The Irresistible Animacy

of Lively Artefacts

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I, Ruairi Padraig Glynn confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Figure 1. Test install of Fearful Symmetry installation in a Tottenham Warehouse, July 2012

Acknowledgements

Figure 2. Fearful Symmetry at the Tate Modern in August 2012.

Abstract

This thesis explores the perception of 'liveliness', or 'animacy', in robotically driven artefacts. This perception is irresistible, pervasive, aesthetically potent and poorly understood. I argue that the Cartesian rationalist tendencies of robotic and artificial intelligence research cultures, and associated cognitivist theories of mind, fail to acknowledge the perceptual and instinctual emotional affects that lively artefacts elicit. The thesis examines how we see artefacts with particular qualities of motion to be alive, and asks what notions of cognition can explain these perceptions.

'Irresistible Animacy' is our human tendency to be drawn to the primitive and strangely thrilling nature of experiencing lively artefacts. I have two research methodologies; one is interdisciplinary scholarship and the other is my artistic practice of building lively artefacts. I have developed an approach that draws on first-order cybernetics' central animating principle of feedback-control, and second-order cybernetics' concerns with cognition. The foundations of this approach are based upon practices of machine making to embody and perform animate behaviour, both as scientific and artistic pursuits. These have inspired *embodied, embedded, enactive, and extended* notions of cognition.

I have developed an understanding using a theoretical framework, drawing upon literature on visual perception, behavioural and social psychology, puppetry, animation, cybernetics, robotics, interaction and aesthetics. I take as a starting point, the understanding that the visual cortex of the vertebrate eye includes active feature-detection for animate agents in our environment, and actively constructs the causal and social structure of this environment. I suggest perceptual ambiguity is at the centre of all animated art forms. Ambiguity encourages natural curiosity and interactive participation. It also elicits complex visceral qualities of presence and the uncanny. In the making of my own Lively Artefacts, I demonstrate a series of different approaches including the use of abstraction, artificial life algorithms, and reactive techniques.

Impact Statement

Imbued with an autonomy of its own, the material of the built environment is increasingly being 'brought to life' by robotics. Over a decade of artistic exploration using robotics as a medium has led me to conclude that there is a lack of understanding of the aesthetic quality of animate behaviour. Understanding why perceptions of life are so irresistible, both in the sense of being uncontrollable and aesthetically enchanting, challenges the rationalist orthodoxy of engineering approaches to robotic design. Scholarly anxiety about the naïvety of these sensations has probably deterred many, particularly from fields of research with an aversion for the irrational. Without accepting such sensations, these research cultures are excluded from a deeper understanding of interaction relationships, and from exploring the full richness of this design space.

This thesis renews attention to cybernetics as an interdisciplinary field able to take on challenging questions that span the design of behaviour and the study of cognitive experience. The lively agency of early cybernetic artefacts pioneered by Norbert Weiner, Ross Ashby and William Grey Walter, not only represented a revolution in the design of intelligent machine behaviour, but also shaped a philosophy of bottom up, situated and self-organising cognition that resisted the Cartesian philosophies of cognitivism. Cyberneticians also pioneered the aesthetic potency of artefacts imbued with a lively agency of their own, as seen in the artwork of Gordon Pask's *Musicolour* and *Colloquy of Mobiles* installations, and Edward Ihnatowicz's robotic sculpture *The Senster*.

This thesis synthesises a neo-cybernetic approach to aesthetics drawing upon the 'bottom-up' attitude of the field, using a theoretical framework informed by literature on visual perception, behavioural and social psychology, puppetry, animation, cybernetics, robotics, and interaction design. This thesis can be seen as a contribution to an aesthetic of animate behaviour and towards a broader theory of aesthetics of behaviour, that I and other scholars[1] have argued is currently missing and needed.

This thesis is intended to provide designers working in this area with the theoretical tools and concepts to further their practice. It also provides practical techniques for achieving animate behaviour in artefacts using robotics. I have interwoven two research methodologies; interdisciplinary scholarship of the perception of animacy, and the complementary artistic practice of building Lively Artefacts. This artistic practice has resulted in installations, at the Centre Pompidou, Paris, Itau Cultural Gallery, Sao Paulo and a commissioned solo exhibition at The Tanks, at the Tate Modern in London.

