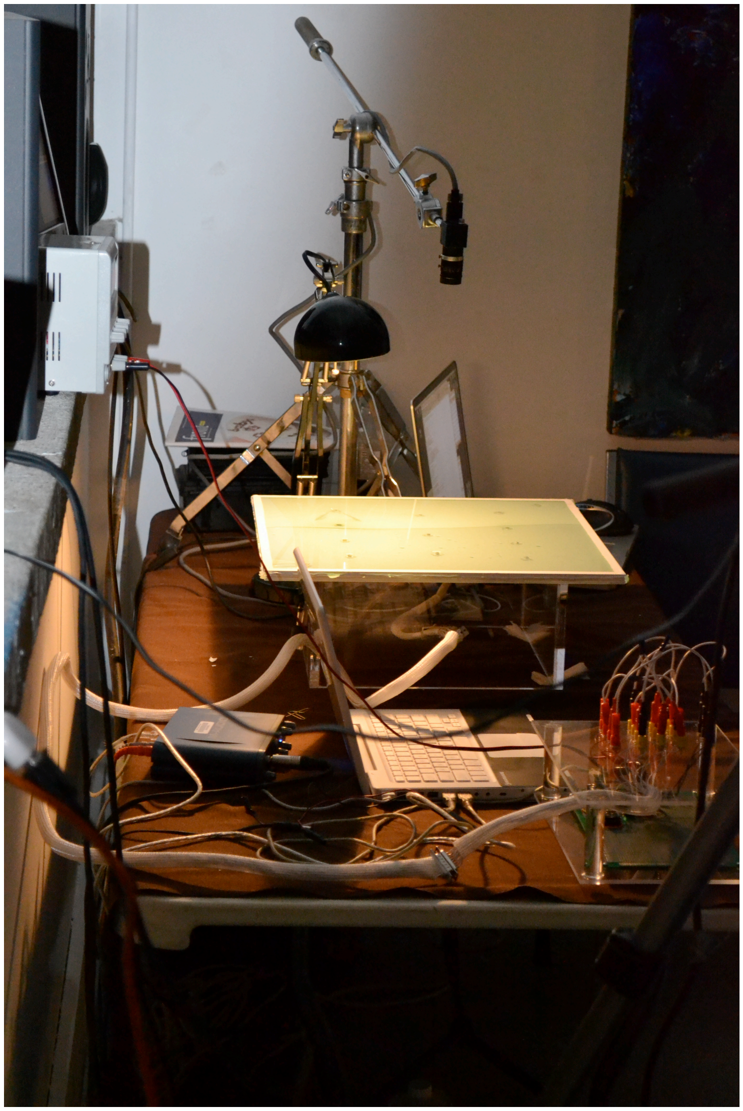


Figure 7.9 The first Biopoiesis set up ("Emergent Relations", Gallery Gachet, Vancouver, BC): (top center) video camera mounted on boom stand, (center) tank housing electrochemical solution with laptop computer running motion tracking software, (lower center) laptop computer running sound synthesis software, (lower right) custom electronics for converting digital data to electrical pulses and connecting to tank; the patch bay is just above the circuit board, (top left) power supply that feeds electrical current into the solution

The first exhibition of the "Organic Learning" implementation was also at Gallery Gachet in Vancouver. This time it was in June 2012 and like *Protocol*, was part of *Proof-of-Process*. We decided to use this as a sort of test run for the upcoming SIGGRAPH exhibition in Los Angeles. This exhibition featured a new tank we had constructed a few months back. This tank was smaller (10x10 inches) and made of acrylic. The top was removable so as to more easily insert and remove the solution but still fit firmly enough to allow for a shallow bath (about .25in) and for the electrodes to reach the bottom of the tank. The holes were also drilled onto the top, thus allowing the electrodes to come in from the top with the wires clearly visible (see Figure 7.10). The electrodes were either glued (using silicone) or fit firmly into the holes using rubber stoppers.

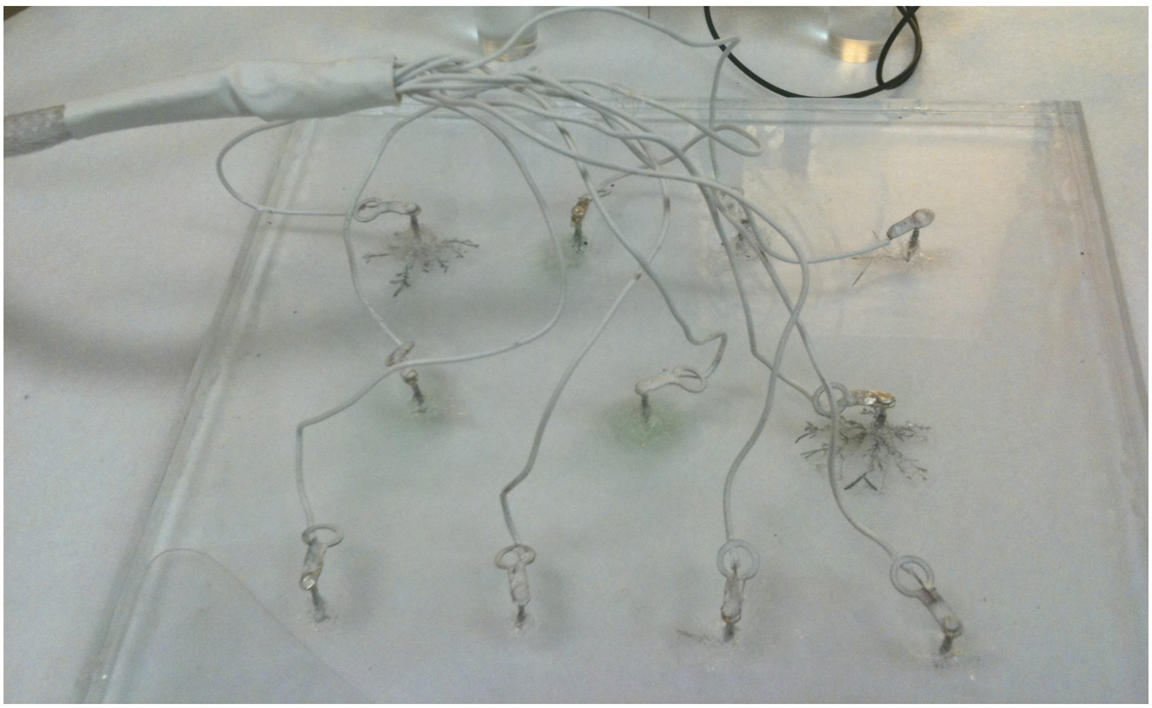


Figure 7.10 Acrylic tank with holes drilled onto removable top.

In this exhibition, the particular features inserted into the solution come from the other pieces in the exhibition and from activity the gallery generally. This included sound and motion of participants near and around the tank itself. For the most part this exhibition was not really an exhibition but more of a continuation of the trial and error process described earlier. In addition to ironing out various technical difficulties, much of what we did consisted of demonstrations and discussions with participants. In essence we spent much of our time showing the “behind-the scenes” functioning of the piece itself as it was built and/or reconfigured. Figure 7.11 show the *Biopoiesis* set-up for *Proof-of-Process* A more proper exhibition was held on the final day of this weeklong event.

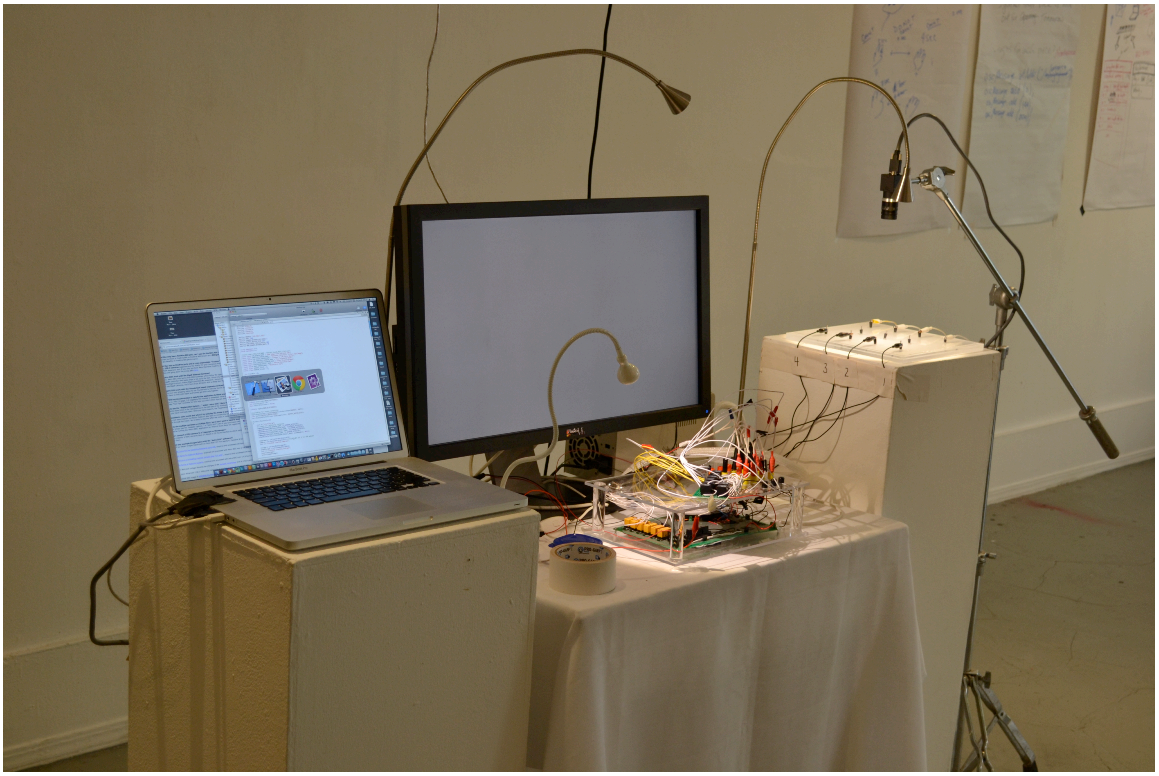


Figure 7.11 System set-up for Proof-of-Process, Gallery Gachet, Vancouver, BC (June 2012)

Although we had some initial problems in eliciting visible growth in the dendrites on this final day, we did notice some interesting patterns of what appeared to be indexical traces conductance. Perhaps having to do with the concentration of the stannous chloride solution we used, we noticed some minor sedimentation in the tank. About two hours into the exhibition we noticed that within the sedimentation were lines of what appeared to be conductance traces (Figure 7.12). This was an interesting historical record not so much of the Organic Learning experiment itself (which was never really properly realized), but rather of the complex flows of electrical current within the solution.

Figure 7.12 Minimal growth (top center) and conductance traces after roughly two hours of operation.

For the Organic Learning implementation exhibited at the SIGGRAPH 2012 Art Gallery another new tank was built. Like the acrylic one it had an easily removable top with holes for the electrodes. This tank however, like the first one, was made of clear glass. It measured 21x21 inches with a 10mm deep inset to hold the solution. As shown in Figure 7.13, this exhibition consisted of the tank, the custom electronics and electrodes, a video camera (not pictured) mounted above the tank and connected to custom motion tracking software. There is also a microphone, which is connected to the spectral analysis software. This exhibition also included visualizations showing the activation/deactivation and magnitude of electrode activity, the overall sonic spectral characteristics of the environment and the amount and location of motion activity in the space.

