Subtle Emergences

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF FINE ARTS

in

THE COLLEGE OF GRADUATE STUDIES

(Interdisciplinary Studies)

THE UNIVERSITY OF BRITISH COLUMBIA

(Okanagan)

September 2015

Abstract

We often understand the world around us by studying its parts. This approach, known as reductionism, has long dominated rational inquiry. The limitations of using this approach in isolation have started to become apparent as people have started to realize that complex systems, such as ecosystems, do not behave as a linear combination of parts. In many cases, the emergent behaviours of complex systems cannot be deduced empirically.

I explore the role of experience and embodied inquiry as an alternative approach to studying complex systems. Through the proposal, production, installation, and exhibition of a complex, interactive art system, *Subtle Emergences*, I argue that experience of complexity is a valid and vital tool in our attempt to grapple with the uncertainty of complex systems. Ultimately, we need to use all available methods together, if we hope to be able to understand complexity.

Preface

This dissertation is an original intellectual product of the author, David C Kadish and is based on work conducted at the Centre for Culture and Technology at the University of British Columbia's Okanagan Campus.

Some of the writing in Chapters 2 and 3 is based on work published as "Kadish and Dulic (2015a). Crafting sustainability: approaching wicked environmental problems through high-low tech practice. *Digital Creativity*, pages 1-17." and "Kadish and Dulic (2015b). Inorganisms: An Emergent Approach to Sustainability. In Westerlub, B., editor, *NORDES 2015: Design Ecologies*, volume 6, pages 1-2, Stockholm.". In both of those publications, I was the primary author and Dr. Aleksandra Dulic took a supervisory role, contributing insight and feedback on the structure of the work and the concepts contained within it.

All of the figures and images contained in the dissertation are original photographs and drawings, with the exception of Figures 2.1 and 2.2, which are in the public domain.

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Acknowledgements

I would like to thank my supervisor, Dr. Aleksandra Dulic, for her help and support throughout my Masters programs. I have learned so much from her over the course of my degrees and I'm grateful for all that she has taught me. I'd also like to thank the members Centre for Culture and Technology for the community they created in the lab. Special thanks to Jeannette Angel for being a wonderful colleague and friend with whom I shared ideas, experiences, and frustrations over the last four years. A big thank you to my committee, Denise Kenney and Samuel Roy-Bois. I have thoroughly enjoyed the coursework and the committee time that I have spent with both of them. Their encouragement and feedback have been invaluable throughout this process. Thanks to Ashok Mathur for his enthusiastic support for all of the creative studies graduate students, to Nancy Holmes for her tireless work for all of the FCCS graduate students, to Fern Helfand for her work as graduate program coordinator, and to Stephen Foster for his support as a co-educator and research project supervisor. Thanks to UBC's Okanagan IT Department, and especially Wade Klaver, for putting up with my various requests for equipment and server time. And a hearty thank you to all of the support staff in FCCS. I could not possibly have completed my project without the help of Don, Kaila, Joanne, Mike, Linda, Toby, Melissa, and Shauna. You are fantastic.

Finally, a special thank you to Kristin Aleklett for being the most amazing partner I could ask for throughout our time in Kelowna. Graduate school has had its ups and downs for both of us, but I've known throughout the process that we would be there for each other and that has helped to get me through it. I could not have done this without you.

Chapter 1

Parts

> *Interactive artworks that behave or perform autonomously challenge the most common interaction paradigm of reacting to what is sensed according to a pre-mapped narrative. Engaging with autonomous works opens up new experiences that are more akin to conversing, performing, or negotiating with something that has its own awareness.*
>
> (Bown et al., 2014)

Complexity. Emergence. Subtlety. Art. Environment. Experience. Interactivity. These are the seemingly disparate parts — the fields, concepts, and ideas — that coalesce into a coherent whole to form my thesis. The interrelationships between parts are what create the richness of wholes, the complexity of systems, and the emergence of patterns and ideas in those whole systems. I begin here by identifying the parts of my thesis — complexity, emergence, subtlety, art, environment, experience, interactivity — so that I can move toward an exploration of the interrelationships between them as I build the whole of my thesis.

Complexity is a defining feature of our socio-ecological world (Glaser et al., 2008) and one that is not well-understood (Rittel and Webber, 1973; Cilliers, 1998; Ambrose, 2014) but it's deeper understanding could significantly improve the way that we relate to complex systems. Complexity is a worldview that involves examining "how relationships between parts give rise to the collective behaviors of a system, and how the system interacts and forms relationships with its environment" (Bar-Yam, 2002). It builds on insights gained from the classical approach to the world in which parts are studied in isolation. These reductionist approaches have produced tremendous understanding of specific phenomena — and they are still crucial to our understanding of the world — but they often fail to capture the complex interplay between different phenomena, to generate an understanding of the system as a whole (Lineweaver et al., 2013; Ambrose, 2014).

Complex systems share a set of general features, patterns, and behaviours such that studying one complex system can lead to insights into how others work. This means that we can learn something about the emergence — the decentralized formation of order and pattern — in an ant colony by studying the emergence of meaning in language and vice-versa (Hofstadter, 1979; Cilliers, 1998). And we can learn something about feedback loops in the climatic system by studying feedback loops in social and economic systems (Dieleman, 2008; Laurel, 2011). Because these features translate from system to system, there is value in understanding complex systems in general.

In building an understanding of a complex system, it is as important to identify what we don't know, what we can't measure, and what is inquantifiable, as it is to be able to quantify the parts of the system (Cilliers, 1998, 35). To do this, we have to seek ways of knowing that can compliment the data-driven inquiry that we find in modern science. As artists, we need to re-engage the role of experience in understanding complexity and complex systems (Kagan, 2010). We need to recognize that our senses and memories have something to tell us about complexity that logic and reason cannot precisely identify (Abram, 1996). It is here that we find a role for art in general — and specifically my own art practice — in creating experience of complexity (Dieleman, 2008).

How do I go about creating an experience of complexity, of emergence? For this, I return to some of the design engineering practices that brought me through my engineering degrees. Experience design is a practice that focuses on studying the relationships between people and artifacts to create a specific experience for 'users'[1]. I also use crafted electronics and high-low technology (Buechley et al., 2010; Perner-Wilson et al., 2011; Fernaeus et al., 2013; Kadish and Dulic, 2015a) strategies to utilize materials in a way that

[1] To frame viewers of the artwork in experience design terms.

is itself complex.

The resulting interactive installation is an immersive experience. The hanging fabric leaves move, curl, and fold, almost imperceptibly. But if you look away for a minute and then return, they have shifted. The lighting is in constant flux, illuminating parts of the environment and casting shadows on the periphery while plunging other sides of the space into darkness. Sound rises from copper sculptures in the space and fades as quickly as it arose, beckoning to approach and strain to hear it again. Even the change is not constant. The experience of that dynamicism is an experience of complexity.

Why is that experience important? Chapter 2 will expand on the ideas of complexity, emergence, and the role of experience and art in understanding them. In chapter 3 I will discuss the process of creating *Subtle Emergences*, and how my methods incorporate notions of complexity into the process of making art. Chapter 4 consists of a focused reflection on the work that lead up to *Subtle Emergences* and the actual show itself. Finally, I will conclude with some thoughts on future directions and lessons from the process in chapter 5.

Chapter 2

Emerging Complexity

Complexity is a term with many meanings. To the layperson, complex often means complicated (Cilliers, 1998; Bloom, 2014; Kadish and Dulic, 2015a). In the sciences, complexity tends to refer to complex systems and the study of "patterns of organisation or networks of non-linear pathways and feedback loops through which information and materials flow" (Bloom, 2014). Kagan (2012, 23) sees complexity as finding the unity, complementarity, competition, and antagonism in a relationship, digging below the surface perception to unearth the complexity in contradiction.

These understandings of complexity are important and I will return to them later in the chapter as I discuss the phenomenon of emergence and its relationship to art and experience. First, however, I think it important to elucidate how I arrived at an interest in complexity. I want to focus on three episodes: my time as a member of Engineers Without Borders (EWB), where I first encountered the power of the types of contradictions to which Kagan (2012) is referring; a lecture on exponential growth given by a professor during my undergraduate education which focused on how poorly we understand non-linear responses; and the beginning of my Master of Fine Art (MFA), when I realized the significant difference between complicatedness and complexity by studying Rube Goldberg machines.

2.1 Seeking complexity

During my undergraduate career, I spent a great deal of time volunteering with EWB[2] on the Waterloo campus and in the national office

[2]I should note that this is specifically Engineers Without Borders Canada. There are other EWB organizations around the world but they are not all necessarily affiliated and

in Toronto. The organization was founded on the premise that young, innovative engineering students and recent graduates should be able to build things that would help people in the developing world break the cycle of poverty[3]. EWB quickly realized as an organization that projects that involve teams of young, bright-eyed Canadians travelling to rural communities in Africa to build infrastructure — schools, wells, hospitals — are at best questionable in their impact. Though they may result in new facilities, more often they "can best be understood as a manifestation of continuing patterns of exploitation and domination of the global South" (Calkin, 2013).

Poverty, it turns out, is far more complex than simply a lack of infrastructure. The causes and effects of poverty are local, regional, and global, and are temporally situated historically, in the present, and in the future. Its implications are social, economic, ecological, and political.

While learning something about the complex realities of poverty, I also learned about the importance of openness and learning from failure. EWB as an organization tries to be transparent about its successes and its failures with its members and with the public[4]. That openness, and discussing the intricacies of international development work with friends and colleagues taught me to look beyond the obvious, to seek contradictions and counterintuition, and to look for the complexities of a situation.

2.2 Understanding growth

> *The greatest shortcoming of the human race is our inability to understand the exponential function.*
>
> (Bartlett and Fuller, 2004)

If EWB left me with an appreciation for deep inquiry and embracing contradiction, it was Dr. Paul Fieguth who bestowed upon me the

many do not share EWB Canada's outlook.

[3]A lot of the language in this sentence is problematic. I use it in this context to demonstrate the naiveté of the organization when it was founded.