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1. Introduction

1.1 Pervasive Animation

Motivation

In his 1976 book *Soft Architecture Machines*[2], Nicholas Negroponte speculates on the possibility of buildings able to achieve a variety of uses, achieved through kinetic transformation. These spaces, he suggests, might learn about occupant behaviour and start adapting their responsive actions accordingly. Negroponte goes as far as to speculate that such forms of intelligence might take on a personality of their own, suggesting they "might giggle at a funny gesture or be reluctant to be transformed into something else"[3]. This might be surprising comment, considered rather trivial and undesirable behaviour, to those interested in the cold logic of computational control. However, as machine makers, Negroponte and his team at MIT invariably had moments where their robotic experiments moved surprisingly or shook uncontrollably, whether it was because of a short circuit, poorly aligned mechanical bearing, or loose poor signal connector. One wonders whether it was in those moments of erratic machine behaviour that the human tendency to empathise with motion cues might have inspired Negroponte's tantalising speculations of architectural agency with a personality.

Negroponte acknowledges that such questions of giggling buildings leave researchers reluctant, perhaps nervous of the academic seriousness of such perceptions, yet he argues, "I strongly believe that it is very important to play with these ideas scientifically and explore applications of machine intelligence that totter between being unimaginably oppressive and unbelievably exciting"[4].

The possibilities of an increasingly animate architecture remain exciting, and the fears are perhaps ever-more present in our minds, with regular examples in the press of the unintended consequences of artificial intelligence. In his book *Why Things Bite Back*, Edward Tenner calls this the "the revenge of unintended consequences"[5], illustrating how the agency of the machines we've invented come to possess a sense of emotional motivation in their autonomy.

Extraordinary progress in driverless cars, autonomous flying vehicles and a proliferation of other forms of mobile and embedded robotics are poised to enter and cohabit our built environment. Today at the Bartlett School of Architecture, where I have pursued this thesis,

there are over a dozen robotic arms, countless MakerBots, and abundance of experimental machines being built. As robotics become part of the designer's tool kit, our typical aesthetic considerations expand to encompass growing questions about the aesthetics of behaviour. Increasingly active, responsive and kinetic, the material of our built environment is being animated, imbued with an autonomy of its own, that holds strange and compelling qualities of 'life'.

I am interested in understanding the perception of animacy or liveliness in robotically driven objects and spaces because I find this phenomenal quality to be aesthetically potent and pervasive. I've had the opportunity over the past decade, with colleagues and students at the Bartlett, to explore a broad behavioural field of aesthetic possibilities with robotics. From that experience I can say, with certainty, that animacy has been the most common quality of the behavioural artefacts we have built. This quality is often an unintended by-product of other functional and aesthetic goals, but one that usually brings some pleasing contribution to a project. In my early work, the quality of animacy was a happy accident, but now it is at the heart of my aesthetic explorations in performance and interaction.

However, I have been surprised to find minimal literature on the aesthetics of animacy in discourses on behavioural art forms. For example, in Katja Kwastek's 2013 book *Aesthetics of Interaction in Digital Art*[6] for MIT Press, her "art-historical perspective" claims to provide "theoretical and methodological tools for understanding and analysing digital art", yet makes no mention of animacy in interactive art. These omissions are not uncommon as seeing things as alive, that are not rationally alive, is often considered a childlike or primitive observation, not worthy of discussion or deeper study. Even in literature on the aesthetics of puppetry and animation, we find stylistic or socio-political discourses are more often the topic of scholarly study, circumventing the ambiguous core experience of non-living artefacts having an Irresistible Animacy. The robotics community tends to discuss aesthetics in limited terms of physical appearance, without acknowledging that movement has primacy in our experience of their Lively Artefacts.

The motivation of this thesis is to better understand the quality of animacy or liveliness found in the behavioural artefacts I have produced, and in the work of other artists. To deepen my understanding, I have built new works and developed novel approaches to creating aesthetic experiences of, what I like to call, Lively Artefacts.

Problem Statement and Research Questions

Successful art can inspire visceral emotional responses within us that draw our attention to our senses. The arts, one might say, are a reminder of the continuity between our physical and psychological experience of our world. There are those, however, who disregard the embodied nature of these encounters, wishing to discuss art as a strictly intellectual pursuit, just as there are those who discuss the interaction of human beings and machines as solely a process of mental reasoning. Cartesian notions of cognition as rational and independent of the body and environment, are untenable, yet the Cartesian cultural force of computing and aligned Computational Theories of Mind (CTM) persist, and heavily influence the way in which we discuss human cognition and aesthetic experience.