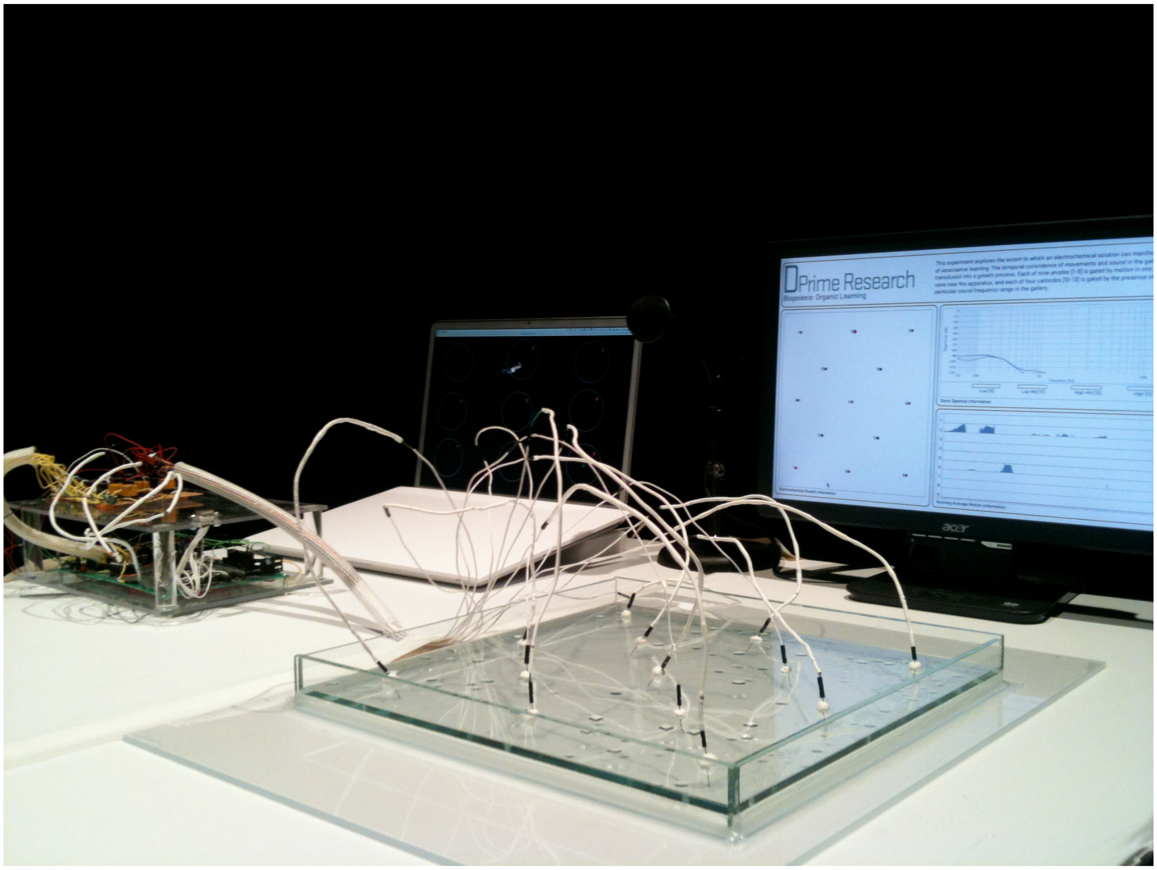


Figure 7.13 *Biopoiesis: Organic Learning* at SIGGRAPH 2012 in Los Angeles. Clockwise from left: custom electronics for converting digital data to electrical pulses and connecting to tank; laptop computer running motion tracking software and displaying areas of motion activity; microphone; visualization showing electrode activity, overall sonic spectral characteristics and overall motion activity; tank containing stannous chloride solution with electrodes attached; not pictured is the video camera (several meters above the table).

The experiment ran for longer than our previous setups: running almost continuously for a period of 4 days. As predicted, plasticity was observed in the growth patterns of the dendritic threads that seemed to be related to the coincidence of particular sounds and motion in the environment (Figure 7.14). We also found something we hadn't observed in earlier systems: at night, when the gallery was empty of visitors and largely devoid of any sound, the dendritic threads would begin to dissolve back into solution. This latter observation is somewhat remarkable, in that it demonstrates that dendritic threads are activity dependent processes — further highlighting the system's organic/biological qualities.

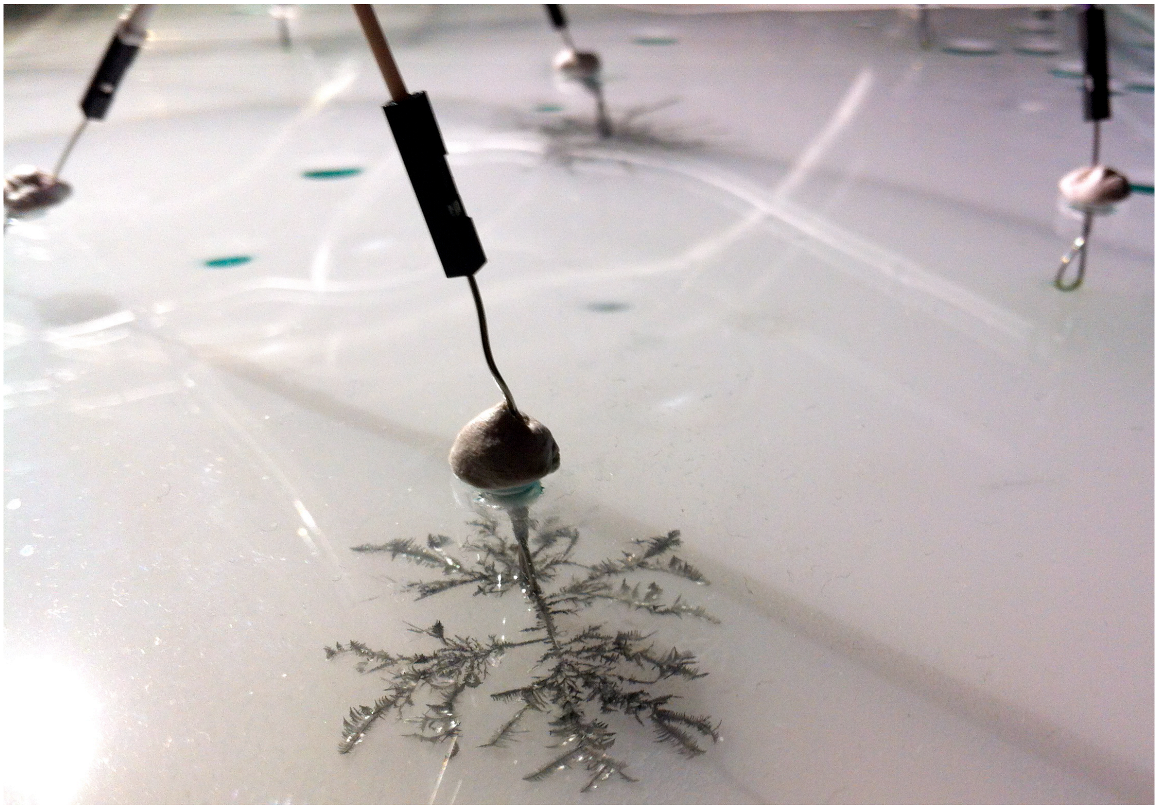


Figure 7.14 A momentary result from day 2 of the Organic Learning experiment at SIGGRAPH 2012. A highly bifurcated dendritic growth pattern can be seen at the cathode in the foreground.

With the success of SIGGRAPH 2012 exhibition it felt as though the *Biopoiesis* project had matured. Although there is still much we would like to do with this project, much of it is a simple matter of slightly changing our existing configuration. The ISEA 2012 exhibition for example was a variant of the Emergent Relations experiment (Figure 7.15). The major difference here were the use of a digital microscope and the recording of images of growth from the microscope (1 per minute). The exhibition at the Scarfone/Hartley gallery in Tampa (Figure 7.16) was essentially the same as in SIGGRAPH 2012 (the Organic Learning experiment). The major difference here was the use of the digital microscope and the way the sound from the gallery was collected: we used more microphones spread out to cover most of the gallery space.