[4]EWB has actually started reporting publicly on its failures in an annual Failure Report that comes out alongside its Annual Report. Both can be found at www.ewb.ca/resources.

realization of just how poorly we understand non-linear relationships. Non-linear relationships are important because they lead to seemingly explosive changes in different parts of a complex system[5].

In the spring of 2009, Dr. Fieguth gave a lecture on exponential growth and the carrying capacity of the planet. Dr. Fieguth, who works in the fields of computer vision and image processing[6], told a story originally devised by Bartlett (1978) to demonstrate our lack of understanding of exponential growth in a finite environment.

> It is 11:00. Imagine you have a jar containing a single bacterium. Pretend that the bacteria reproduce every minute so that after one minute there are two bacteria, after two minutes there are four, and so on[7]. By 12:00, you see that the jar is completely full of bacteria.

The bacteria double in population every minute; the growth of the bacterial community is exponential[8]. We were asked to keep that relationship in mind as we contemplated the following two questions:

1. At what time was the bottle half full?
2. When would the bacteria have realized that they were running out of space in the jar?

The answer to the first question sounds surprising; the bottle is half full at 11:59, with one minute until no space remains. Most people — including

[5]We will get to why in the section on complexity.

[6]His course in pattern recognition formed part of my interest in the computer vision work that I ended up doing for my MASc.

[7]This is actually faster than the reproduction rates for most bacteria in lab conditions, but for this story it does not really matter. The important points in the story are in terms of relative amounts of time.

[8]At any minute within the hour (t), the number of bacteria (n) is given by the number of bacteria in the last minute ($t-1$) multiplied by 2. In mathematical terms, $n(t) = 2 \cdot n(t-1)$. But, the relationship can be represented another way. Since the number is multiplied by 2 every time, we know that the number of bacteria at, for example, 4 minutes is $1 \times 2 \times 2 \times 2$ or 2 multiplied by itself 3 times. This can be written in exponential form as 2^3, or for any minute in the hour as $n(t) = 2^{t-1}$, which is an exponential relationship.

many of the engineering students in the room that day — do not get this correct. We tend to think that there is more time between half full and full, especially given that there were 59 minutes before the bottle was half full. But that is the nature of exponential growth. Remember, the population doubles every minute, so if the bottle is half full one minute, it will be completely full the next minute.

The answer to the second question is even more astounding. At 11:55, 5 minutes before the bottle is completely full and the bacteria are out of space, only 3% of the bottle is full of bacteria. 97% of the space remains empty. Would the bacteria (and by extension of the analogy, humanity) realize that they are in trouble when the vast majority of the space is still empty? It is unlikely.

The story demonstrates what is for most of us a fundamental lack of understanding of types of patterns that govern the behaviour of complex systems. It isn't a computational misunderstanding; I'm sure each of us in that class could have pulled out a sheet of paper, plugged some numbers into a basic equation and come up with the same answers that we were given. It's an intuitive misunderstanding. We didn't have a sense of how quickly things would get out of hand for the bacteria.

Exponential growth — the type of growth experienced by the bacteria — is a non-linear function[9]. As we will see, non-linear functions describe many of the relationships that occur within complex systems (Hauk, 2014). Non-linear relationships are also harder to model than linear relationships (Heimann and Reichstein, 2008), which means that our ability to analyze and predict the behaviour of complex systems using computer models can be limited. This episode, combined with later realizations about the role of non-linearity and exponential growth in our complex world lead me to wonder: What are non-analytical ways that we can try to understand non-linear dynamics?

[9]This just means that the output is not proportional to the input. In other words, small changes in the input (the elapsed time) can result in large changes in the output (the population of bacteria) and vice versa.

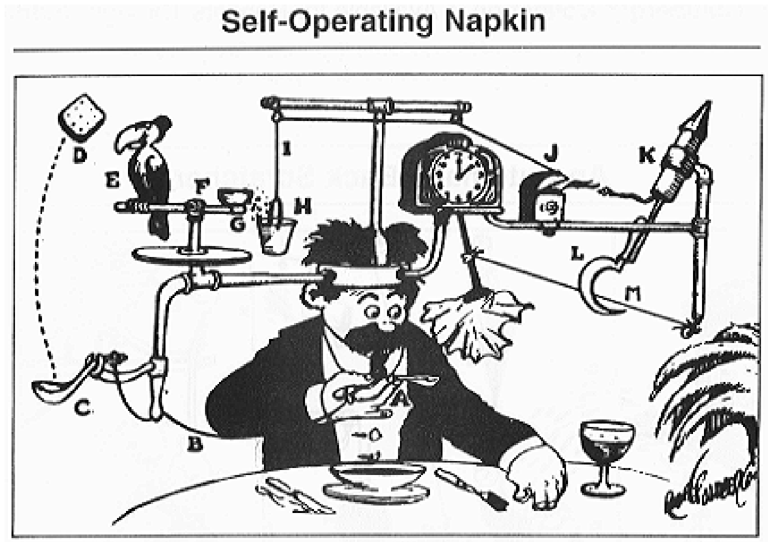

Figure 2.1: *Professor Butts and the Self-Operating Napkin* by Rube Goldberg (Public Domain)

2.3 Rube Goldberg machines

By the time I began my MFA in 2013, memory of Dr. Fieguth's lecture had faded into the distance. I had just finished my Master of Applied Science (MASc) working on computer vision, pattern recognition, and machine intelligence. I was interested in how computers 'know' things and whether a relationship with ecosystems mediated by technology could help us to experience parts of our environment that were normally beyond our perception. I was also thinking about Rube Goldberg machines.

I have been fascinated by Rube Goldberg machines for almost as long as I can remember. Rube Goldberg machines are the brainchild of cartoonist Rube Goldberg, who would draw exceptionally complicated sets of relationships as a critique of the "ironic relation between effort and result" (Kostelanetz and Brittain, 2001, 252) that is often found in industrial-age machinery.

The concept has often been adopted and re-mixed. In film, the best-known example is from Charlie Chaplin's *Modern Times*, where Chaplin's character endures feeding and punishment from a machine that looks remarkably similar to Goldberg's *Professor Butts and the Self-Operating Napkin* (Figure 2.1). The timing — the film was produced in the 1930's, not long after the initial cartoon was released — and film's depiction of the monotony of industrial work meant that the machine retained much of Rube Goldberg's original critical stance.

Fischli and Weiss (1987) adopted the concept of the linear chain reaction in their 30-minute long art film *The Way Things Go*. Now, long removed from Goldberg and Chaplin, Fischli and Weiss leave behind the factory and move to a once-empty warehouse that they have filled with ordinary, everyday objects. Still, they maintain the banality and humour of Goldberg's drawings by turning the notion of trying to accomplish anything on its head. Instead, the film proceeds as an exploration of the collision of materials in a successful attempt to achieve nothing.

Fischli and Weiss's work was imitated[10] by Bardou-Jacquet (2003) in his 2003 advertisement for Honda, *Cog*. *Cog* featured a Rube Goldberg machine made entirely from the parts of a Honda Accord, which form a chain reaction resulting in a fully assembled car rolling off a platform and a voiceover saying, "Isn't it nice when things just work?" While the basic chain reaction format remains intact in *Cog*, the underlying message has shifted entirely. The Honda commercial replaces the haphazard complicatedness of Goldberg and the utter pointlessness of Fischli and Weiss with a message about the masterful engineering and simple usability of the Accord. Perhaps it is fitting that it is a commercial for a car, of all things, that first divorced Rube Goldberg machines from their critique of industry.

The music video for *This Too Shall Pass* by OK Go (2010) also begins with a car — this one being a toy truck emblazoned with the logo of the video's corporate sponsor, State Farm Insurance. The video follows a series of Goldbergian chain reactions, some of which actually produce some of the audio for the video, to a conclusion that sees the band sprayed with paint cannons with a cheering technical crew in the background. The chain reactions incorporate subtle self-references, including balls running over their

[10]Some, including Fischli and Weiss, would say plagiarized.

old albums and a sledgehammer smashing a TV that is playing a previous music video of theirs. Though the reactions are thoughtful, they don't quite capture the same futility as Fischli and Weiss and the cheering crowd at the end points once more to a feat of technical wizardry as opposed to a sort of critical stance on societal processes.

Herscher (2011) brings the Rube Goldberg concept back to its original form, that of a linear set of chain reactions that accomplishes a simple task in a complicated manner. *The Page Turner* follows a chain reaction that begins with Herschler lifting his coffee mug and ends with the turning of the page of the newspaper that he is reading. The parts in the machine are clever and he manages to avoid many of the elements that have become cliche parts of Rube Goldberg machines over the years. For all that, *The Page Turner* still feels like a triumph of the designer, and seems to lack a critical stance toward the world. Perhaps, it is the very act of realizing Goldberg's absurd machines that moves them from the realm of critique in imagination to prowess in design.

It was, in part, that realization that lead me to shift my thinking about what I wanted to accomplish with my MFA. From the outset, I had conceived of a Rube Goldberg machine that shifted the notion of time in chain reactions. I thought about constructing something that operated on the scale of weeks, months, and years instead of mere minutes. And I wanted to incorporate ecosystem processes — the changing of the seasons, the growth and reproduction of plants, and the migrations of animals — into the chain reaction. But I realized that, in creating something exceedingly complicated, I would have merely been creating a monument to myself as an engineer and designer.

The hubris involved in that sort of endeavour is similar to that which lead EWB to originally think that it is possible to engineer simple solutions to poverty. It reinforces the illusion that many of us have of control over the world and assumes that we have the absolute ability know and repair it. I realised that I needed to create something that was less linear, less certain of itself, and less about the accomplishment of some feat. I needed to create something that is precarious and invokes a sense of humility and subtlety. I needed to create something complex.