Computational Theories of Mind commit what John Dewey has described as 'The Philosopher's Fallacy', where the intellectualised reading of experience provides a disembodied and narrowly rational account of cognition, that is irreconcilable with contemporary cognitive science. Across computationally intensive disciplines, such as human-computer interaction (HCI) and human-robot interaction (HRI), the reliance on CTM explanations limit the ability for designers to better understand and design for interaction experiences. Alternative 'post-cognitivist' theories of cognition now offer *embodied, embedded, enactive and extended* (4E) understandings of how we performatively construct our experience of our world, through continuous and situated interaction. Recent attempts have been made to address the cognitive gap in relation to behavioural art forms, with Nathaniel Stern's 2013 book *Interactive Art and Embodiment: The Implicit Body as Performance* [7] describing the unfolding of meaning from the body, in response to worlds sensations, concepts and matters enfolding in. Simon Penny's new book *Making Sense: Cognition, Computing, Art, and Embodiment* [8] critiques Cartesian computational models of cognition as "inadequate for addressing performative practices", arguing that embodied and situated approaches open up new understandings of the experience of interactive art, and media arts more generally. Penny argues that a "radically interdisciplinary approach" is needed, developing his performative aesthetics of behaviour, drawing on philosophy, critical theory, biology, psychology, neuroscience, cognitive science, artificial intelligence and cybernetics. Penny himself acknowledges that he lays out the "rudiments" rather than a completed aesthetic theory, describing it as a step "Towards an Aesthetics of Behaviour". This is a large and complex project because of the heterogeneous nature of behavioural media, the heterogeneous nature of contributing disciplines and the challenges it creates in synthesising disciplinary knowledge, expertise and technologies.
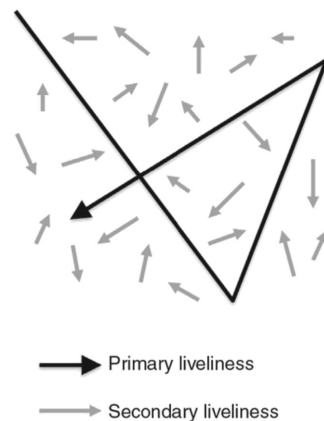
Figure 3. Kenny Chow's representation of the relation between primary and secondary liveliness [9]

As a contribution towards an 'Aesthetics of Behaviour', this thesis examines the critical sub-domain of animate behaviour, limiting itself to the visual perception of animacy, drawing on some of the aforementioned disciplines that Penny applies, and extends into puppetry, animation and visual perceptual science. The thesis further limits itself to exploring the aesthetics of individual agents and does not extend into aesthetics that can emerge from the interaction of many agents, seen in flocking and dancing. Digital media scholar Kenny Chow distinguishes these as primary and secondary orders of animacy. He makes a point of not giving prominence to either. In his words, "They represent the two 'sides' of the same coin" [10]. After all, the agency of a single bird may exhibit primary animacy, and the flock of birds exhibit secondary animacy. Chow suggests that instead of discussing animacy and animation, the term 'liveliness' helps to focus attention on perceptual and experiential qualities, without association to particular materials, media, or contexts. As the thesis title demonstrates, I use both terms interchangeably, though I acknowledge that I find 'liveliness' suggests more of a qualitative gradient than animacy, which has binary connotations.

This thesis asks the following three questions:

1. How do we perceive life in moving human artefacts, and are there notions of cognition that explain these perceptions?

2. Why are perceptions of life so irresistible, both in the sense of being uncontrollable, and aesthetically enchanting?

3. How might one go about making objects that are perceived as animate?

A Neo-Cybernetic Approach

In the context of radical interdisciplinarity and the study of behaviour, cybernetics offers a systemic approach to studying the control and communication of animals and machines[11], with a means to compare and contrast behaviour – natural and synthetic. Its contributions to the development of fields of robotics, neuroscience, psychology, ecology, the social sciences and cognition, are well documented. As I will discuss, it also holds a particularly important place in the history of machine making, and behavioural art. Cybernetics was also the progenitor of today's interdisciplinary field of artificial life (ALife), which features two distinct communities, Hard ALife following truly Promethean pursuits of making synthetic life and Soft ALife mimicking animate behaviours without making any claims of making life. This thesis would therefore fit into the softer approach to mimetic, comparative approaches first established in cybernetic research.