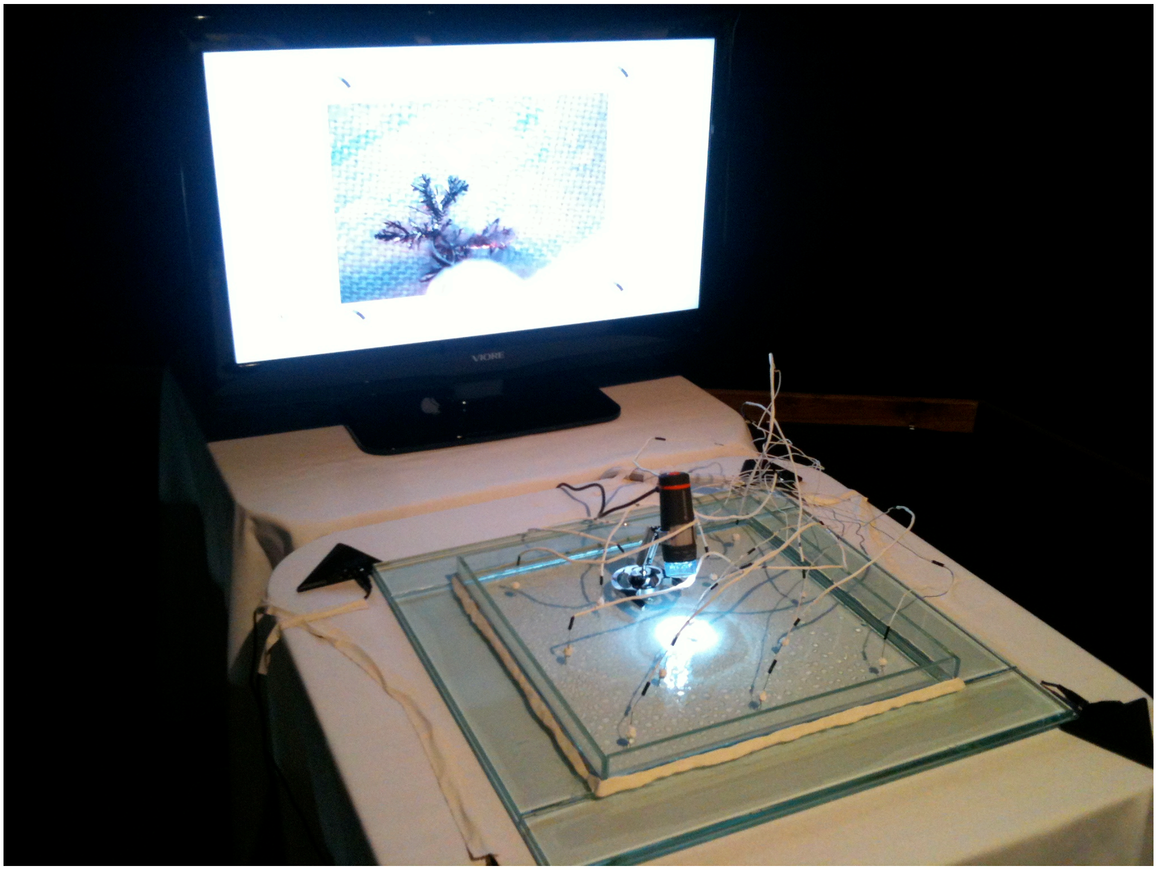


Figure 7.15 *Biopoiesis* at ISEA 2012

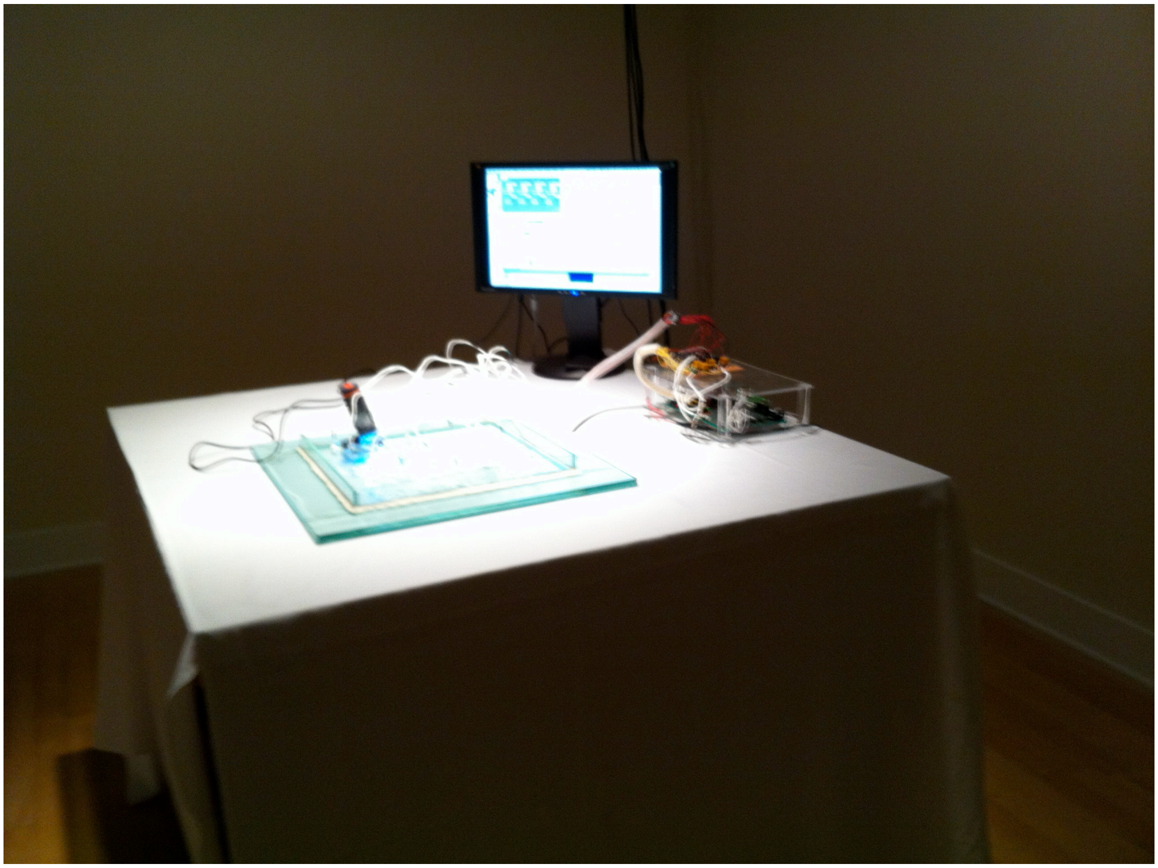


Figure 7.16 *Biopoiesis* at the Scarfone/Hartley Gallery in Tampa, FL.

7.7. Analysis and Reflection

Perhaps the most enduring aspect of the piece for me is the considerable care and supervision that it required. This was not a piece that can simply be set-up and left to run unsupervised. Like many technological artworks it required a fair amount of maintenance and set-up time. Unlike most technological artworks however, it required constant replenishment. The solution either had to be added to the tank every two or three days or completely replaced altogether. The growth was constantly monitored to make sure it was within acceptable parameters. The overall experience was of taking care of something. Making, exhibiting and observing collapsed into on each other. Often when removing the solution from the tank there was sense of loss, of trying to preserve it for posterity. Not in the sense of a digital back up but the way one would preserve a moment with a photograph, or make an imprint. There was also a sense of that the piece as evolving and growing in broader sense. For example, by the end of the third day of the SIGGRAPH 2012 installation, we noticed that some white chalky material was building up on the bottom of the tank (Figure 7.17). We also noticed that the quality of the dendritic threads had changed: whereas on the first few days of the installation the threads were characteristically silver in color with clearly delineated branching patterns (as in Figure 7.14), by the end of the third day the dendritic threads were black and it was harder to discern branching. In some cases the growth constituted a shifting black clump of material focused at the electrode tip (Figure 7.18). The system also seemed to be less plastic, in that it was harder to observe changes in the threads. All of this was an annoyance at first, and we were tempted to completely empty the solution and start anew. But upon further consideration we realized that this degradation of the solution and the dendritic threads only lent further weight to the assertion that this complex system is comparable to a biological system: it appeared to be aging. This further added to the sense of loss I experienced at the end of every exhibition.

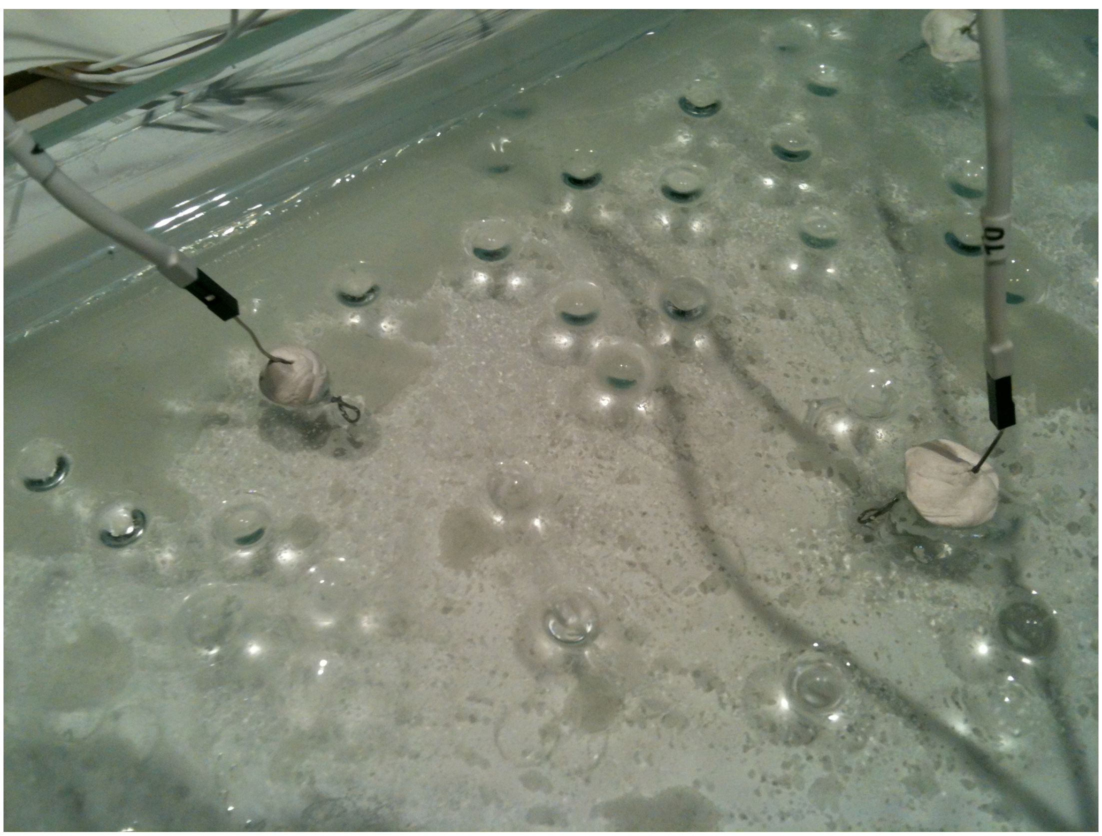


Figure 7.17 Chalky material building up on bottom of tank after several days of growth.

Figure 7.18 *Biopoiesis*, “aging” threads.

This curious relationship I had with the system, was borne in part from what I see as its inchoate, emerging or potential **autonomy**. This is not autonomy perhaps in the scientific or even autopoietic sense, but in the phenomenological sense, via relations that echo Merleau-Ponty’s notion of reversibility. Following from his notion of ambiguity, reversibility is the idea of seeing the system as other in its emerging, dynamic and mercurial relationship to me (to my motion, breathing, speaking); as just one entity among many that it and I are embedded in. I can never know the system in itself, as Merleau-Ponty would say, but I could access it (at least on an abstract/cognitive level) in its circular, reversible relation to me — all within this zone of ambiguity. Thus my experience with this is piece is perhaps closest to the distributed aspect of symbiogenic experience, as the construction of the piece, the study of its conceptual foundations, the exhibition, as it adumbrates a sense of being interdependent with nature/technology, blurring the boundaries, foregrounding ambiguity (in the Merleau-Pontian sense). Technology grows in this piece as a result of the independent action of myself participants and the system itself. It may however been seen as showcasing the enactive aspect of symbiogenic experience, as the piece came from the idea that an "organic" piece of technology can enact a world for itself (develop its own sensitivities to environmental factors impinging on it). *Biopoiesis* was a sort of performative sketching of such a dynamic.

For many years now, artists have experimented with different mediums, techniques and locations without knowing exactly what the results would be. Thus, as an artist, this Paskian approach of *Biopoiesis* does not feel that different from certain other artistic modes of experimentation. Andrew Pickering notes how in Pask and Stafford Beer's work there is a belief in the agency and variability of matter. He notes how rather than marshalling (or dominating) "inert lumps of matter" (as the building of computers and industrial machinery entails), there is an attempt to couple this variability to human concerns (Pickering 2010, 236). My experience with *Biopoiesis* in part lead me to the idea that project like it encourages us to view the world as full of co-emergent, co-evolving systems too complex to be fully apprehended or objectively explained. A world that is in a perpetual state of becoming, characterized and brought forth via emergent relations of complexity that adumbrate an experience of the world that I characterize as open-endedly ambiguous. When I say that we exist in dynamic interplay with our technology, it is really another way of saying we exist in circular and complex interplay with nature – what I characterize as co-evolution. Ambiguity, complexity are another way of saying co-evolution and *Biopoiesis* showcases this, standing out as what Andrew Pickering calls an "ontological icon" of symbiogenic experience.

Thus, when I say we are co-evolving with technology, I mean we are co-evolving with nature, as technology always involves a negotiation between nature and humans, again the nature/culture divide is blurred (Ihde 2011; Haraway 1991). Complex sets of human-material interactions (interactions in a broad sense, not just in a digital or interactive art sense. e.g. breathing is interactive) are necessary for any technology. This was an important realization that emerged and was threaded through the practice and intersubjective experience of making *Biopoiesis*. The desire to harnessing the complexity of matter and the environment in the manner cyberneticist like Pask and Beer wanted to do were grounded not only their faith in the agency of matter (Pickering 2010), but more generally in the complex interdependence between this matter (living or not) and the humans who are harnessing it. Both depend on one another for their development, their (co)evolution. To state it another way we are in a sense in conversation with our technological environment.

8. Conclusion

This chapter provides a summary of the theoretical framework outlined in this dissertation as well as the development of the two artworks documented in Chapters 6 and 7 that form the practical component of the framework's development. It also includes ideas on some possible future directions for the research.

8.1. Summary: Symbiogenic Experience and the Emergent Arts

For some time now artists, humanities scholars and scientists have been exploring ideas of human co-evolution with technology. Much scholarly work has been taken up in recent years that explores and examines relations between human perception and technology's ability to influence it. What I set out to do in this dissertation was to add a bit to this chorus, from what I hope is my own unique perceptive as a conceptually and technilogically inclined artist and scholar. Though the diversity of perspectives on the issue of human-technology co-evolution are certainly encouraging, there are still, I feel, gaps that need to be narrowed. In particular, little attention has been payed to subjectivity, embodied subjectivity in particular. Complex interactions, emergence and self-organization with a technological environment after all, happen to embodied subjects. Though cyberneticist Gordon Pask did some notable work in accounting for subjectivity in one realm of human evolution (learning) and Katherine Hayles, Mark Hansen and Don Ihde among others are certainly notable examples from within the humanities, the intellectual foci by and large has remained with evolution as an anonymous, disembodied process and not as a process that is experienced *by* embodied subjects. Following Merleau-Ponty and the existential phenomenological tradition, I have argued in essence, that if we did not think of concepts such as co-evolution, emergence and self-organization from the perspective of someone who is implicated in these very processes, we could not think of them at all.