2.4 Complexity

> *Many systems appear simple, but reveal remarkable complexity when examined closely (e.g. a leaf). Others appear complex, but can be described simply, e.g. some machines, such as the internal combustion engine. To compound matters, complexity is not located at a specific, identifiable site in a system. Because complexity results from the interaction between the components of a system, complexity is manifested at the level of the system itself.*
>
> (Cilliers, 1998)

Complexity is often confused with complicatedness, but the two are entirely different (Kagan, 2011). Imagine a mass of tangled string, knotted and looped around itself, over and over. The resulting mess of fibres is complicated. It is difficult to untangle, but still singular, linear, and eventually separable. Complexity is a cluster of strands that weave in and out of one another. They split and recombine, braid and curl, forming a length of rope that cannot be disentangled. The simple strands form an indivisible whole.

Complexity, at its root describes a system of relationships. Unlike the linear relationships of a Rube Goldberg machine, where one piece moves the next, which moves the next and so on until the process ends in a predictable fashion, the very composition of a complex system can change as the system is underway, leading to unpredictable results.

Earth's climate is an excellent example of a complex system (Margulis, 2004; Ramankutty et al., 2006; Hauk, 2014). The system is full of the types of feedback loops that characterize complex systems (Holldobler and Wilson, 1990; Hürlimann, 2009). A feedback loop, in its most simple form, is when one thing affects another thing, that affects the first, as though our Rube Goldberg machine had looped back on itself.

Feedback loops can be positive or negative[11]. For example, there is a

[11] This is a mathematical, not a moral alignment.

negative feedback loop between the amount of carbon dioxide (CO_2) in the atmosphere and the growth of plants (Farquhar et al., 1978). As CO_2 levels rise, there is more carbon for plants to breathe, and they tend to grow more. As more and more plants grow, it reduces the amount of CO_2 in the air as the plants convert it to oxygen (O_2). This makes it harder for plants to grow, which causes the levels of CO_2 to eventually rise again, re-starting the cycle. This is an example of a negative feedback loop because the effects of both actors in the loop (the plants and the CO_2) negate the other's actions.

If we move north, we find an example of a positive feedback loop between the permafrost and the amount of greenhouse gasses (methane and CO_2) in the atmosphere. As summer temperatures rise in the north, permafrost[12] begins to thaw. The thawing permafrost releases methane and CO_2, which further contribute to warming temperatures (Heimann and Reichstein, 2008).

Those two examples are actually grossly oversimplified[13], but what is important about the latter is that feedback loops often have non-linear effects, much like the growth of our jar of bacteria. The other important factor is that positive and negative feedback loops work against each other, with positive feedback loops driving a system to extremes — think extreme climates — and negative feedback loops counteracting those effects. When a system combines many of these effects, any uncertainty about how different parts of the system will respond means that the reaction of the entire system is impossible to predict precisely[14].

Scientific inquiry tends to deal with the uncertainties in such systems by

[12] Soil that typically remains frozen throughout the year.

[13] For most of these systems, there are feedback loops within feedback loops. The permafrost example actually has a second positive feedback loop within it, in which microbes in the soil become more active as the ground heats up. As the microbes become more active, their activity generates heat, which accelerates the rise in ground temperature, which melts the permafrost further and accelerates the release of greenhouse gasses from the permafrost.

[14] This is part of why we see all of those different scenarios every time the Intergovernmental Panel on Climate Change (IPCC) puts out a report on the effects of climate change. There is uncertainty built in to the models because we are not precisely sure of the strength of the various effects.

identifying a range of possible system responses[15]. This is a useful tool for understanding the situation, but the levels of uncertainty involved means that scientific and engineering analyses of a scenario cannot necessarily identify a single, optimal approach to a complex problem. In any case, "complex systems nested within complex, multi-layered contexts are far too intricate for us to understand through a single conceptual lens" Ambrose (2014). This opens up space for artistic and creative inquiry to play a role in understanding complexity and complex systems.

Artistic inquiry provides tools that are useful complements to analytical approaches to complexity. Merleau-Ponty (1945) points to perception as one such tool in *Phenomenology of Perception*. He argues that all knowledge is derived at some point from experience, from sensory engagement with the world. Representations of that knowledge — in language, data, scientific theories, or otherwise — are always second-order expressions. If perception is our primary way of knowing the world, perhaps a perceptual engagement with complex systems can be a fruitful method of inquiry.

The gestalt effect explains how we create meaning from our perceptions and hints as to why perception may be a useful tool in the study of complexity. Gestalt theory maintains that a whole is qualitatively *different* from the sum of its parts (Arnheim, 1943; Behrens, 1998). In Figure 2.2, we don't see four sets of legs, a head, tail, and body, and a spotted pattern in a particular configuration and build an understanding of the animal in the image from its parts. We see a dog, without explicitly seeing its component pieces. In fact, we see a dog, and the mottled-looking surface on which it stands. Instead of dividing wholes into parts, gestalt psychology divides perceptual experiences into figure and ground — what we identify immediately and what remains as the backdrop.

The gestalt effect is important to the consideration of complexity because it tells us that we can use our perception to understand a complex system as a whole system. If we can combine this perceptual understanding of complexity with the insights of the atomized understandings of scientific

[15] We see this, for example, in the range of scenarios that are typically given in IPCC reports.

Figure 2.2: The dog picture is a popular example of emergence from the field of gestalt psychology (Boyer and Sarkar, 2000). Though the outline of the dog is not clearly defined, we can perceive the dog as a whole entity within an unclear image. Public Domain.

inquiry, then perhaps we can generate a more complete picture of complex systems.

What are some of the aesthetics of complexity that can help play a role in that inquiry? I propose the following as an incomplete and open inventory of features that contribute to a complex aesthetics and provide examples of artwork that makes use of these features:

Internal contradiction, uncertainty and indeterminacy (Kagan, 2012) Complex art leaves the viewer/audience/participant unsure of exactly what has transpired in their experience of the artwork. Velàsquez accomplishes this in *Las Meninas* (1965) by creating uncertainty around the movements of the figure in the doorway and the viewpoints of the royal couple depicted in the mirror. M.C. Escher's work often includes a type of internal contradiction, most famously in his lithographs *Relativity* (1953) and *Waterfall* (1961). Around the same time, Jean Tinguely's self-destructive sculpture, *Homage to New York* (1960), created an indeterminate situation were both artist and viewer were unsure of what form the sculpture would ultimately take. Joseph Beuys's 1974 *I Like America and America Likes Me* was another experiment in indeterminacy, as Beuys took up residence in a New York Gallery with a coyote and proceeded to negotiate the space with the animal for the next three days. rAndom International's *Rain Room* (2012) brings uncertainty and internal contradiction to participants as they walk through an indoor rain storm that avoids wetting them.

Relationships and interdependencies (Bourriaud, 2002; McCormack and Dorin, 2001; Bishop, 2004; Bown et al., 2014) A focus on relationships and interdependencies between the artwork, audience, and the context and environment in which the relationships exist is central in complex art. In *Las Meninas*, this can be found in the perspective of the viewer and their relationship to the royal couple, the painter and the painting being produced in the image. Beuys's sharing of an enclosed space with a coyote involves the constant re-negotiation of the relationship between himself and a wild animal. Daniel Jolliffe's *Untitled Ball* (1993) explores the relationship between a shy robotic ball and a person, while Rafael Lozano-Hemmer uses technology to visualize the relationships between people's beating hearts in *Pulse Room* (2006). Tomás Saraceno's *14 Billions* (2010) provides an opportunity for the viewer to immerse themselves into a web of interconnection and interdependency.

Feedback, cycles, and non-linearity (Bateson, 1972; Hofstadter, 1979; Dieleman, 2008) Escher's work regularly included feedback mechanisms and cycles. In *Waterfall* (1961), the water forms an ever-flowing loop, prompting an examination of the infinite and the perpetual. Hans Haacke's *Condensation Cube* (1963) is also decidedly cyclical with the water trapped inside a sealed transparent cube continually evaporating and then recondensing as the environment around it shifts.

Openness and ceeding control (Bateson, 1972; Weintraub, 2012) In bringing a coyote into a shared space, Beuys created a situation in which he was complicit and effected, but over which he had little ultimate control. Abramović accomplishes a similar openness, but with the human animal as a partner in *Rhythm 0* (1974). Jolliffe's openness is found in quality of the interaction between the participant and *Untitled Ball*. The participant is given no instruction — explicit or implicit — other than the behaviour of the ball relative to their own motions. Tinguely's work demonstrates these features as it began to self-destruct and ultimately failed to do so entirely. The creation of a work that self-destructs is in itself departure from the typical level of control exercised by the artist, but the failure to successfully accomplish said self-destruction is a testament to the openness of the work.

Scale, multiple scales, and self-similarity across scales (Giddens, 1984; Dieleman, 2008) Spatial scale plays an important role in Velàsquez's *Las Meninas*, where important figures appear in a variety of sizes within the image. Lozano-Hemmer pays attention to multiple scales as *Pulse Room* begins with the individual heartbeat, moves to a single light, and then fills a room with the light from beating hearts. Saraceno's *14 Billions* exhibits a fractal-like self-similarity at different scales as ropes form ever denser networks in the installation space.

This list is by no means comprehensive, but it presents a useful starting point from which to consider artworks that deal with complexity. There is one phenomenon, however, that I have omitted from the discussion so far. We now turn to emergence, which is both a feature of complex systems and a strategy for creating and understanding complexity.

2.5 Emergence

> *It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the external conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.*
>
> (Darwin, 1859)

Complex systems often exhibit a phenomenon called emergence. Emergence describes the non-teleological appearance of patterns and forms from a complex system. The quotation from Darwin that begins this section reveals the biological origins of the notion of emergence. It demonstrates one of the most important features of emergence from complex systems: the lack of a direction, controlling influence, or overarching plan. The plants, birds, insects, and worms, the "elaborately constructed forms" are a result of "laws acting around us". The species are not perfect, they are not fixed. They are merely at a point in their evolutionary history, driven there by forces around them.