Though cybernetics today exists somewhat on the fringes as an "anti-disciplinary" provocateur, promoting a broad spectrum of theoretical and technical synergies, it appears to be making a resurgence in popularity. Joi Ito, Director of MIT's Media Lab, launched their new journal *Design and Science* in 2016, saying in his introduction, "In many ways, the cybernetics movement is a model for what we are trying to do — allowing a convergence of new technologies to create a new movement that cuts across the disciplines". Citing Ranulph Glanville, he says if "cybernetics is the theory, design is the action" [12].

Humberto Maturana described cybernetics as "The Art and Science of Human Understanding"[13], the distinction between art and science, defined as acting with intuition on the one hand and acting with practical know-how on the other. Returning to the metaphor of the steersman he explains how "the skipper acts both as a scientist and as an artist." Cybernetics as a foundation for this thesis has been useful in a number of distinct ways.

- It provides precise and thoroughly discussed definitions and relationships between the key concepts of behaviour, including control and adaption, agents and environments, observers and systems.

- It can be discussed as lower and higher orders of description – on the one hand narrow objective descriptions and on the other subjective description, acknowledging the role of the observer.

- Its original insights into the embodied nature of cognition, provided essential ground work for contemporary theories of Autopoiesis, and related Enactive and Performative Aesthetics.

- A number of cyberneticians have explored its performative and aesthetic potential in gallery contexts, including Gordon Pask, Nicolas Schöffer, Roy Ascott, and Ranulph Glanville.

- The cybernetic principle of self-organisation from circular feedback mechanisms, and the complex behaviour that emerges from it, offer systemic views of both the nature of cognition and life.

Now, I certainly do not intend to contribute to the thorny debate of what constitutes life. I only assert the importance of the cybernetic principle of self-organisation from feedback control, an idea that may eventually prove to be more essential to understanding life than that DNA. In his 2014 book *Life Unfolding[14]*, Jamie Davies describes two current views of life. The first is the gene-centred model, where variety comes from a "gene for this" and a "gene for that" acting deterministically to construct cells, bodies, or features of behaviour. The second model is loop-centred describing cells, bodies and ecosystems constructing themselves adaptively in concert with their environment. Davies makes the assertion that "Beyond Earth, life without DNA is just about thinkable (one can imagine alternative strategies for storing information). Life without feedback loops, though? I have never met any biologist who can imagine that" [15]. A number of theoreticians, such as Robert Rosen[16] and Fritjof Capra [17] who have developed systemic views of life that are fundamentally cybernetic.

The cybernetic abstraction of living systems into feedback loops and adaptive self-organisation allows new perspectives on the relationships between subcellular assemblies, right up to the co-operating interactions of species in ecosystems. In the field's early use of electro-mechanical machines, life-like behaviour would phenomenally emerge from primitive feedback mechanisms. Take, for example, William Grey Walter's robotic 'tortoises', *Elmer* and *Elsie* (1948-9) [18], who were an instant phenomenon appearing at the Festival of Britain and garnering international press attention. The tortoises fame was not due to any technological sophistication. By the engineering standards of the day, these machines were electro-mechanically primitive, assembled out of war-surplus items and bits of old alarm clocks. Wielding Occam's razor, Walter had built his robots with the simplest of stimulus-response mechanisms, yet when placed into their environment, they moved with a complex and enchanting sense of animacy. Their audiences perceived them as seemingly alive, regardless of their crude metallic appearance.

It is striking that observers were so easily compelled to see life in these primitive machines and that these perceptions viewed today by audiences familiar with robotics remain irresistible. Studies of how we visually perceive and distinguish between animate and

inanimate behaviour have revealed fast stimulus-response reflexes to animacy, forming the foundations of our social perception of the world. Their automatic nature offers a psychophysical perspective on why - against higher-order cognitive processes of logical reasoning – we perceive such strong impression of life in robots. I call this almost inescapable perception of life in machines, 'Irresistible Animacy' – a feature of human psychology that when carefully manipulated, as puppeteers do, can stimulate visceral and aesthetic experiences. Irresistible is therefore used both to point to the automatic, reflexive nature of primitive animacy perceptions, and to my observation that these can be aesthetically potent.

One can look at the stimulus-response mechanisms of Grey Walter's tortoises, or comparable studies in neuroethology and the growing body of psychophysical research around perception of animacy and recognise that there is a compelling case that animate behaviour must be understood to be built upon primitive reflexes. Life appears to emerge bottom-up both behaviourally and perceptually. This view is contrary, however, to the prevailing dogmas of contemporary robotic research, that approach design and analysis of experience from the top-down based on reductive rational models. In fields, such as human-robotic interaction and social robotic research, anthropomorphic approaches – formal and behavioural – supported by the rational aesthetics of Computational Theory of Mind, are pervasive. Herein lies a critical schism in philosophies to design and aesthetics, between bottom-up cybernetic and top-down Cartesian thinking.