Whether Hollywood cyborg-style scenarios or techno-aesthetic explorations by contemporary artists, ideas of human-technology co-evolution continue to fascinate and inspire us and continue to be more important aspects of both contemporary fine arts and mainstream popular culture. I have argued that the complex technological infrastructures of Western society are catalyzing shifts in our embodied perception via their increasing collective agency (Hansen 2009a), causing “juxtapositions” that reorient time and space (Thrift 2004) and giving rise to a background sense of a reconfigured relationship to our external cognitive scaffolding (Clark 1998). I further argue that interactive/new media arts can make us aware of these changes via direct embodied experience. I have thus sketched out a theoretical account of the phenomenal and longitudinal aspects of this dynamic, via what I call symbiogenic experiences. I have asked “how can co-evolution be felt”, made apparent via the subjective contours of sedimented experience, and I ask if and how interactive artworks can amplify and heighten these feelings, thus helping us to understand and apply meaning to them. In other words, I have asked if interactive arts can heighten our experience of co-evolution with an increasingly technologized environment? Can it make us more aware of it, and if so how?

My claim is that there are certain interactive/new media art works that can be said to engender experiences that attune us to this heterogeneous, co-emergent dynamic between humans and their technological lifeworld. A specific range of artistic deployments of technology — what I call the emergent arts — heighten our perceptions, and may make us more aware of how humans and their technologized environment interrelate to give rise to a sedimented, longitudinal experience of co-evolution, operating consciously and non-consciously via processes that can be thought of as locatable both within the traditional bounds of the subject and also dispersed without, in a myriad of intelligent technological structures. Though a few scholars have discussed how interactive art amplifies the technical dimensions of embodiment and our technogenesis (e.g. Hayles, Hansen; and in Hansen’s case doing it from a phenomenological perspective), the co-evolutionary experiences themselves have not been too deeply studied. My goal in part has been to ask how this technogenesis can be felt and understood via direct phenomenal experience. I have argued that the co-evolutionary experiences that these works engender can be identified, but they currently lack a cohesive theoretical framework from which to study and analyze them.

I have endeavored in this dissertation to take a step toward filling this gap by offering what I hope is a unique perspective on how we may interpret and analyze these works. The result is an adumbrative, provisional framework that accounts for and helps us analyze and interpret how interactive/new media art is making us "feel" or in some sense become aware of how the complexified technological structures that serve as the background and context for experience in contemporary western society (I use the phenomenological term "lifeworld") are engendering shifts in how we perceive and experience our lives, which in turn influence how we relate, interact with and construct new technologies. I have argued that this may be regarded as a contextual change, a sense that our relationship with technology is shifting the general perceptual conditions of our daily lives. This change is not purely cognitive I argue, but may be felt in our embodied perception, which is tied to material anchors in the real world that can amplify this inchoate sense. This necessarily requires that a new vocabulary of sorts be developed. Thus, in order to steer clear of Darwinism, I have unpacked and re-casted the term co-evolution in order to refer more to dynamic processes of reciprocal interplay, and mutual co-emergence that do not occur in isolation but in relation to an environment that is also dynamic, adaptive and technologically textured.

It is quite apparent that at this stage, the questions raised by this provisional theoretical explication of what comprises a symbiogenic experience are perhaps as plentiful as the answers. While I have partially answered some of these questions, the answers are not meant to be authoritative, but are rather a means of establishing some degree of conceptual, ontological and epistemological grounding. By exploring scientific ideas such as autopoiesis, emergence and self-organization, from an artistic and phenomenological perspective and in relation to the concept of symbiogenic experiences, this dissertation offers a unique contribution to the field of interactive art.

The research can generally be broken up into three overlapping and interrelated parts: (1) the emergent arts, a taxonomical model of a range of artworks that thematize reciprocal interplay of human and machine over representations and purely mental processes (where each is cast as separate from the other). I have argued that the emergent arts may give rise to new networks of perceptual and conceptual complexity that give rise to experiences that may be thought of as a form of self-organization and neocybernetic emergence. These experiences, starting from an amplification of everyday experience (Dewey), are part of incipient processes of perceptual connection to a technologically complexified world. Understanding these works sets us up for the theoretical core of the research: (2) the symbiogenic framework. This is an abstract phenomenological model based upon a synthesis of the ideas of existential phenomenologist Maurice Merleau-Ponty and those of neocybernetic theory and the material practices of what can be called an alternative cybernetics. I introduced four theoretical concepts that I consider to be the cornerstone of symbiogenic experiences in the emergent arts. I stressed that these experiences are emergent, sedimented and longitudinal. That is, they are always in flux and accrete over time. They are also distributed, which is to say that they occur in relation to an environment that serves as a sort of embodied and cognitive scaffolding. Finally, I argue that these experiences do not exist in isolation but are part of the larger generational and historical embeddedness of the subject. (3) The third portion of this dissertation is the interactive arts projects that were constructed and exhibited and the phenomenological descriptions of those processes. These projects, *Biopoiesis* and *Protocol,* functioned as a method of inquiry that was grounded in the theory but also pushed the theory, to form new ideas that further developed the framework. Thus, the artworks simultaneously function as methods to generate ideas and — in conjunction with the more traditional scholarly argumentation and analyses — a concrete actualization of those ideas.

As they share some important characteristics (constructivist epistemology, subjectivity of observers and, as I have argued, an ontology of ambiguity and unknowability) Merleau-Ponty's phenomenology and cybernetics allowed me to better analyze how interactive art showcases and amplifies a sense of being in constant relation to one's increasingly technologized environment — where reciprocal interplay and mutual co-determination are the threads through which human experience is woven. Crucial here is that the framework allows one to avoid simplistic Darwinian scenarios that view the environment as static and instead allows for the building of analyses and interpretations from a perspective of dynamic organism/system-environment as the unit of analysis, rather than the organism/system in isolation from a static environment. The focus here is on how each is implicated with the other. In particular, neocybernetic theories of enaction, structural coupling and autopoiesis illustrate the mutual, reciprocal relationship that we have with our environment. Combining this with Merleau-Ponty's embodied phenomenology and descriptive analyses of interactive artworks allow for interactive art experiences to be viewed through this redeployed notion of co-evolution.

8.2. Theory as Praxis/Praxis as Theory

The approach taken in this research has centered upon going beyond textual descriptions, something particularly crucial when dealing with not only issues of embodiment but also with highly abstract concepts that are paradoxically, also primordial to experience. As the combination of artistic making and theoretical argumentation is a somewhat new phenomenon in academic research, some extra notes regarding the use interactive art as a method in this research is warranted.

This dissertation has detailed the construction and exhibition of two interactive art systems, *Biopoiesis* & *Protocol*, as well as reflections and analysis of my experience with and through them. These works have functioned as reservoirs of experience from which to ground my analysis and thus function as part of the same circular making/thinking process. As mentioned above, many scholars have looked at questions co-evolution of humans and technology but few have explored how this co-evolution can be felt and understood within the context of interactive art experiences. Though many scholars (such as Hayles and Hansen) have used interactive arts as tools from which to build their technological philosophies of embodiment, I have argued for a method that combines theory and practice, art and philosophy as part of the same hermeneutic and reflexive process. I view each as co-emergent with the other, with my particular approach featuring combinations of interactive art, cybernetics and existential phenomenology. In much the same way that writing down ideas on paper is not a record of the ideas in one's head but the method and materials by which the ideas are actualized, interactive artworks, their construction, exhibition and documentation, in concert with scholarly argumentation and analyses *are the work*, they *are* the actualization of the ideas.[29] Thus, this dissertation is not only a record of the ideas that took shape but also the process *by which* they took shape. *Protocol* and *Biopoiesis*, the experiences with and through them, and the scholarly, theoretical writings that they are bound up with may be seen as a version of Andy Clark's extended cognition, wherein abstract ideas in the head and material/experiential anchors in the physical world work together in a dynamic of circular causality where the abstract and the concrete cannot be understood in isolation. This incorporation of art or technological systems in humanistic theoretical argumentation is sometimes referred to as the use of "objects-to-think-with" or "tools-to-think-with". For me, *Biopoiesis* & *Protocol* functioned as natural components of my artistic-theoretical process, of putting theories to the ontological test. I have used these works as a way to engage and explore the ideas here; to push the theory, augment traditional textual/humanistic arguments, analyses and close readings. Thus, in addition to the theoretical framework and the artworks themselves, this dissertation itself also represents the processes by which a theoretically informed practice (or practically informed theory) was developed.

It is also important to note that each of these works yielded their own unique results. I have already mentioned in Chapter 6 how *Protocol* was an awkward transition away from an AI and machine learning-based mindset of optimization and behaviour-based interactions and toward a greater focus on complexity and heterogeneity. *Protocol* instigated a shift to more holistic and non-symbolic cybernetic ideas on intelligence, computation, autonomy and emergence among others. For example, *Protocol's* attempt at establishing "equilibrium" or constructing shared meanings between human and machine was in part inspired by Gordon Pask's model of conversation (Pask 1975; 1976). The experience with the piece led me to look at other ways that intelligence could be considered as well as the circular/autopoietic nature of meaning construction. This led me to *Biopoiesis,* which in turn led me to think of meaning, perception and ultimately, symbiogenic experience as evolving from an open-ended, ambiguous and continually emerging space of possibilities. *Biopoiesis* helped nail down the cybernetic ideas, as my

[29] Andy Clark illustrates the potential for technological tools to extend memory with a story from Nobel Prize-winning physicist Richard Feynman. In a meeting with historian Charles Weiner, Feynman argues that his handwritten notes are not a record of his work but rather that the act of writing down was integral to his thinking process and thus *are* the work in some sense (quoted in Hayles 2012, 93).

experience with it (at least the exhibition portions) gave me a sense of what I see as its inchoate or potential autonomy emerging from the growth of the electrochemical dendrites. These works then, were really experiments in trying to further develop abstract theoretical ideas related to symbiogenic experience, or at least aspects of it.

8.3. Implications and Future Directions

In this dissertation I have approached the analysis of interactive art from a slightly different perspective than those traditionally deployed by most art theorists and humanities scholars. I have used the experiences of art-making as part of the process of theorizing and textual argumentation. I have argued that this is crucial if we are to understand how interactive art may influence one's (or a culture's) sedimented experience. Until recently, most interactive/new media art analyses did not attend too much to the actual experience of the artwork (instead they focused on formal concerns or its conceptual underpinnings). Even fewer have looked beyond the momentary experience of one's immediate encounter with an artwork, or studied how these experiences can influence us longitudinally, relating to other experiences in a complex, sedimented fashion. The framework I have sketched out here will aid in these types of analyses. This interpretive and analytical framework will give artists and scholars the opportunity to look at artworks not only from the point of view of experience and at what they do (in addition to what they are), but how they relate to what may be called our techno-ecological context (this is discussed further below). In doing so, this dissertation begins to fill a gap between themes and concepts of human-technology relations in the arts that often view the environment as static and draw from notions of co-evolution that are either purely discursive or objective (as in the humanities and sciences respectively). This framework looks at experiences (and the meanings applied to them) in an interactive arts context, as arising from within the co-emergent flux of our technological environment. From a neocybernetic perspective this may be characterized as a subjective realization that we are not *us* but *us and our* (increasingly dynamic, emergent and technologized) *environment*, and that that should be the primary unit of analysis.

Artists are generally viewed as forward-looking risk-takers that can show us aspects of culture, technology and experience that often escape the purview of others.

Often, they work without the bounds of (often rigidly) prescribed methodologies and institutional structures, or see their job as provoking or questioning the status quo. It was anthropologist and cyberneticist Gregory Bateson who posited that consciousness plays an important role in the human organism's ability to adapt to society and with the larger ecosystem (Bateson 2000). I have argued and demonstrated in this dissertation that the unique experiences offered by a range of artist practices that I refer to as the emergent arts can put us in touch with an environment that we are now perhaps beginning to understand our place in.