In complex systems, "interesting global behavior emerges from many local interactions" (McCormack and Dorin, 2001). The cannonical example of an emergent system is that of an ant colony (Hofstadter, 1979). Ant colonies can be fabulously complex structures. They can have many different kinds of chambers — for nesting, brooding, waste, food storage — connected by a complex system of underground tunnels (Holldobler and Wilson, 1990). But these structures are not designed by a master ant architect. The ants manage to build and maintain their colonies using a system of relatively simple rules.[16] In fact, using models that simulate ants moving in very simple patterns, responding to pheromones release by other ants, researchers have been able to simulate the types of building behaviours that ant colonies exhibit (Khuong et al., 2011).

The same kinds of emergent patterns can be found in generative art. Jazz music is an excellent example of improvised, emergent forms. "Free jazz is about adaptation, since one instrument depends completely on another, and all instruments depend on the 'environment' of 'un-intention' around them" (Morton, 2010, 109). In an emergent conception of a jazz band, the musicians play the role of the 'ants' in a musical 'colony'. Each musician has a. understanding of the general rules and conventions of jazz music and the specific band in which they are playing, but their performance in the moment is a response to their neighbouring[17] musicians.

The explicit use of emergent phenomena in visual art began with the

[16] An excellent TED Talk on how colonies as complex, emergent systems direct the activities of their members can be found at http://www.ted.com/talks/deborah_gordon_digs_ants.

[17] I use the language of neighbour here specifically because studies in emergence often deal with localities and discuss the effect of neighbouring actors on each others' actions.

introduction of computing and electronics into art. Works like Gordon Pask's *The Colloquy of Mobiles* (1968) and Ruairi Glynn's *Performative Ecologies* (2008b) use emergence as a property of their complex systems artworks to explore the relationships between communities of machines and the humans in their environments.

Beesley's *Hylozoism* Series (2010) explicitly adds the element of the physical environment into the mix, extending the conversation to include materials that support life. It is here that the discussion becomes specifically ecological in nature, and the work starts to explore the way that we relate to the planet as opposed to focusing exclusively on how we relate to technology.

In part, artists are turning to emergence in order to challenge their own expectations of what their artwork can do. This movement in electronic and robotic art can be considered a response to a similar challenge to the static, permanent nature of artwork mounted by the likes of Jean Tinguely in *Homage to New York* and Raphael Montañez Ortis in his *Piano Destruction Concerts* (1966) — a key difference being the *con*structive nature of the work of the electronic artists as opposed to the *de*structive work of Tinguely and Ortis. "Most electronic artists are looking for an out-of-control quality that will result in their work actually having outcomes that they did not anticipate. If the piece does not surprise the author in some way then it is not truly successful in my opinion" (Lozano-Hemmer and Ranzenbacher, 2001).

The notion of "out-of-control" can imply chaos or pure randomness, but here Lozano-Hemmer is actually talking more about "out-of-the-artist's-control" than an entirely random system. Jim Campbell (2000) explains why the creation of emergence is important. "Most programs are trivial with randomness thrown in to make them seem complex. What this does is make the communication shallow and confusing." Emergent complexity creates unpredictability and sheds notions of top-down control, but leaves in place a sense of pattern and some form of fluid order.

Ihnatowicz (1970) noticed the difference between random and unpredictable responses when developing his 1970 work *The Senster*. *The Senster* was a hydraulic robot, commissioned by Philips for installation at the Evoluon in Eindhoven, that reacted to sound, positioning itself to confront any noise made in its environment. During the development process, Ihnatowicz had the robot move randomly (not in response to sound), which terrified a number of children who saw the robot flailing about. Once *The Senster* was installed and responding to sound, however, nobody appeared to be frightened by the creature. In fact, visitors began to attribute intelligence and autonomy to the robot, despite — and likely because of — its response remaining partially unpredictable (Bown et al., 2014). It became clear to participants that there was some sort of underlying pattern and order to the motion and this allowed them to engage in a back-and-forth relationship with the novel machine.

In this configuration, emergent artworks can become conversation pieces (Kester, 2004; Bown et al., 2014), spaces for the re-examination of relationships. Due to the mechanical and computational nature of the art systems that create these emergent installations, the relationship that is examined is often one of the human to the machine. While this is an important relationship to critique and examine, I think it is actually important to begin to use complex art systems to examine our relationship to the very nature of complexity and emergence. McCormack and Dorin (2001) think that it is possible do just that: "Generative art usually involves poeisis, which suggests that it should reveal the world in ways that nature can't — hence technology seems a possible, but not necessarily unique, vehicle to achieve this aim."

Generative art also reveals the world in a way that is very different — and complimentary — to that of the analytical methods of science. It deals with experience, a way of knowing that has "an emergent quality, which is neither entirely reducible to its underlying elements and processes nor fully explainable by them." (Hassenzahl, 2010). In this, experience may be the perfect vehicle for exploring the emergent and complex.

2.6 Experience

Artistic inquiry takes place in the realm of experience. In fact, Dewey (1994) posits that "the actual work of art is what the product does with and in experience." The aesthetic experience of complexity that participants have in the space of *Subtle Emergences is the art.* "This fact constitutes the uniqueness of esthetic experience, and this uniqueness is in turn a challenge to thought. It is particularly a challenge to that systematic thought called philosophy" (Dewey, 1994, 219).

I have often been asked why I bother to create a complex system, an ecosystem, out of electronics when I could simply ask people to go out into the "wilderness"[18] and experience complexity there. Part of the answer has to do with the creative experience that I get in the process of shaping the system and its parts. But another part of the answer is the shift that can happen when we experience something in a new way. Adorno addresses this in his discussion of mimesis (Schultz, 1990), arguing that imitation allows to contemplate that which does not exist by seeing what we already know in a new light.

"When past and present fit exactly into one another, when there is only recurrence, complete uniformity, the resulting experience is routine and mechanical; it does not come to consciousness in perception." (Dewey, 1994, 218). The strangeness of *Subtle Emergences* adopts elements our past experience in ecosystems, but introduces material elements such as acrylic, pure copper, and silicon that do not "fit exactly". This, along with the context of the system — its place in an art gallery, in an environment that is deliberately sterile — enables a perceptual shift from the routine and the mechanical.

How does one go about creating such an experience? For this, we move to a discussion of the roles of experience design, crafting, and hacking in the making of an interactive art environment.

[18] Let us for a moment ignore the problematic nature of "the wild"

Chapter 3

Building Complexity

Having built up an understanding of complexity and some of the approaches, we now move to a discussion of the methodologies that I employed in the creation of *Subtle Emergences*. How did I take some of the aesthetic features of complexity and embed them into my process and the resulting installation? What role does emergence play in the design of the work, and how did I build emergence into *Subtle Emergences*'s behaviour? How did I account for the experience of visitors, participants, and observers?

Experience design is a design methodology that focuses on the relationship between people, objects, and their environments and how that shapes experiences. Along with critical making and crafting, experience design forms the basis of my artistic practice. All of these methods are linked by their focus on reflective practice and the role of embodied knowledge.

3.1 Experience Design

The primary lens through which I view my artistic practice actually belongs to another field entirely [19]. I came to Experience Design (XD) as part of my undergraduate education, introduced to the idea as part of a series of Engineering Design courses. Though lacking a single, consensus definition (Wakkary, 2009), XD is widely applied, especially in design and engineering fields. The field grew out of research on User-

[19] There is much discussion about the relationship between the fields of art and design (Novitz, 1992; Coles, 2007), most of which relies on defining boundaries between two constantly evolving and expanding fields. For me, defining said disciplinary boundaries is not of particular import. My work draws on multiple disciplines, moving fluidly between them, and incorporating practices from each. The disciplines are toolkits, sets of ideas and worldviews that can be used or discarded, as best fits the process at hand.

Centred Design (Norman, 1988) and Human-Computer Interaction in the 1990s (Winograd, 1997), as the number, variety, and complexity of products that were being produced started to explode. Designers realized that it was becoming difficult to keep up with reading a manual for each new product, and that an alternative might be to design user interactions with their products so that their use is intuitive[20] (Norman, 1988).

In product design, XD is a shift in perspective from a focus solely on technical operation of the artifact that is being created. Norman (1988) uses the process of designing a telephone system as an example. A pre-XD approach would inquire as to whether the telephone is technically capable of completing a phone call and recording a message when nobody answers. An experience designer would ask about the lived experience of someone going to place a call and check the messages. As a result, XD inquiry incorporates phenomenology and experience into the design process (Merleau-Ponty, 1945).

Hassenzahl (2010) proposes four crucial properties of experience that designers should acknowledge. Experience is *subjective*, *holistic*, *situated*, and *dynamic*. He also suggests that experience itself is emergent, "neither entirely reducible to its underlying elements and processes nor fully explainable by them" (Hassenzahl, 2010, 6). In many ways, this conception of experience is similar to the characterization of complexity, suggesting that Experience Design is itself a complex task.

Prototyping and testing of designs is crucial, because XD relies on the lived experience as part of the process of inquiry. In my thesis work, prototyping manifested both in the lab, as I constructed the work, and in the shows leading up to *Subtle Emergences*, where I was able to test the work in situ. The incorporation of my own experiences with the work as I design and test, observations of others' experiences, and informal interviews with participants are part of what Dewey (1933) and Schön (1983) call a

[20]Think about the number of new products that you use on a regular basis today and the number for which you have to seek the manual versus the number of products that you simply understand from past experience. These cues from past experience are referred to in design practice as affordances.

reflective practice.

The focus on embodied knowledge had another consequence for my working process. If I was to create an environment for an embodied, experiential understanding of complexity I was going to have to have an embodied understanding of the materials that I was going to use to create that space. For this, I turned to crafting, critical making, and Do-It-Yourself (DIY) cultures.