At the same time, the increasing importance of non-reductionist scientific approaches such as complexity and dynamical systems theory and a resurgent interest and appreciation of its progenitors in cybernetics and neocybernetic theory, in addition to a resurgence in interest in phenomenology and the experiential aspects of the body, have helped open up new avenues of exploration of human beings' relationships to their technology and their ecology. Thus, a natural extension of this research as I see it, is an exploration of our ecological context, perhaps a combination of ecosophy and conceptual "eco-art".[30] This may seem paradoxical, as technology is often seen to be in opposition to the natural environment. However, ecologists have for some time now spoken of a "technosphere", a part of the environment where technodiversity interacts or extends its influence into the biosphere (Naveh 1982) — what I have called our increasingly technologized environment. Some have called for a greater realization of how "technoecosystems" are interdependent with natural ecosystems and how they may enter into more reciprocal and mutualistic relationships with one another (in a sense making the technoecosystems more "natural") (Odum 2001). This large-scale techno-ecological perspective on human-technology relations may open up new avenues of explorations for interactive/new media art. For instance, the emergent arts may explore ways of amplifying an awareness of what eco-philosopher Timothy Morton calls a "hyperobject" (Morton 2013). Hyperobjects refer to things that are outside of or beyond human temporal and physical scales. Hyperobjects can be black holes, global warming

[30] Ecosophy (or eco-philosophy) is a neologism formed by combining the terms ecology and philosophy. The term is often used to designate the concepts of philosopher and psychoanalyst Félix Guattari and philosopher and founder of the deep ecology movement Arnes Næss. Though their work is conceptually related, their ideas are quite different and oftern contradictory. See Guattari (2005) and Næss (1973).

or the technosphere. One important aspect of hyperobjects which is similar to symbiogenic experience is their *nonlocality.* This refers to the notion that any experience that a human has with a hyperobject (say shopping online or experiencing above average temperatures), is considered a local manifestation of the hyperobject but not the hyperobject itself. Morton argues that hyperobjects are never fully available to human experience; they exist beyond the lifeworld and thus require a rethinking of what phenomenological experience and lifeworld mean. The emergent arts perhaps can be said to produce "local manifestations" that heighten our access to technological hyperobjects.

Regardless, what I can say here is that if there is one broad conclusion I have reached in this research, it is that while the relations of alterity in the emergent arts that give rise to symbiogenic experiences are multifaceted and perhaps sometimes disruptive, they are not always alienating. Indeed, emergent artworks may be seen as amplifying a sense of technology as part of nature and not as an alienating other to it (Kluitenberg 2012). The symbiogenic framework then, is in a sense, a framework that enables a more ecological reading of art and technology and the social, cultural and environmental relationships into which it is embedded.

Whether a theory of symbiogenic experiences can be expanded to encompass the complex interactions within a continually changing ecology is of course a matter for future inquiry and cannot be resolved here. However, it is important to recognize that in suggesting this, I am presupposing that a new sort of eco-consciousness is indeed emerging. If so, then it is perhaps being cultivated in part due to the consciousness of co-emergence and co-evolution that, as I have argued, is made possible by the emergent arts. While the comprehensive and complexified nature of our technologically-textured everyday lives is something that we are not always conscious of in western society, it may paradoxically be instigating or portending a greater awareness of connection to the real environment. In essence, by extending human insight and experience, emergent artworks (and technology more broadly) may actually be implicitly bringing us closer to nature. Now this may give rise to a broad set of complicated questions regarding implications with the technological superstructure (and power relations) within western society and its impact on resources and the global ecology and climate of the planet. Thorny political issues may inevitably arise and must be dealt with.

A more ecological reading of symbiogenic experiences must also make a greater consideration of both the time scales of co-evolutionary experience and pragmatics of how we may actually become aware. Issues of time scales no doubt arise when dealing with long-term adaptation between humans and the technologies they create, as they often work in radically different temporalities. Katherine Hayles has done an admirable job of addressing this issue and her analyses (in part) come down to how one defines (co)evolution (Hayles 2012) (though as I have already indicated there is little attention to payed to how we as humans may “feel” this co-evolution and become aware of it on some level). In addition, we must look at time and space (or rather our perceptions of them, which is ultimately all that we have) not as static pre-formed things but in terms more akin to neocybernetic observer->observed relationships; as being themselves open to restructuring. This may be another avenue of future exploration for the ideas presented here.

With regard to the practical aspects of how we may become aware (however faintly) of our co-evolutionary relationship with intelligent technologies, Depraz, Varela and Vermersch offer a concrete, systematic set of practices and methods for exploring human experience, including those that are often unexamined or lie just outside of immediate reflection, such as those I have presented here (Depraz, Varela, and Vermersch 2003). Aside from the practical, step-by-step nature of their approach, the practices they outline may be well suited for interactive/new media work, as they tend to emphasize the processural character of phenomenal descriptions.

Because a symbiogenic experience is enacted through the reflexive nature of artistic-theoretical inquiry, it necessarily requires that well-established positions on both the nature of art and technology be reexamined. Ultimately, I believe that new models of analysis appropriate for the study of complex, dynamic systems need to be developed when we analyze art, for art is no longer merely expression, and technology is not merely technical. Thus, the artist-researcher’s role should necessarily be partly theoretical and wholly, indeed radically, experimental and enactive.

In his influential essay “Death of the Author”, French poststructuralist philosopher Roland Barthes showed us that the blurring of roles between the reader and the writer undermines the static nature of meaning and thus necessitates the creation of a different model of literary criticism (Barthes 1978, 142–148). As the increasing scale and scope of our technologically-textured world continues to influence both techno-scientific research and artistic practice — particularly for those involved in networks and intelligent systems — deeply held notions of authorship and interpretation are continuing to break down. Similarly, Lynn Margulis has shown that the differences between species are not as vast as they once appeared. I have also shown here that the distinctions between human and technics, body and environment, and art and science are not as extensive as once thought. Yet, even small distinctions are important, for they give the arts its distinguished (though not privileged) role within the cultural landscape.

References

Abraham, Wicklifee C., and Anthony Robins. 2005. “Memory Retention--the Synaptic Stability versus Plasticity Dilemna.” *Rends in Neurosciences* 28: 73–78.

Adam, Alison. 1998. *Artificial Knowing: Gender and the Thinking Machine*. Routledge.

Ambrose, Stanley H. 2001. “Paleolithic Technology and Human Evolution.” *Science* 291 (5509): 1748–53.

Ascott, Roy. 2003a. “From Appearance to Apparition: Communication and Culture in the Cybersphere.” In *Telematic Embrace: Visionary Theories of Art, Technology,and Consciousness*, edited by Edward A Shanken, 276–83. Berkeley: University of California Press.

———. 2003b. “Behaviourist Art and the Cybernetic Vision.” In *Telematic Embrace: Visionary Theories of Art, Technology,and Consciousness*, 109–56. Berkeley: University of California Press.

Ashby, W. Ross. 2004. “Principles of the Self-Organizing System.” *E:CO Special Double Issue* 6 (1-2): 102–26.

Assayag, Gérard, Georges Bloch, Marc Chemillier, Arshia Cont, and Shlomo Dubnov. 2006. “OMax Brothers: A Dynamic Topology of Agents for Improvization Learning.” In *AMCMM ’06: Proceedings of the 1st ACM Workshop on Audio and Music Computing Multimedia*, 125–32.

Bach-y-Rita, Paul. 1972. *Brain Mechanisms in Sensory Substitution*. New York: Academic Press Inc.

Bach-y-Rita, Paul, Kurt A. Kaczmarek, Mitchell E. Tyler, and Jorge Garcia-Lara. 1998. “Form Perception with a 49-Point Electrotactile Stimulus Array on the Tongue: A Technical Note.” *Journal of Rehabilitation Research & Development* 35 (4): 427. doi:Article.

Bach-y-Rita, Paul, and Stephen W. Kercel. 2003. “Sensory Substitution and the Human–Machine Interface.” *Trends in Cognitive Sciences* 7 (12): 541–46.

Balsam, Peter D., Michael Drew, and C. R. Gallistel. 2010. “Time and Associative Learning.” *Comparative Cognition and Behavior Reviews* 5: 1–22.

Barton, J. L., and J. O'M. Bockris. 1962. "The Electrolytic Growth of Dendrites from Ionic Solutions." *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 268 (1335): 485–505.

Bateson, Gregory. 2000. *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*. 1st ed. University Of Chicago Press.

Bolter, J. David, and Richard A Grusin. 2000. *Remediation: Understanding New Media*. Cambridge, Mass.: MIT Press.

Brentano, Franz. 1973. *Psychology from an Empirical Standpoint*. London: Routledge and Kegan Paul.

Brooks, Rodney A. 1986. "A Robust Layered Control System for a Mobile Robot." *IEEE Journal of Robotics and Automation* 2 (1): 14–23.

———. 1990. "Elephants Don't Play Chess." In *Designing Autonomous Agents: Theory and Practice from Biology to Engineering and Back*, edited by P. Maes, 3–15. Cambridge, MA: The MIT Press.

———. 1991. "Intelligence Without Representation." *Artificial Intelligence Journal* 47 (1-3): 139–59.

Brown, Andrew R. 2005. "Exploring Rhythmic Automata." In *Applications on Evolutionary Computing*, 551–56. Berlin: Springer.

Burnham, Jack. 1968. "Systems Esthetics." *Artforum* 7 (1): 30–35.

———. 1970. "The Aesthetics of Intelligent Systems." In *On the Future of Art*, 95–122. New York: Viking Press.

———. 1986. "Art & Technology, the Panacea That Failed." In *Video Culture: A Critical Investigation*, edited by John G Hanhardt, 232–48. New York: Gibbs M. Smith, Inc. in association with Visual Studies Workshop Press.

Cariani, Peter. 1992. "Emergence and Artificial Life." In *Artificial Life II, Santa Fe Institute Studies in the Sciences of Complexity, Vol X*, edited by C.G. Langton, C. Taylor, J.D. Farmer, and S. Rasmussen, 775–97. Redwood City, CA: Addison-Wesley.

———. 1993. "To Evolve an Ear: Epistemological Implications of Gordon Pask's Electrochemical Devices." *Systems Research* 10 (3): 19–33.

Castellanos, Carlos, Diane Gromala, and Philippe Pasquier. 2010. "Heterogenesis: Collectively Emergent Autonomy." In *Workshop on Interactive Multimedia Installations and Digital Art*, 1606–11. Singapore.

Clark, Andy. 1998. *Being There: Putting Brain, Body, and World Together Again*. MIT Press.

———. 2003. *Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence*. New York: Oxford University Press.

Clynes, Manfred E., and Nathan S. Kline. 1995. “Cyborgs and Space.” In *The Cyborg Handbook*, edited by Chris H. Gray, Heidi Figueroa-Sarriera, and Steven Mentor, 29–33. New York/London: Routledge.

Coffin, Jill. 2008. “Robotany and Lichtung: A Contribution to Phenomenological Dialogue.” In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction*, 217–20. Bonn, Germany: ACM. doi:10.1145/1347390.1347439.

Collins, Nick. 2008. “Reinforcement Learning for Live Musical Agents.” In *Proceedings of the International Computer Music Conference*. Belfast, Northern Ireland.

Cover, T. M., and P. E. Hart. 1967. “Nearest Neighbor Pattern Classification.” *IEEE Transactions on Information Theory* 13 (1): 21–27.

De Loor, Pierre, Kristen Manac’H, and Jacques Tisseau. 2009. “Enaction-Based Artificial Intelligence: Toward Co-Evolution with Humans in the Loop.” *Minds and Machines* 19 (3): 319–43.