3.2 Critical Making, Crafting, and DIY

Experience Design is the basis for my process of creating an experience of complexity. Critical making is the process by which the material part of that experience is constructed. Where reflection in an XD practice is focused on people's experience with the result, the reflective practice of critical making is concerned with learning from the actual crafting of the material. It places its focus on "the constructive process as the site for analysis" (Ratto, 2011, 253). Matt Ratto, the researcher who proposed the idea of critical making in its current form, suggested that the practice could be particularly useful in trying to understand complex problems in an interdisciplinary manner. Critical making, as a way of exploring new materials and techniques, served me as an embodied and reflective way of learning about complexity. It was also a key methodology in the *Inorganisms* workshops that I ran in December and June[21].

The practice of critical making has roots in the arts and crafts movement that began in the 1860s with, among others, William Morris. Morris (1884) was a writer, designer and social activist dissatisfied with the effects of the industrial revolution in England. Morris was dismayed at the "boring, soul-destroying labour" (Wall, 2003, 10) that was foisted upon English workers as

[21]The *Inorganisms* workshops were not actually a part of my thesis, but drew on the ideas of emergence and complexity that I developed in my thesis work. The workshops engaged participants in the creation of an ecosystem of inorganic organisms (or inorganisms) that engage each other and their environments through a variety of electronic senses. The goal of the workshops is to eventually build enough inorganisms that the collection of them displays emergent behaviour though their complex interactions.

the Industrial Revolution advanced and envisioned a return to work "worth doing" (Morris, 1884). He longed for a form of utopian socialism with craft as the basis for creative work, and envisioned such a society in his novel *News from Nowhere*.

Morris's views are credited with inspiring a host of modern environmental movements and organizations (Guha, 2000). His work is also the basis for some of the critical and activist roots of modern crafting communities — those communities housed within Makerspaces and on web sites such as Ravelry[22] and Instructables[23] (Richardson et al., 2013). Those communities also have elements of a utopian vision to them, but their approach is better described by Bourriaud. "Instead of a 'utopian' agenda, today's artists seek only to find provisional solutions in the here and now; instead of trying to change their environment, artists today are simply 'learning to inhabit the world in a better way'; instead of looking forward to a future utopia, this art sets up functioning 'microtopias" in the present" (Bishop, 2004).

Craft, in these communities, is bound to a Do-It-Yourself (DIY) ethos. 'Yourself', in this case, does not mean 'alone'. It often means that the physical work will be done by oneself, but the process often relies on guides written by community members, instructional videos, and forums where the details of the work are discussed and questions are answered by those with experience on a particular project. In fact, these creative communities operate as complex networks of people and ideas. Projects are combined and new ideas emerge from the sharing of adaptations and enhancements. The original creators often improve their original design by incorporating some of the ideas from subsequent attempts to create creative feedback loops.

Engagement with these crafting communities is part of my practice and informed the designs and strategies that I used in crafting *Subtle Emergences*. Maintaining an active role in the equivalent programming communities[24] is also an integral part of my practice.

[22] www.ravelry.com

[23] www.instructables.com

[24] The model of online sharing and exchange used in many crafting communities has

An interesting development in the last few years has been the emergence of communities that operate at the intersections of craft and technology. Buechley (2006) initiated much of the academic research into the field, beginning in her graduate work with the design of the Arduino Lilypad, a sewable microcontroller, and continuing into her High-Low Tech lab at the MIT Media Center. Since then, many people have begun to work at the intersections of craft, textile, and electronics (Perner-Wilson, 2011; Fernaeus et al., 2013; Kadish and Dulic, 2015a), myself included. Influences of high-low tech and soft electronics can be seen in the way that the leaves are constructed for *Subtle Emergences*.

roots in the ways that programmers share code and libraries through version control repositories like www.github.com and www.bitbucket.org.

Chapter 4

Complex Art Systems

> *Most electronic artists are looking for an out-of-control quality that will result in their work actually having outcomes that they did not anticipate. If the piece does not surprise the author in some way then it is not truly successful in my opinion.*
>
> (Lozano-Hemmer, 2001)

We have gathered all of the parts. In chapter 2, we examined the ubiquity of complex systems and defined an aesthetics of complexity; we considered the emergence of an order, of sorts, from complexity; and we identified the role of art and experience in appreciating and understanding complexity and complex systems. We looked at experience through the lens of design in chapter 3 and pondered the role of craft and critical making communities in producing those designed experiences.

This is the chapter where those concepts and methodologies coalesce. I discuss here the production of *Subtle Emergences*, the installation process, and the finished installation and its impacts. Throughout the chapter I weave elements of complexity, emergence, experience, and crafting into the discussion to create a cohesive picture of the project in its context.

4.1 Production

The process for physically crafting *Subtle Emergences* has roots in a 2009 project that I undertook in collaboration with Angie Hostetler as part of a course at the University of Waterloo. *Sub Rosa* (Figure 4.1) was a shy, interactive sculpture that closed in retreat when the room was noisy and bloomed when the exhibition space was quiet. Motion was driven by an Arduino that monitored the microphone and then actuated Shape Memory

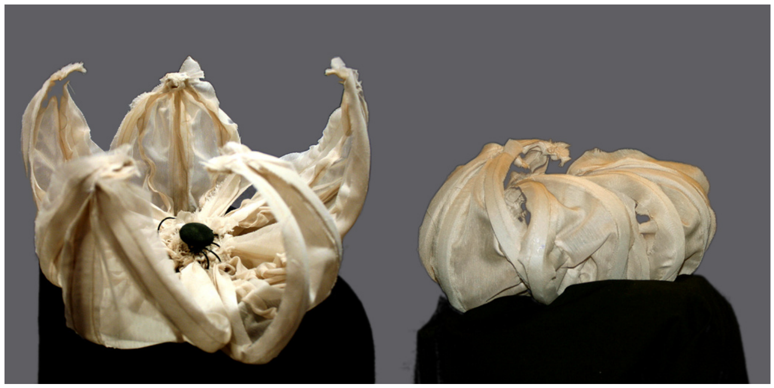

Figure 4.1: *Sub Rosa* (2009) by David Kadish and Angie Hostetler. On the left, the sculpture is shown in its open position and the microphone is visible. When people in the space are loud, the *Sub Rosa* closes its petals and hides, as in the image on the right.

Alloy (SMA) embedded in the fabric. Support was provided by re-purposed plastic from drinking containers, which held the structure up and guided it back open when the room quieted.

Conceptually, *Sub Rosa* was the beginning of my interest in exploring shy electronics[25]. The interactivity is not complex; there is a direct relationship between the sound levels and the open-or-closed position of the petals. Yet, it represents the beginning of my exploration of the intersection of people, technology, and environment, and opens the question of how we relate to technologies that do not perform for us, as we often expect technology to do.

The basic structure of *Sub Rosa* was the starting point for the research and prototyping that lead to *Subtle Emergences*. For a first attempt, which resulted in the two hanging leaves in *Photosynthetics* (Figure 4.2), I replicated much of the technical work that I had done in *Sub Rosa*,

[25]The idea of a *shy art* is one currently being developed by Angel (2014). In her artist statement for *Materiality* (2014), she writes: "This is the beginnings of shy art, media works that require patience and attentiveness. These are sensitive interactions where gallery attendees bear witness to leaves that almost imperceptibly curl and unfold, images that may choose to appear or sounds that shift in quality so faintly that to breathe might mean missing the change in tone. In an age of overstimulation these works ask for a slow engagement, a quiet listening and a careful touch."

Figure 4.2: *Photosynthetics* (2014) by David Kadish. The structure of the two hanging leaves is based on the construction of the petals from *Sub Rosa*.

substituting the process of hand-cutting the plastic ribbing for a laser cutting process and using acrylic sheets instead of discarded drinking containers. These leaves served as the starting point for the cycles of prototyping, testing, and observation from which the leaves in *Subtle Emergences* developed.

The production of *Subtle Emergences* really began in April 2014, with the design and installation of the two hanging leaves for *Photosynthetics*. *Photosynthetics* hung in the FINA Gallery as part of the *Materiality* exhibition for the 2014 Interdisciplinary Graduate Students' conference. The behaviour was simple — the two leaves and the accompanying lights operated in on-off cycles, with no interactivity — but the installation was a good test of the visual aesthetics of the work. I was able to assess how the hanging leaves might fill the space and how people might interact with them.

One of the first things that I observed was that the motion was *far* too subtle for most people to notice. I wanted the motion to be subtle and non-performative, so as to generate an interest in the behaviour and our relationship with it and not the spectacle of the technology. However, I realized with *Materiality* that there is a fine line between subtle but observed and completely overlooked. I also came to the understanding that different people might perceive the motion differently. One visitor might see the motion of the leaves, and another might see only the changing lights.

Part of the task, then, would be to design layers of interaction into the experience, so that it would still be possible to have an interesting shallow experience, but one could also build a deep relationship with the installation. That type of multi-scale self-similarity is also a defining feature of complex systems (Figure 2.4), so it makes sense that it would be necessary in designing a complex experience. I realized then that simple, pre-programmed cycles were not going to produce the kind of complex behaviours that I was seeking and so after that show, I began to experiment with other ways of creating kinetic motion.

The next generation of the work was the *In A Tension* show in September 2014 in the FINA Gallery. As a full gallery installation, this show began to give me a better picture of what my thesis would look like. *In A Tension* consisted of four hanging leaves, lights, and as a new element, three copper sculptures that produced quiet sound. The leaves were suspended from the ceiling of the FINA Gallery by the copper wire that powers them. Each leaf was lit from multiple angles and the copper sculptures — two hung on the walls and one resting on the floor — were also lit.

In addition to the new leaves, one of the major changes in this show was in the way the leaves and lights behaved. The lights and the leaves were converted from running on fixed cycles to using a basic on-off state machine system[26] (Harel, 1987; Thalmann and Musse, 2013). In practical terms, this means that instead of turning on and off at regular intervals, the shifts between on and off had some degree of randomness. A state machine forms the basis for a probabilistic structure called a Markov chain. A Markov chain defines the probabilities of transition from one state of a state machine to

[26] State machines are conceptual structures used in automatic control systems, network communications, language and text parsing, and agent-based modelling. State machines have a single active state and a set of non-active states. The state machine defines how the system is able to transition between states.