Depraz, Nathalie, Francisco J. Varela, and Pierre Vermersch. 2003. *On Becoming Aware: A Pragmatics of Experiencing*. John Benjamins Publishing.

Dessalles, Jean Louis, Jean Pierre Müller, and Denis Phan. 2007. “Emergence in Multi-Agent Systems: Conceptual and Methodological Issues.” In *Multi-Agent Models and Simulation for Social and Human Sciences*, edited by Frédéric Amblard and Denis Phan, 327–56. Oxford: The Bardwell-Press.

Dewey, John. 1958. *Art as Experience*. New York: Capricorn Books.

Dourish, Paul. 2001. *Where the Action Is: The Foundations of Embodied Interaction*. Cambridge, MA: MIT Press.

Dreyfus, Hubert L, and Stuart E Dreyfus. 1999. “The Challenge of Merleau-Ponty’s Phenomenology of Embodiment for Cognitive Science.” In *Perspectives on Embodiment: The Intersections of Nature and Culture*, edited by Gail Weiss and Honi F Haber, 103–20.

Dreyfus, Hubert L. 1992. *What Computers Still Can’t Do: A Critique of Artificial Reason*. Cambridge, MA: MIT Press.

Dumitriu, Anna, and Blay Whitby. 2011. “Cybernetic Bacteria 2.0.” *Leonardo* 44 (3): 264–65.

Dupuy, Jean-Pierre. 2000. *The Mechanization of the Mind*. Translated by M. B. DeBevoise. Princeton University Press.

Ehrlich, Paul R., and Peter H. Raven. 1964. “Butterflies and Plants: A Study in Coevolution.” *Evolution* 18 (4): 586–608.

Eigenfeldt, Arne. 2006. “Kinetic Engine: Towards an Intelligent Improvising Instrument.” In *Proceedings of Sound and Music Computing*. Marseille.

Elkins, James. 2009. *Artists with PhDs: On the New Doctoral Degree in Studio Art*. Washington, DC: New Academia Publishing.

Embree, Lester E, ed. 1997. *Encyclopedia of Phenomenology*. Contributions to Phenomenology v. 18. Dordrecht: Kluwer Academic Publishers.

Feenberg, Andrew. 1991. *Critical Theory of Technology*. New York: Oxford University Press.

———. 2009. “Democratic Rationalization: Technology, Power, and Freedom.” In *Readings in the Philosophy of Technology*, edited by David M. Kaplan, 2nd ed., 139–55. Rowman & Littlefield.

Fish, Stanley Eugene. 1980. *Is There a Text in This Class?: The Authority of Interpretive Communities*. Cambridge, Mass: Harvard University Press.

Gallagher, Shaun. 1986. “Lived Body and Environment.” *Research in Phenomenology* 16: 139–70.

———. 1995. “Body Schema and Intentionality.” In *The Body and the Self*, edited by José Luis Bermúdez, Anthony J. Marcel, and Naomi Eilan, 225–44. Cambridge, MA: MIT Press.

———. 2000. “Disrupting Seriality: Merleau-Ponty, Lyotard, and Post-Husserlian Temporality.” In *Rereading Merleau-Ponty: Essays Beyond the Continental-Analytic Divide*, edited by Lawrence Hass and Dorothea Olkowski, 97–119. Amherst, NY: Humanity Books.

Galloway, Alexander R. 2006. *Protocol: How Control Exists after Decentralization*. MIT Press.

Gaver, William W., Jacob Beaver, and Steve Benford. 2003. “Ambiguity as a Resource for Design.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 233–40. Ft. Lauderdale, Florida, USA: ACM.

Gilchrist, Bruce, and Jonny Bradley. 1996. *Divided by Resistance*. http://www.artemergent.org.uk/dbr/dbr.html.

Goodall, Jane. 2005. “The Will to Evolve.” In *Stelarc: The Monograph*, edited by Marquard Smith, 1–31. Cambridge, MA: MIT Press.

Grabes, Herbert. 2008. *Making Strange: Beauty, Sublimity, and the (Post)Modern “Third Aesthetic.”* Postmodern Studies 42. Amsterdam: Rodopi.

Gracie, Andy. 2004. *Fish, Plant, Rack*. http://hostprods.net/project/fish-plant-rack/.

Greene, Jo-Anne. 2010. “Interactivity and Agency in Real Time Systems.” In *Soft Borders Conference & Festival Proceedings Centro Universitário Belas Artes de São Paulo*. São Paulo.

Gromala, Diane. 2003. “Biomorphic Typography.” In *TypO Exhibition*. Liverpool, England: FACT (Foundation for Art & Creative Technology).

———. 2007. *Towards a Phenomenological Theory of the Visceral in the Interactive Arts*. Plymouth, UK: University of Plymouth.

Guattari, Félix. 2001. “Machinic Heterogenesis.” In *Reading Digital Culture*, edited by David Trend. 4. Malden, MA: Blackwell Publishers.

———. 2005. *The Three Ecologies*. Continuum International Publishing Group.

Hansen, Mark B. N. 2005. “Embodiment: The Machinic and the Human.” In *aRt & D: Research and Development in Art*, edited by J. Brouwer, S. Fanuconnier, A. Mulder, and A. Nigten, 150–65. Rotterdam, The Netherlands: V2_NAi Publishers.

Hansen, Mark B. N. 2006. *Bodies in Code: Interfaces with Digital Media*. New York: Routledge.

———. 2009a. “System-Environment Hybrids.” In *Emergence and Embodiment: New Essays on Second-Order Systems Theory*, edited by Bruce Clarke and Mark B. N. Hansen, 113–42. Durham, NC: Duke University Press.

———. 2009b. “Living (with) Technical Time: From Media Surrogacy to Distributed Cognition.” *Theory Culture & Society* 26 (2-3): 294–315. doi:10.1177/0263276409103109.

Haque, Usman, and Robert Davis. 2005. *Evolving Sonic Environment*. http://www.haque.co.uk/evolvingsonicenvironment.php.

Haraway, Donna. 1991. “A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century.” In *Simians, Cyborgs, and Women: The Reinvention of Nature*, 149–81. New York: Routledge.

Hayles, N. Katherine. 1999. *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: University of Chicago Press.

———. 2002. “Flesh and Metal: Reconfiguring the Mindbody in Virtual Environments.” *Configurations* 10 (2): 297–320.

———. 2005. *My Mother Was a Computer: Digital Subjects and Literary Texts*. University of Chicago Press.

———. 2007. “Hyper and Deep Attention: The Generational Divide in Cognitive Modes.” *Profession* 2007 (1): 187–99. doi:10.1632/prof.2007.2007.1.187.

———. 2010. “Cybernetics.” In *Critical Terms for Media Studies*, edited by W. J. T. Mitchell and Mark B. N Hansen, 145–56. Chicago: University Of Chicago Press.

———. 2012. *How We Think: Digital Media and Contemporary Technogenesis*. Chicago□; London: The University of Chicago Press.

Heidegger, Martin. 1977. “The Question Concerning Technology.” In *Basic Writings*, 283–317. New York: Harper & Row.

———. 1978. *Being and Time*. Oxford: Blackwell.

Heylighen, Francis, and Cliff Joslyn. 2001. “Cybernetics and Second-Order Cybernetics.” In *Encyclopedia of Physical Science & Technology*, edited by Robert A. Meyers, 3rd ed. New York: Academic Press.

Higgins, Adrian. 2009. “We Can’t See the Forest for the T-Mobiles.” *The Washington Post*. http://www.washingtonpost.com/wp-dyn/content/article/2009/12/14/AR2009121403347.html.

Holland, John H. 1995. *Hidden Order: How Adaption Builds Complexity*. Reading, MA: Addison-Wesley.

Husserl, Edmund. 1954. *The Crisis of European Sciences and Transcendental Phenomenology*. Translated by D. Carr. Evanston, Ill: Northwestern University Press.

Hutchins, Edwin. 1995. *Cognition in the Wild*. Cambridge, MA: The MIT Press.

Ihde, Don. 1990. *Technology and the Lifeworld: From Garden to Earth*. Indiana Series in the Philosophy of Technology. Bloomington: Indiana University Press.

———. 1993. “Deromanticizing Heidegger.” In *Postphenomenology: Essays in the Postmodern Context*, 103–15. Evanston, Ill: Northwestern University Press.

———. 2011. “Of Which Human Are We Post?” In H+-*: Transhumanism and Its Critics*, 123–35. Philadelphia: Metanexus Institute.

Janzen, Daniel H. 1980. “When Is It Coevolution?” *Evolution* 34 (3): 611–12.

Johnson, Norman L., Steen Rasmussen, Cliff Joslyn, Luis Rocha, Steven Smith, and Marianna Kantor. 1998. “Symbiotic Intelligence: Self-Organizing Knowledge on Distributed Networks, Driven By Human Interaction.” In *Artificial Life VI: Proceedings of the Sixth International Conference on Artificial Life*, edited by Christoph Adami, Richard K. Belew, Hiroaki Kitano, and Taylor E. Charles, 403–7. Cambridge, MA: MIT Press.

Juarrero-Roqué, Alicia. 1985. “Self-Organization: Kant’s Concept of Teleology and Modern Chemistry.” *The Review of Metaphysics* 39 (1): 107–35.

Kaczmarek, Kurt A., John G. Webster, Paul Bach-y-Rita, and Willis J. Tompkins. 1991. “Electrotactile and Vibrotactile Displays for Sensory Substitution Systems.” *IEEE Transactions on Biomedical Engineering* 38 (1): 1–16. doi:10.1109/10.68204.

Kaelbling, Leslie P., Michael L. Littman, and Andrew Moore. 1996. “Reinforcement Learning: A Survey.” *Journal of Artificial Intelligence Research* 4: 237–85.

Kauffman, Stuart A. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. 1st ed. Oxford University Press, USA.

Khakhina, Liya Nikolaevna. 1992. *Concepts of Symbiogenesis: A Historical and Critical Study of the Research of Russian Botanists*. Edited by Lynn Margulis and Mark McMenamin. Translated by Stephanie Merkel and Robert Coalson. Bio-Origins Series. New Haven: Yale University Press.

Kirschner, Roman. 2005. *Roots*. http://www.romankirschner.net/index.php?roots.

Kluitenberg, Eric. 2012. “Techno-Ecologies: Inhabiting the Deep-Technological Spheres of Everyday Life.” *Acoustic Space*, no. 11: 9–15.

Koza, John R. 1990. “Genetic Programming: A Paradigm for Genetically Breeding Populations of Computer Programs to Solve Problems.” *Stanford University Computer Science Department Technical Report STAN-CS-90-1314*.

Kozel, Susan. 2007. *Closer: Performance, Technologies, Phenomenology*. Cambridge, MA: The MIT Press.

Lautenschlaeger, Graziele, and Anja Pratschke. 2011. “Don’t Give up! Media Art as an Endless Conversational Process.” *Kybernetes* 40 (7/8): 1090–1101. doi:10.1108/03684921111160322.

Leder, Drew. 1990. *The Absent Body*. Chicago: University of Chicago Press.

Licklider, J. C. R. 1960. “Man-Computer Symbiosis.” *Human Factors in Electronics, IRE Transactions on* HFE-1 (1): 4–11.

Lovelock, James E. 1979. *Gaia, a New Look at Life on Earth*. Oxford/New York: Oxford University Press.

Margulis, Lynn. 1981. *Symbiosis in Cell Evolution: Life and Its Environment On the Early Earth*. San Francisco: W. H. Freeman.

———. 1993. “Origins of Species: Acquired Genomes and Individuality.” *Bio Systems* 31 (2-3): 121–25.

———. 1998. *Symbiotic Planet: A New Look at Evolution*. New York: Basic Books.

Margulis, Lynn, and Dorion Sagan. 1986. *Microcosmos: Four Billion Years of Evolution from Our Microbial Ancestors*. New York: Summit Books.