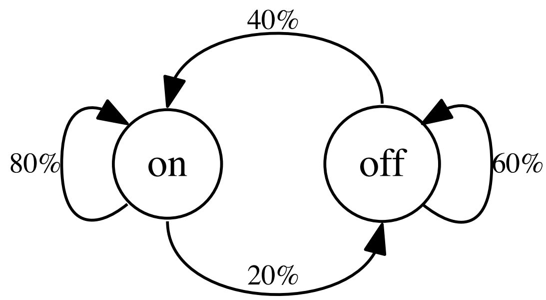

Figure 4.3: The state machine and markov chain diagram for *In A Tension*. There are two states, *on* and *off*. If the current state is *on*, the next state has an 80% chance of being *on* and a 20% chance of being *off*. If the state is *off*, there is a 60% chance that the next state will be *off* and a 40% chance that the next state will be *on*.

another.

Figure 4.3 shows the type of state machine and Markov chian that I used to control the lights and leaves in *In A Tension*. There are two states, *on* and *off*. Each state has two transition probabilities, defined by the percentages written next to the transition lines. At any point in time, if the state is *on*, the next state has an 80% chance of being *on* and a 20% chance of being *off*. If the state is *off*, there is a 60% chance that the next state will also be *off* and a 40% chance that the next state will be *on*.

As a result of this behaviour programming, the motion of the lights and leaves was less regular in *In A Tension* than in *Photosynthetics*. Although there was still no interactivity built into the system — there were no sensors with which the system could gather information about the world to interact with — some visitors to the gallery still attributed the movement of the work to their presence and motion.

In addition to updated behaviour, *In A Tension* also saw the addition of copper tubing as a material to the work, and the integration of sound into the installation. The copper sculptures were initially inspired by the pistil and stamen structures of plants. The pistil and stamen are the plant's reproductive organs, with the stamen producing the pollen and the pistil producing the ovule[27]. In plant sexual reproduction, pollinating insects such as bees often play the role of transmitting pollen from the stamen of one plant to the pistil of another. Nectar, pollen, and colouration (Raven et al., 1999) are used by the plant to attract pollinators. In *In A Tension*, the gallery visitors were envisioned as the pollinators, attracted to the copper sculptures by the low-level sound that emanates from them. In order to hear the sound, visitors must approach very close to the sculptures, almost placing their ears directly on the sculptures.

The orientation of the copper sculptures here was purposeful as were the low sound levels. In their design, I take a biomimetic cue from the plants that serve as the inspiration. The placement of the sculptures away from ear-level, combined with the low level sound entices participants to contort their bodies to approach the sculptures, much like the colours and scents of a flower attract pollinators. In doing so, they invite participants to change their perspective on the space, by twisting their heads to the wall, or lowering themselves to the ground. The act is an embodiment of the goal of getting people to consider the complex world in new ways. The sound adds another layer onto the experience and is first step to creating experiences at different sensory scales.

The use of copper as the material for the sound sculptures is also significant. Copper is new as an aesthetic element of the work, but it is embedded into nearly every part of the installation as wires and electronics. As such, its use is conceptually consistent with the rest of the installation. It is cold and metallic, while remaining relatively soft and pliable exemplifying the often contradictory nature of complexity that the work expresses. Finally, as a connector, an element that transmits heat and electricity, joining elements across space, copper as a material fits well into an aesthetic of systems and relationships.

One piece of feedback that I got from that show was that I had not paid enough attention to the shadows that the lighting had created. Shadow had the potential to build the work to fill the room, but I had missed details,

[27]Which matures into a seed when pollinated.

Figure 4.4: Installation view of *In A Tension*. Note the shadow from the hanging sculpture travelling from the wall to the floor. It does not appear to have been purposefully placed in that way.

for example unintentionally leaving portions of shadows running from wall to floor (Figure 4.4). I had missed the ways that shadow — in addition to light — had created spaces within the installation. I decided to focus on shadow for my next work, *Traces*.

Traces (Figure 4.5) was installed in the BC Tree Fruits Packing House as part of the 2015 instalment of the Mad Hatter art show, titled "Beyond the Invisible". The space itself had imposing high ceilings, beautiful wooden walls, and puddles on the floor that were in constant flux as water dripped into the space from the soaked sawdust insulation in the roof.

I suspended the four leaves from just above the floor to midway down from the ceiling, staggering them vertically and horizontally. Each leaf had a spotlight that projected its shadow onto a space on the wooden wall. The lights slowly faded in and out and, if one paid close attention, the leaves would move, their movement amplified into massive shadows on the wall. The shadows dwarfed the physical objects, filling the space, and creating reflections on the pooled water. The dripping ceiling added a sonic element to the environment and I decided not to interrupt that with my own added sound.

The installation process for *Traces* was complex in a way that is very different from a gallery-based installation. In a gallery, the artist typically has near-total control over the environment. Here, the process was much more about identifying places for intervention in an already rich environment and finding relationships between my work and the space. The size of the space also meant that I had to pay particular attention to scale, transforming small into substantial to bridge the difference in size between the objects and the space.

After *Traces*, I installed the pieces that I had in the black box studio in CCT to spend about three months experimenting and preparing for *Subtle Emergences*. In the time in the CCT the work went through three significant shifts: the generative systems that controlled the leaves and lights were overhauled; I held a critical making workshop that resulted in the addition of some detail to some of the leaves; and, in collaboration with Emily MacMillen, I built seven new leaves for the show.

In *Traces*, I wasn't quite satisfied with the quality of the motion that I had been seeing from the leaves or the shifts in lighting that had been occurring. The system to create motion and lighting changes had remained the same since *In A Tension*. The movements that it was creating were not emotive enough, not varied enough, and it was also unable to incorporate sensors into its decision system, so there was no possibility for interaction with participants. The software was, as Campbell (2000, 135) puts it, "trivial with randomness thrown in to make [it] seem complex. What this does is make the communication shallow and confusing." I realized that if I wanted emotive responses, then the leaves would need to have behaviours that were more complex than semi-random fluctuations between on and

Figure 4.5: Installation view of *Traces*. In this installation, the physical sculptures are quite small compared to the vastness of the former warehouse. The shadows play a central role in creating the environment within the space and in fact, the piece is much more about the shadow than the physical sculptures.

off[28].

Motion in the leaves is represented in the code as a series of numbers that are fed to the controller that tell it how much to turn on at any given point in time[29]. At first, I attempted to design tables of control sequences by hand, by typing numbers into a list and then sending that sequence of commands to the leaf, but I was still not getting the quality of motion that I wanted. Then, it dawned on me that I could create a circuit (Figure 4.6) to control the motion of the leaves using a dial and then record the control signals that created those movements, moving the process of designing motion from the realm of mathematics[30] to the realm of my own experience.

This shift in approach is exactly the larger shift that *Subtle Emergences* is designed to spark. Designing the motion by creating graphs is an abstract, analytical approach typical of an engineering design process (Cross, 1982). Using the dial transforms the process into something akin to the playing of an instrument. It allowed me to incorporates visual feedback and my emotional response into the process of composing the motion. The process became gestural and immediate.

Using this system, I created a set of six behaviours for each of the leaves: relaxed, rhythmic, agitated, contracting, contracted, and relaxing (Figure 4.7). Each leaf has its own motions for every behaviour, set by hand to utilize the individual range of movements of each leaf. The transition probabilities[31] are set individually for each leaf, so where one may prefer

[28] Recall how the state machine in *In A Tension* and *Traces* worked.

[29] Digital electronics are typically limited to being either *on* or *off*, but through an electronic technique called *Pulse Width Modulation*, the control signal can be fractionally *on*. Using that technique, I can instruct the leaf to be, for example 50% on if I want it to move more slowly that it does when it is fully on. By sending the leaf a series of these instructions, it is possible to create different qualities of motion.

[30] Creating the tables of control sequences involved creating graphs of control sequences and then turning those into numerical tables.

[31] Transition probabilities are the likelihood of a leaf moving from the state that it is currently in to any of the other states. For example, if a leaf is currently relaxed, the transition probabilities might be: relaxed: 50%; rhythmic: 10%; agitated: 15%; contracting: 25%; contracted: 0%; and, relaxing: 0%. It is most likely to stay relaxed, but it could also transition to rhythmic, agitate, or contracting. It cannot transition to contracted or relaxing, because it has to be contract*ing* before it can move through those states.

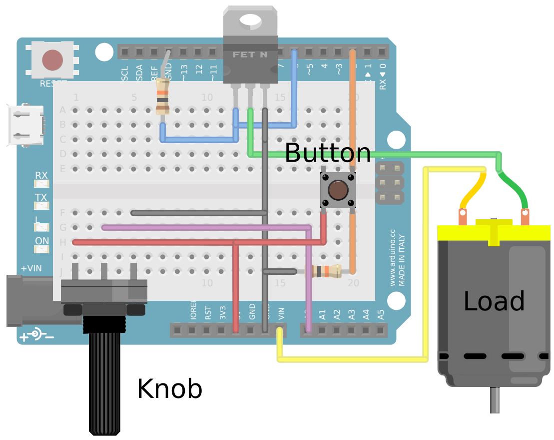

Figure 4.6: Behaviour calibration system. When the knob is turned it changes the amount of power going to the leaf that is being calibrated. I would use that to generate the kinds of motion that I wanted and practise it a few times. Then, when I had the motion figured out, I would press the button to save the sequence and then I had a behaviour. The load — a motor in the image — represents the SMA inside the leaves.

to be in the relaxed state, another may show preference for being in the rhythmic state. Furthermore, the transition probabilities are modified by the sensor readings. This is how the leaves respond to the presence of people and changes in their environment. For example, if the leaf that generally prefers to be in the relaxed state senses a lot of light, it might shift its preference to be in the agitated state.

I realize that my coverage here of the state system may be overly technical and not terribly interesting to the general reader, but the details that I have presented[32] are important to understand the underlying processes behind the activity and interactivity of the art system. The development of these strategies was also an important part of my process. At each stage of development, I thought I had created a system that would be complex enough to elicit the types of behaviours that I wanted, but at

[32] I have still left out many of the details of how the leaves and lights work, but I think this text provides a suitable overview of the systems. For those interested in further details, a full system diagram is shown in Figure 4.8.

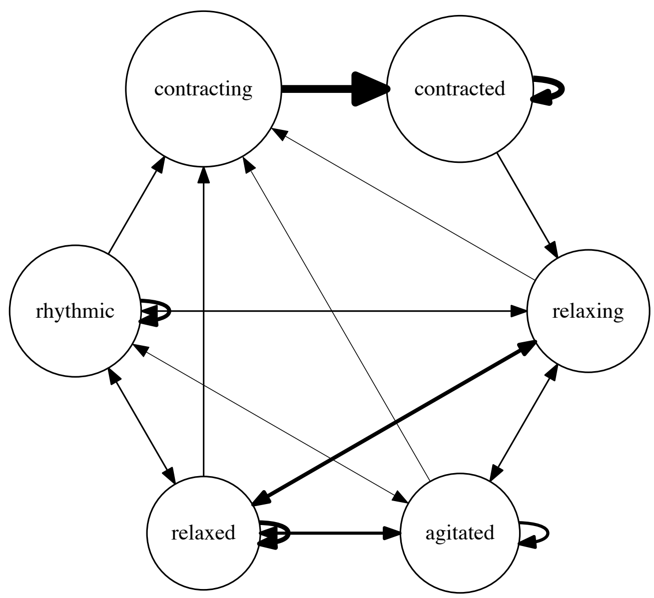

Figure 4.7: State machine drawing for the leaves in *Subtle Emergences*. The drawing is an example of what the state machine could look like, with the varying thickness of the lines and arrows representing different transition probabilities between states. For example, in this diagram, the contracted state can transition either back to itself or to relaxing, but it is much more likely to transition back to itself.

each stage I came to the realization that there were missing layers in the system. Each layer that I built into the code added a richness to the motion and brought the work closer to the type of complex experience that I was hoping to build.

I continued to develop and tweak the behaviours of the leaves and lights up until the installation was complete, but in the meantime I received a piece of important feedback about the work as it was installed in the CCT. In a final committee meeting before I began to install the show, it was pointed out to me that the leaves themselves lacked a certain visual depth and complexity. If part of an aesthetic of complexity (Figure 2.4) is building detail at different scales, the leaves operated at only one scale. There was not enough detail in their design to create a sense of dynamism and generate interest in exploring them up close. It was possible to perceive the entirety of each leaf from afar. On the other hand, I still had only four leaves and so there was not enough detail at a room scale to create a sense of a complex environment. This was mitigated somewhat by the creative use of the lights to shape the environment, but I needed more material to make the installation a success.

The large scale detail was the easier of the two to address. I had been working with Emily MacMillen since January, teaching her the design and construction process for the leaves. In the next couple of weeks, we designed and produced seven new leaves. Strategic placement of the movable wall and the use of the copper wiring as a sculptural element also helped to create a sense of visual complexity and depth at a room scale.

I was unsure of what to do about the small-scale detail and so I decided to bring in some new eyes[33]. I invited my partner and microbial ecologist, Emily, Kristin Aleklett, my lab colleague and fellow artist, Jeannette Angel, and her daughter Etta Marguerite Angel-Fox to the CCT's black box studio for a critical making workshop (Figure 4.9). I brought along a range of materials and asked the participants to attack the existing leaves with materials to see if we could discover what was missing from them.

A number of interesting approaches developed from the afternoon. We

[33]And hands. We are, after all, talking about a hands-on, embodied process.

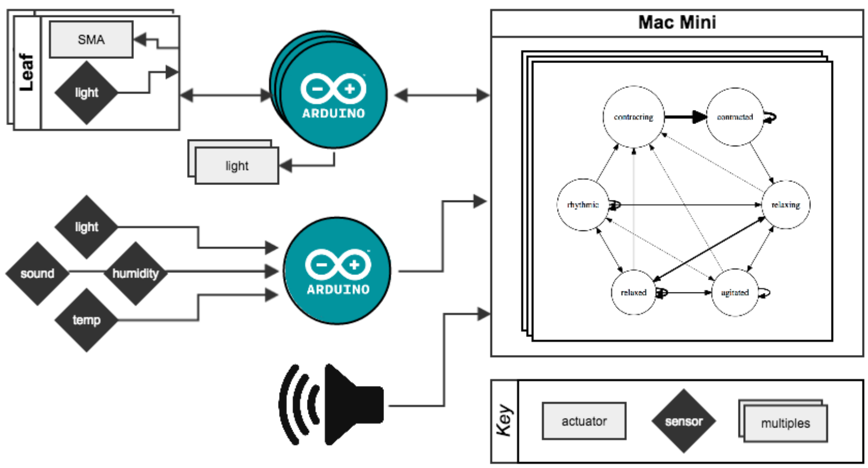

Figure 4.8: System diagram for *Subtle Emergences*, showing the interactions between the various components. One set of Arduino microcontrollers are connected to leaves and lights, and the other Arduino is connected to a set of global sensors. The Arduino microcontrollers connect to the Mac Pro that runs the exhibition and transmit sensor information and receive control signals to drive the show.

(a) Workshop participants experiment with different materials in relation to the leaves.

(b) We experimented with physically connecting leaves to visualize their relationships with each other.

Figure 4.9: Critical making workshop in the CCT.

experimented with augmenting the leaves with different materials and with various ways of physicalizing the relationships between the leaves. One leaf gained a companion, as proposed by Kristin. The companion was in the form of a hanging conical shape with protruding copper wire filaments, looking something like a strange upside-down paper and copper lily. The addition changed the sculpture's upward motion into a longing reach as the tip of the leaf stretched toward the copper filaments but never quite made contact.

The workshop was an incredibly useful and interesting process and a lot of good ideas came out of it (Figure 4.10). I was especially interested in finding companions for some of the rest of the leaves to create more explicit relationships between objects. However, with the workshop happening so close to the actual installation, I didn't have the time or mental space to really explore the possibilities for each of the leaves[34]. I ended up re-crafting the hanging conical companion to the white leaf and using that in the show. I also adopted the hanging fabric on the blue leaf that seemed to give the leaf more presence and vitality and amplified its motion when it moved.

4.2 Installation

I got into the gallery a week before the show opened. The first thing I did was to begin to envision the macro composition of the space. Where would the temporary wall go? How could I position the leaves to create pathways for people to move about the space? What configurations would make use of the centre of the room and employ the walls and floor as shadow projection surfaces? How could the vertical spread of the leaves use all of the elevation from floor to ceiling?

I began by positioning the wall to face the entrance and create a space that was not immediately visible upon entry to the gallery. I wanted to break up the room, but I also needed to block some of the ambient light coming in from the hallways as it is difficult to create a light-based composition with

[34]That is an interesting approach that I am excited to use in the future to keep pushing the work forward.

Figure 4.10: Ideas from the critical making workshop that ended up in the installation. The conical companion to the white leaf and the hanging fabric from the blue leaf were both designed by workshop participants as we experimented with materials in the CCT.

shifting ambient lighting[35].

Next, my focus shifted to the placement of the leaves. In previous installations, I had simply hung the leaves from the copper wire that powered them, but with the number of leaves in this installation, I decided to hang the leaves from fishing line first in order to get a feel for the space, before cutting lengths of wire. This was a good idea, in part because I ended up hanging, removing, and re-hanging some of the leaves a number of times as I explored the space — and as people came into the space and gave me feedback on the layout. However, it was also useful because I ended up leaving the fishing line in place even after the copper wires were attached. I realized, after wiring the first leaf into its electronic control system, that using the fishing line as support allowed the copper wire — the visible element in the hanging system — to float freely off of the leaves instead of hanging taut. This made

[35]I suppose that I could have considered the ambient lighting to be a feature of the space's environment that I should work with as part of the complex nature of the installation, but practicality dictated that I only had so much time to get the show ready and this was a variable that I could control rather easily. In future installations of the work, I would be interested to explore how I could incorporate existing natural and artificial lighting into the work.

the leaves appear to be floating in the space, and allowed the copper wire to appear more as a branch or root structure than as a supporting wire.

The shift may seem minor, but I think it really contributed to the overall visual aesthetic of the space. The story illustrates the importance of an openness to the unexpected in the design process and not being too rigid with a plan. Approaching the installation process and being open to new methods was key in creating the sort of feel that I was looking for.

It is important to acknowledge that the installation was a communal process. I directed the process and did much of the work, but I had help and input from many people, in keeping with the ethos of communal crafting and DIY practices. Emily was integral in helping to prepare the final leaves for hanging; Jeannette and Kristin assisted with a wide range of the construction and installation work and, along with members of my committee, provided helpful outside eyes on the composition of the space; and Jeannette once again brought her family into the process with her daughter Eva Rae helping with some of the installation work.

4.3 Subtle Emergences

> You walk through the glass panelled doors at the Alternator Centre for Contemporary Art in Kelowna, BC. The air is cool and dry and there is a faint sound, like a jackhammer on aluminum sheeting, coming from somewhere to your left. As your eyes adjust to the dim space behind the wall jutting out from the right side of the room, lights slowly come up on an eggshell white form suspended from the ceiling. You approach the form and take notice of the copper wires running out from the top, up to the ceiling, flowing back and forth across the invisible rafters, draping down and then back up again. The wire comes to a point atop the jutting wall, where it meets with dozens of other wires, each tracing its way back across the space.
>
> Back to the white form. The straight, narrow top of the structure splits at the bottom into two curling appendages that resemble

> conjoined snow peas. You hesitate — Am I allowed to touch the art? — but then feel the white fabric, noticing the irregularity of the fibres that comprise the fabric's face. As your fingers linger on the cloth, you sense a certain warmth emanating from its edges. You pull your hand away; the fabric is moving.
>
> The motion is a slow rise and fall, which you match unconsciously with your breath. A flash of light in your right eye draws your attention. You leave the snow peas and move to explore the side of the room as the light fades on the white sculpture...