Massumi, Brian. 2002. *Parables for the Virtual: Movement, Affect, Sensation*. Durham, NC: Duke University Press.

Matthews, Eric. 2006. *Merleau-Ponty: A Guide for the Perplexed*. London: Continuum International Pub. Group.

Maturana, Humberto R., and Francisco J. Varela. 1980. *Autopoiesis and Cognition: The Realization of the Living*. Dordrecht, Holland; Boston: D. Reidel.

———. 1992. *The Tree of Knowledge: The Biological Roots of Human Understanding*. Rev. ed. Boston: Shambhala.

Mazlish, Bruce. 1995. *The Fourth Discontinuity: The Co-Evolution of Humans and Machines*. New Haven: Yale University Press.

Merleau-Ponty, Maurice. 1963. *The Structure of Behavior*. Boston: Beacon Press.

———. 1968. *The Visible and the Invisible*. Edited by C Lefort. Translated by A Lingis. Evanston: Northwestern University Press.

———. 2002. *Phenomenology of Perception*. Translated by C Smith. 2nd ed. London/New York: Routledge.

———. 2004. *The World of Perception*. Translated by Davis Oliver. London/New York: Routledge.

Miranda, Eduardo Reck, and Marcelo Wanderley. 2006. “Biosignal Interfaces.” In *New Digital Musical Instruments: Control And Interaction Beyond the Keyboard*, 173–217. Middleton, WI: A-R Editions.

Monro, Gordon. 2009. “Emergence and Generative Art.” *Leonardo* 42 (5): 476–77. doi:10.1162/leon.2009.42.5.476.

Morton, Timothy. 2013. *Hyperobjects: Philosophy and Ecology After the End of the World*. University of Minnesota Press.

Næss, Arne. 1973. “The Shallow and the Deep, Long-Range Ecology Movement.” *Inquiry* 16: 95–100.

Nagel, Thomas. 1989. *The View From Nowhere*. Oxford University Press, USA.

Naveh, Zev. 1982. “Landscape Ecology as an Emerging Branch of Human Ecosystem Science.” *Advances in Ecological Research* 12: 189–237.

Noe, Alva. 2006. *Action in Perception*. Cambridge, MA: MIT Press.

Odum, Eugene P. 2001. “The Techno-Ecosystem.” *Bulletin of the Ecological Society of America* 82 (2): 137–38.

Page, R.M. 1962. “Man-Machine Coupling - 2012 A.D.” *Proceedings of the IRE* 50 (5): 613–14.

Pangaro, Paul. 2006. “CYBERNETICS — A Definition.” In . http://www.pangaro.com/published/cyber-macmillan.html.

Pask, Gordon. 1958. “Organic Control and the Cybernetic Method.” *Cybernetica* 1: 155–73.

———. 1959. “Physical Analogues to the Growth of a Concept.” In *Mechanisation of Thought Processes: Proceedings of a Symposium Held at the National Physical Laboratory on 24th,25th, 26th and 27th November 1958*, 877–928. London: H. M. Stationery Off.

———. 1960. “The Natural History of Networks.” In *Self-Organizing Systems: Proceedings of an International Conference, 5 and 6 May*, edited by M. C. Yovits and S. Cameron, 232–63. New York: Pergamon Press.

———. 1971. “A Comment, a Case History and a Plan.” In *Cybernetics, Art, and Ideas.*, edited by Jasia Reichardt, 76–99. London: Studio Vista.

———. 1975. *Conversation, Cognition and Learning: A Cybernetic Theory and Methodology*. Oxford: Elsevier.

———. 1976. *Conversation Theory: Applications in Education and Epistemology*. Oxford: Elsevier.

Penny, Simon. 1996a. “From A to D and Back Again: The Emerging Aesthetics of Interactive Art.” *Leonardo Electronic Almanac* 3 (4): 339.

———. 1996b. “The Darwin Machine: Artificial Life and Interactive Art.” *New Formations* 29: 59–68.

———. 1997. “Embodied Cultural Agents: At the Intersection of Art, Robotics and Cognitive Science.” *AAAI Socially Intelligent Agents Symposium*, 103–5.

———. 2011. “Towards a Performative Aesthetics of Interactivity.” *Fibreculture*, no. 19: 72–108.

Penny, Simon, and Jamieson Schulte. 1995. *Sympathetic Sentience*. http://simonpenny.net/works/sympathetic.html.

Picard, Rosalind W. 1997. *Affective Computing*. Cambridge, MA: MIT Press.

Pickering, Andrew. 2007. “Ontological Theatre: Gordon Pask, Cybernetics, and the Arts.” *Cybernetics & Human Knowing* 14 (4): 43–57.

———. 2008. “New Ontologies.” In *The Mangle in Practice: Science, Society, and Becoming*, edited by Andrew Pickering and Keith Guzik, 1–14. Science and Cultural Theory. Durham, NC: Duke University Press.

———. 2010. *The Cybernetic Brain: Sketches of Another Future*. Chicago: University of Chicago Press.

Rinaldo, Kenneth E. 1998a. “The Flock.” *Leonardo* 31 (5): 405–7.

———. 1998b. “Technology Recapitulates Phylogeny: Artificial Life Art.” *Leonardo* 31 (5): 371–76.

Rocha, Luis M. 2001. “Adaptive Recommendation and Open-Ended Semiosis.” *Kybernetes* 30 (5-6): 821–54.

Rokeby, David. 1986. *Very Nervous System*. http://www.davidrokeby.com/vns.html.

———. 1995. “Transforming Mirrors: Subjectivity and Control in Interactive Media.” In *Critical Issues in Electronic Media*, 133–57. New York: State University of New York.

Rosenboom, D. 1976. *Biofeedback and the Arts*. Vancouver: A.R.C. Publications.

Sapontzis, S. F. 1978. “A Note on Merleau-Ponty’s ‘Ambiguity.’” *Philosophy and Phenomenological Research* 38 (4): 538–43. doi:10.2307/2106575.

Saunders, Frank A. 1983. “Information Transmission Across the Skin: High-Resolution Tactile Sensory Aids for the Deaf and the Blind.” *International Journal of Neuroscience* 19 (1): 21–28.

Saunders, Frank, William Hill, and Barbara Franklin. 1981. “A Wearable Tactile Sensory Aid for Profoundly Deaf Children.” *Journal of Medical Systems* 5 (4): 265–70. doi:10.1007/BF02222144.

Schiphorst, Thecla. 2005. “Soft, Softer and Softly, [whispering] between the Lines.” In *aRt&D: Research and Development in Art*, edited by J. Brouwer, S. Fanuconnier, A. Mulder, and A. Nigten, 166–75. Rotterdam, The Netherlands: V2_NAi Publishers.

Schön, Donald A. 1983. *The Reflective Practitioner: How Professionals Think in Action*. Basic Books.

Schwartz, Mark S., and R. Paul Olsen. 2005. “A Historical Perspective on the Field of Biofeedback and Applied Psychophysiology.” In *Biofeedback: A Practitioner’s Guide*, Third Edition, 3–19. The Guilford Press.

Sengers, Phoebe. 1996. “Fabricated Subjects: Reification, Schizophrenia and Artificial Intelligence.” Edited by Geert Lovink and Pit Schultz. *ZKP-2 Net Criticism Reader*.

Stelarc. 1990. *Ping Body/Amplified Body/Third Hand*. http://stelarc.org/?catID=20265.

Stenslie, Stahl. 1994. *Inter_skin*. http://www.stenslie.net/stahl/projects/interskin/ise.html.

Stern, Nathaniel. 2011. “The Implicit Body as Performance: Analyzing Interactive Art.” *Leonardo* 44 (3): 233–38.

Stern, Robert M., William J. Ray, and Karen S. Quigley. 2001. *Psychophysiological Recording*. 2nd ed. New York: Oxford University Press.

Stiegler, Bernard. 1998. *Technics and Time 1: The Fault of Epimetheus*. Stanford, CA: Stanford University Press.

Stuart, Greg J., and Michael Häusser. 2001. “Dendritic Coincidence Detection of EPSPs and Action Potentials.” *Nature Neuroscience* 4: 63–71.

Sullivan, Graeme. 2005. “Practice as Theory.” In *Art Practice as Research: Inquiry in the Visual Arts*, 187–222. Thousand Oaks, CA: Sage Publications.

Sutton, Richard S., and Andrew G. Barto. 1998. *Reinforcement Learning: An Introduction*. Cambridge, MA: MIT Press.

Swenson, R. 1992. “Autocatakinetics, Yes - Autopoiesis, No: Steps Toward a Unified Theory of Evolutionary Ordering.” *International Journal of General Systems* 21 (2): 207–28.

Thacker, Eugene. 2000. “SF, Technoscience, Net.art: The Politics of Extrapolation.” *Art Journal* 59 (3): 65–73. doi:10.2307/778028.

Thompson, Evan. 2007. *Mind in Life: Biology, Phenomenology, and the Sciences of Mind*. 1st ed. Belknap Press.

Thrift, Nigel. 2004. “Remembering the Technological Unconscious by Foregrounding Knowledges of Position.” *Environment and Planning D: Society and Space* 22: 175–90.

Tsuda, Soichiro. 2009. “Robot with Slime ‘brains.’” *Technoetic Arts: A Journal of Speculative Research* 7 (2): 133–40.

Tsuda, Soichiro, Stefan Artmann, and Klaus-Peter Zauner. 2009. “The Phi-Bot: A Robot Controlled by a Slime Mould.” In *Artificial Life Models in Hardware*, edited by Andrew Adamatzky and Maciej Komosinski, 213–32. London: Springer-Verlag.

Varela, Francisco J, and J Shear. 1999. “First-Person Methodologies: What, Why, How?” In *The View From Within*, 1–14. Thorverton, England: Imprint Academics.

Varela, Francisco J. 1981. “Autonomy and Autopoiesis.” In *Self-Organizing Systems: An Interdisciplinary Approach*, edited by Gerhard Roth and Helmut Schwelger, 14–23. New York: Campus Verlag.

Varela, Francisco J., and Paul Bourgine. 1992. “Towards a Practice of Autonomous Systems.” In *Toward a Practice of Autonomous Systems*, edited by Francisco J. Varela and Paul Bourgine, xi–xvii. Cambridge, MA: MIT Press.

Varela, Francisco J., Evan T. Thompson, and Eleanor Rosch. 1992. *The Embodied Mind: Cognitive Science and Human Experience*. New Ed. Cambridge, MA: MIT Press.

Verbeek, Peter-Paul. 2008. “Cyborg Intentionality: Rethinking the Phenomenology of Human–technology Relations.” *Phenomenology and the Cognitive Sciences* 7 (3): 387–95.

Von Foerster, Heinz. 1960. “On Self-Organizing Systems and Their Environments.” In *Self-Organizing Systems: Proceedings of an International Conference, 5 and 6 May*, edited by M. C. Yovits and S. Cameron, 31–50. New York: Pergamon Press.

Von Glasersfeld, Ernst. 1987. *The Construction of Knowledge: Contributions to Conceptual Semantics*. Seaside, California: Intersystems Publications.

———. 1995. *Radical Constructivism: A Way of Knowing and Learning*. Studies in Mathematics Education Series 6. London; Washington, D.C: Falmer Press.

Wallin, Ivan E. 1927. *Symbionticism and the Origin of Species*. Baltimore: Williams and Wilkins.

Webster, Andy. 2010. “Finding Fluid Form: A Process Aesthetic as a Means to Engage with the Prevailing Entitative Model of Thinking in Ecological Art”. London: University of Arts London.

Whitelaw, Mitchell. 2004. *Metacreation: Art and Artificial Life*. illustrated edition. Cambridge, MA: MIT Press.

Wiener, Norbert. 1961. *Cybernetics: Or the Control and Communication in the Animal and the Machine*. MIT Press.

Wilson, Stephen. 1993. “The Aesthetics and Practice of Designing Interactive Computer Events.” In . http://userwww.sfsu.edu/~swilson/papers/interactive2.html.

———. 2002. *Information Arts: Intersections of Art, Science, and Technology*. Cambridge, MA: MIT Press.

Wolfe, Cary. 2009. *What Is Posthumanism?* University of Minnesota Press.

Wooldridge, Michael. 2002. *An Introduction to MultiAgent Systems*. 1st ed. New York: John Wiley & Sons.

Appendices

Appendix A.

Protocol Documentation

This appendix contains additional documentation on *Protocol*. Notes, video, source code and additional images can be viewed at the companion web site to this dissertation: dissertation.ccastellanos.com.

Credits

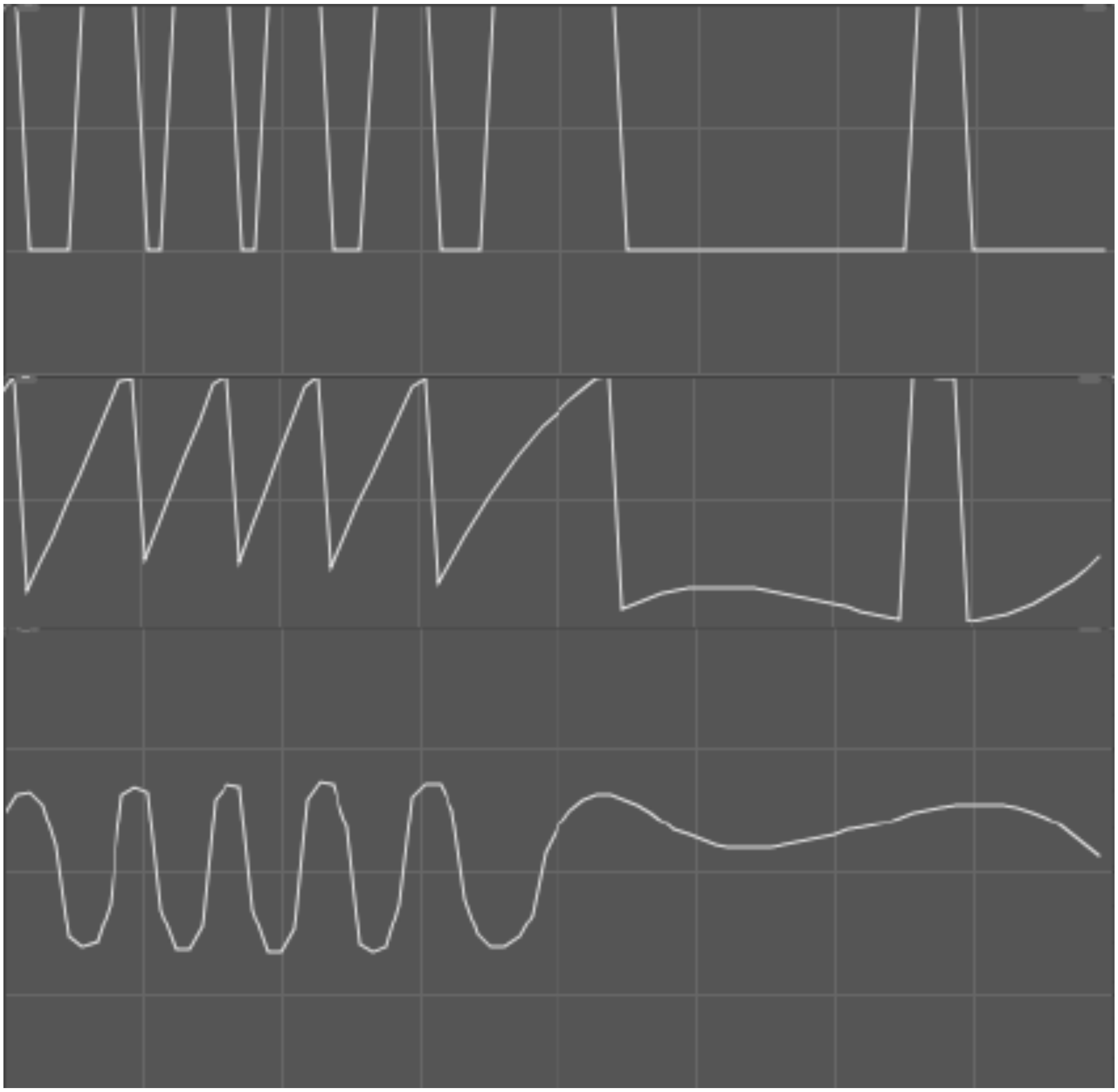
Carlos Castellanos: Concept, Sound Design, Electronics, and Software Development

Yin He: Belt sowing and Electronics

Participant Interaction

Clockwise from left: participant attempts to establish communication with the *Protocol* agents.

Electrotactle Patterns



Representations (from a digital oscilloscope) of electro-tactile patterns generated by the system.

Appendix B.

Biopoiesis Documentation

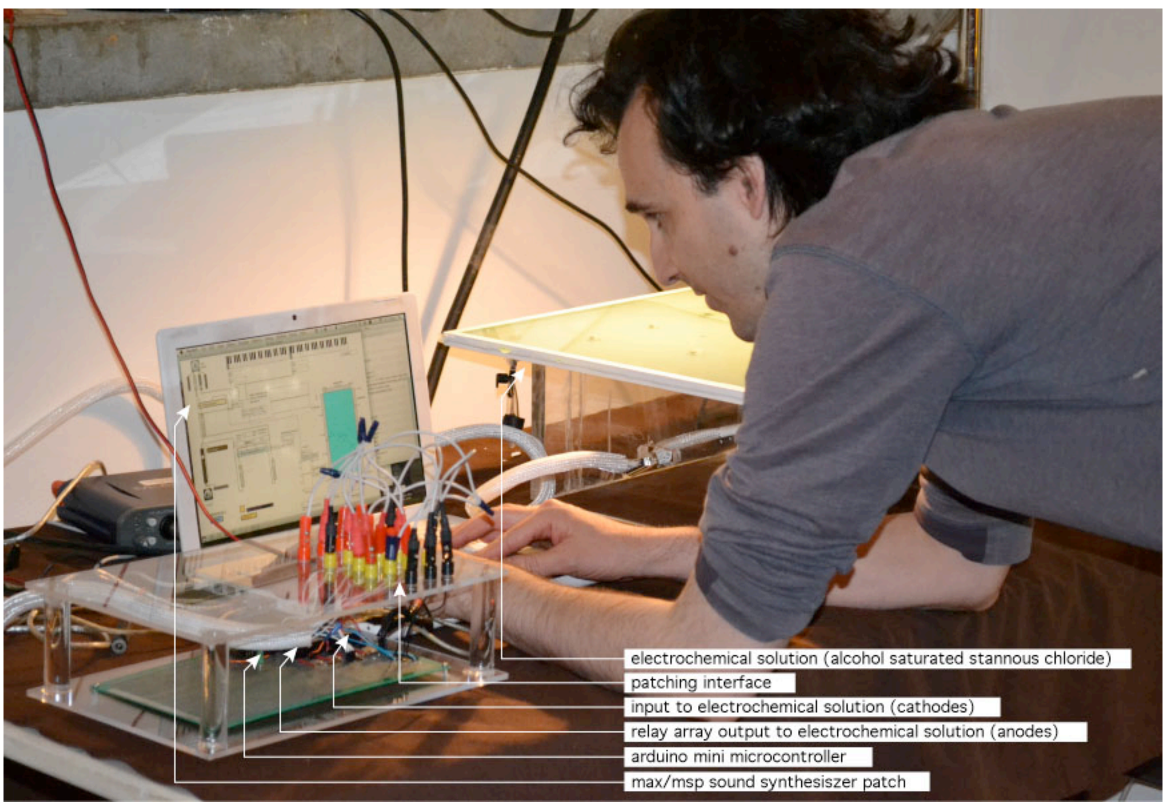
This appendix contains additional documentation on *Biopoiesis*. Notes, video, source code and additional images can be viewed at the companion web site to this dissertation: dissertation.ccastellanos.com.

Credits

Carlos Castellanos: Concept, Experiment Design, Construction, Electronics, Sound Software, and Visualization

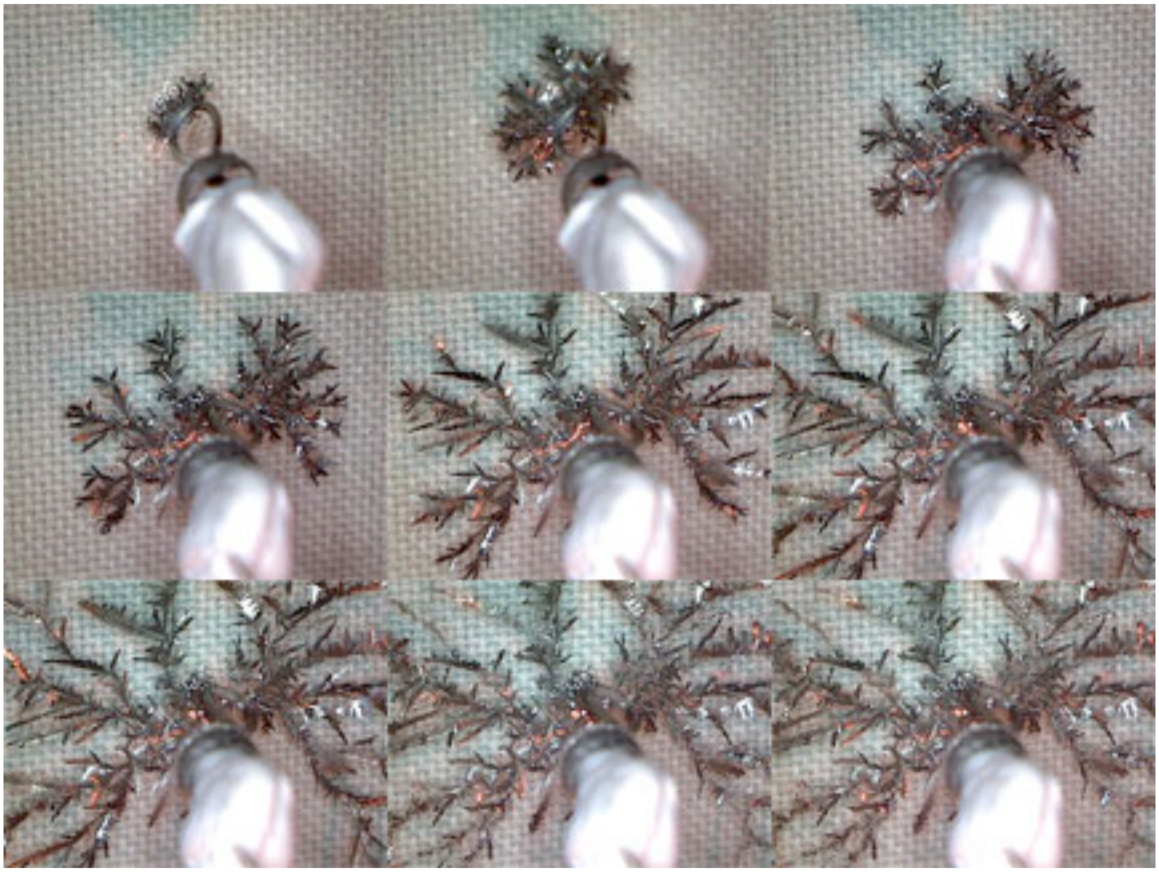
Steven J. Barnes: Experiment Design, Construction, Motion Tracking Software and Visualization

Technique



A typical *Biopoiesis* set-up

Electrochemical Growth/Dissolution



Growth/dissolution of threads over a roughly 8-hour period.