Subtle Emergences (Figure 4.11) is best viewed for long, focused periods of time; but then, if you could experience complexity in single-serve, that would somehow seem too easy. Complexity itself is such a nebulous concept that it is difficult to imagine what it looks like as an experience, but I think that *Subtle Emergences* makes an approach.

What is happening in the space is not immediately obvious for most people. Many will see the changes in lighting — those shifts are more obvious — but if people fail to examine the space with a certain patience, they often miss the motion of the leaves. That is okay. The motion is a language that takes time to learn in order to be able to converse with it. It exists at a different perceptual scale than the changing lights, as does the sound coming from the copper sculptures. Delving beyond the obvious dynamics of the space is not an easy experience in a world where our attention is balanced on a knife-edge.

Part of the challenge of engaging with *Subtle Emergences* is its openness. We have, in many ways, forgotten how to explore. There are no buttons to press, no instructions for how to use it, and no obvious mappings to our past experiences of technology (Norman, 1988; Campbell, 2000; Bown et al., 2014). How do we relate to this space? If people arrive at that question, then they have begun to poke and prod at the notion of complexity.

McCormack and Dorin (2001, 11) say that to achieve emergence in an artwork, "engagement with the computer needs to suggest that the work is more than its design intended it to be — it must be informationally open." This can be done "through interaction (a feedback loop) with the work in real-time, where continuous re-assessment of the work suggests (for example) dynamics beyond the physical or virtual elements that compose the work". The feedback loops in *Subtle Emergences* are open, delayed, and partially hidden from the view of the participant. The openness is because, for example, a change in light bulb that is shining on a particular leaf will result in a change in how much light the leaf senses and therefore how it will behave. But changes in the light could also be due to the time of day, the shadows cast by people moving in the space, or someone shining their cell phone LED at the leaf. Even as the light changes, it merely changes the likelihood of different behaviours, the behaviour *profile* if you will, and so we are not guaranteed to perceive a particular response. In this way, there is an openness to the interpretation of the behaviours and relationships.

People[36] can — and did — find relationships between the various elements of the space that are not explicitly written into the code, at least not the way they described them. One visitor was seen tugging at one of the leaves during the opening reception. Concerned that they were going to pull the leaf down, somebody went up to them and asked politely that they be more gentle with the artwork. The visitor replied that they were just trying to get the leaf "to work" and the previous day, it had only started working when it was pulled on.

In a way, this anecdote is maybe the most interesting response to me. In part, I expect that this sort of idea arises from the knowledge that this is clearly a technological system and that's the sort of interactivity that we have come to expect from technology. But it also illustrates how crucial it is that we really engage thoroughly with a system when we want to use experience as a way of knowing and collaborating with it.

We can't simply use the language of experience as a shorthand for dispensing with an empirical understanding of complex systems. They must go together. One of the most satisfying conversations I had at the opening was with a professor studying complex environmental systems, who told me that they thought it would be interesting to do a scientific analysis of the

[36]Myself included, when I spent a lot of time with the installation while I was filming.

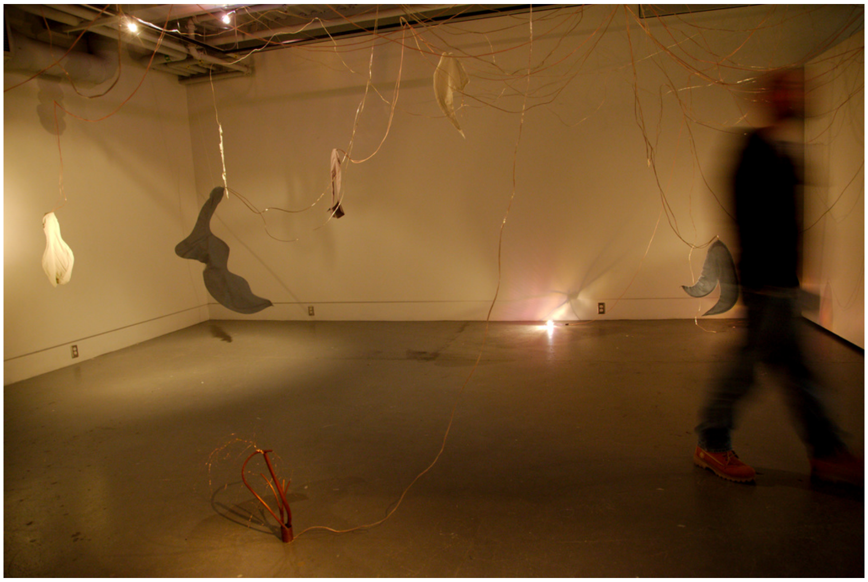

Figure 4.11: *Subtle Emergences* installed at the Alternator Centre for Contemporary Art

behaviours of the various elements in *Subtle Emergences*. It was satisfying precisely because it demonstrated the different ways that we can go about understanding a complex system, and reinforced the importance of being open to as many ways of knowing as possible.

Returning to the notion of openness, one of the things I took care to ensure was I was leaving the forms in the show open to interpretation. While the initial leaves were clearly that — leaves of trees — I made a concerted effort to evolve from the visual language of plants with the later additions to the show[37]. The goal in my design — which was also the goal that I gave to Emily when she did new designs — was to use the initial structure as a base and to move towards something that you might think you could find in a forest, but haven't.

Speaking to visitors during the show revealed the diversity of impressions

[37]I refer to them as leaves throughout this text because that is how I initially envisioned them, and they still retain a vestigial leafiness. However, that language shouldn't close off the space of possibility for what they might be. And in fact, it didn't for many viewers of the work.

of what the forms in the gallery environment represented: the inside of a human body complete with different organs; an underground system with roots stemming from a tree and connecting to various animals and fungi[38]; various animals and animal parts; and an ecosystem of plants.

The variety of interpretation is, to me, an indicator of the success of the visual vocabulary of the work. What is interesting — and intentional — is that all of those interpretations, while varied, belong in the realm of biology. While experiencing this clearly technologically-driven system, people were drawn out of the language of machines, robotics, and cybernetics and into a space of complex biological and ecological systems. A part of creating that experience was the decision to hide the electronics. In the same way that our skin hides our internal organs, the leaves' fabric hides their electronic and acrylic guts. The computer and control circuits were tucked away atop the temporary wall that divided the gallery space.

This hiding, masquerading, was done with an attention to the experience of participants in the space and was part of the designed experience of the gallery. Elements that remained visible, such as the wires, were used as visual elements, incorporated into the visual design of the space to amplify the sense of complexity and interconnection. I have often found that, when electronic artwork lays bare its electronics, the artwork becomes about the gadgetry, the technical mastery of the electronic form, and the 'how it works' as opposed to the 'why it does what it does'. The mechanisms are a distraction, easily drawing us into the consumer world of gadgets, especially in a when the work is so focused on subtlety.

Subtlety is a key focus of the work and a central part of creating the aesthetic of complexity that I was seeking with *Subtle Emergences*. If a complex approach to the world requires us to examine systems closely and beyond their surface, a subtle ecosystem invites that type of scrutiny. In order to fully appreciate the work, one has to inspect it, delve into its motion and stillness, approach it, and inquire as to its motivations.

In this, I take the opposite approach to Glynn (2008b) in his installation

[38]There was a contingent of mycologists — biologists who study fungi and fungal networks — at the opening so this one may have come from them.

Performative Ecologies[39]. Glynn's work consists of multicoloured lit rods that hang from the ceiling of the gallery and twist and turn in order to "attract people within the gallery but also out on the street, almost beckoning them to come inside" (Glynn, 2008a). *Subtle Emergences* is expressly non-performative. The leaves and lights respond to people, but they are also perfectly satisfied to remain unobserved and undisturbed.

That behaviour — that indifference — is meant to evoke sense that the system, like the ecosystems we inhabit, is not there *for* us, per se. It is there, as are we. We can engage deeply with it, and if we do, then we get something out of the experience. We are a part of the system, but not necessarily an integral part. We affect it and we know this, but we don't quite understand how. But if we want to understand it, even a little better, then we need to engage with it in all of its complexity.

[39] http://www.ruairiglynn.co.uk/portfolio/performative-ecologies/

Chapter 5

(W)holes

> *As human beings, one of the major problems we face is that we do not see ourselves as complex systems or as parts of even greater complex systems. We reduce ourselves to isolated individual "things" with no real connection to anything else. From that point of view, we can give the finger to someone else, dump toxic waste into the environment, over-fish a lake or ocean, and bomb other cultures without seeing the consequences for the well-being of ourselves, of others, and of the very environments of which we are a part.*
>
> (Bloom, 2014)

We are complex beings, living in complex societies, in complex ecosystems, on a complex planet. In order to make sense of our world, to find the patterns that allow us to plan and predict, we simplify. We ignore outliers, linearize trajectories, and bound our analyses to include only what is certain. We do this because it works. It has given us steam engines and skyscrapers, telegraphs and Teslas.

But in a complex world, everything is connected. Simplifying has given us ecosystems as an afterthought, an externality in an economic model. And it has given us the false confidence that there are simple solutions and that we just need to start fixing.

Subtle Emergences is the beginning of an exploration of those connections and the complexity that arises from them. It is incomplete and requires further synthesis. It is engaging, but could be more immersive. Its features are intriguing from a distance, but could be more complex at a smaller scale. Its sounds draw attention, but could envelop a person in the space.

The lesson of *Subtle Emergences*, the lesson of complexity, is that there are no simple answers. There is no magic bean or magic bullet. If we want to truly understand complexity and complex systems, we cannot limit ourselves to one way of knowing. We must explore them all. We need to study the parts of the system and we need to study the relationships between the parts. We need to use our analysis of the data together with our sensory experiences.

And then, after we apply different methods, engage different senses, synthesize different models, we will still not fully know the system. New patterns will emerge that we did not expect, did not predict, and do not fully understand. And we must be prepared to change what we know.

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