In some ways the schism is comparable to that between the behaviourist and anthropomorphic approaches to animal psychology at the turn of the 20th century.

> *"In no case may we interpret an action as the outcome of the exercise of a higher psychical faculty, if it can be interpreted as the outcome of one which stands lower in the psychological scale."*[19] *(Morgan, 1894)*

Morgan argued that, all too often, animal behaviour was explained in terms of human mental processes when there was no scientific basis for such anecdotal descriptions. The infamous Morgan's Cannon[20], as it came to be known, reversed anthropomorphic rationalism in what has been described as an application of Occam's razor to animal psychology. This principle supported the development of 'Behaviourist' approaches, not only to animal but also human psychology, developing the argument that behaviour, no matter how complex, can be

reduced to a simple stimulus-response mechanism. Behaviourism in turn helped shape a variety of fields, including the formation of neuroscience and cybernetics. Grey Walter, for example, built an electrical learning circuit for his tortoise named CORA ('Conditioned Reflex Analogue'), inspired by behaviourist forefather Ivan Pavlov.

With an analogous critique to Morgan's Cannon, I strongly believe the field of robotics all too quickly turns to anthropomorphism. This is a critique shared and well-argued by leading roboticists, such as Rodney Brooks, Hod Lipson and Rolf Pfeiffer. Their critiques, however, are limited to matters of designing behaviour and do not address the human observer's experience. A contemporary cybernetic approach I will illustrate must integrally consider the observer, and that these experiences can be aesthetic.

Due to the pervasive anthropomorphist rationalism of robotics, aesthetic experience is all too often considered through the complimentary rational cognitivist framework of Theory of Mind, otherwise referred to as Computational Theory of Mind (CTM). As I have just touched upon, our experience is not entirely rational, and is influenced by reflexes that structure the foundations of our social cognition and behaviour.

I wish to argue that CTM does not give us a satisfactorily complete theory of these experiences, just as strictly rational approaches to aesthetic appreciation of art fail to recognise the embodied and layered complexity of cognitive processes. As the worlds of robotics, art and architecture increasingly intersect, the aesthetic opportunities for new synthetic forms of animate behaviour are set to flourish in our built environment. Cybernetics, I believe, holds an important role in framing this discourse and resisting reductive Cartesian dogmas. As I will discuss in chapter 2, the cyberneticians Grey Walter, Ross Ashby and Gordon Pask, demonstrate that the making of performative machines, as embodiments of circular feedback mechanisms, encourages a view of interaction as continuous, adaptive, embodied and situated. I have interwoven two research methodologies throughout this thesis; one is based in academic scholarship and the other in the building of my own performative artefacts, that have been exhibited in public gallery contexts internationally.

My review of various disciplinary perspectives on Lively Artefacts has led me to draw most heavily on cybernetic machine makers, puppeteers, pioneers of animation and computer agents, and robotics artists to construct a theoretical framework grounded in practice. This thesis has given me the opportunity to personally reflect on my own relationship between practice and theory and reinforced my belief in the old engineering adage that the difference between theory and practice is greater in practice than in theory. I acknowledge in focusing on makers of Lively Artefacts, I have omitted some contemporary theoretical frameworks

coming from philosophy, namely Actor Network Theory, and the later Agential Realism, Speculative Realism and Object Orientated discourses that have emerged in the past decade. These later developments appear to show a shift back towards animist, panpsychist views of the material world. There are obvious connections to lively art forms I've focused on, however the contemporary theoretical discourse remains detached from practice.

Glossary

Animacy & Liveness

The phenomenal quality of things that seem alive. By contrast to distinction of living and non-living, animate and inanimate distinctions are perceptual qualities. A plant for example is living but not always perceptibly animate. By contrast Robots are not living but can seem animate. Fundamental perceptions of animacy appear to be based on motion perception rather than perception of form. Liveliness and animacy are used interchangeably. The term 'liveliness' helps to focus attention on perceptual and experiential qualities, without association to particular materials, media, or contexts. Liveliness suggests more of a qualitative gradient than animacy, which has binary connotations.

Performance, Performative, Performativity

Terms used widely and inconsistently from theatrical and fine arts, linguistics and philosophy, through to theoretical and applied sciences. This thesis discusses performance in two distinct ways. First notions of staged performance of agentic lively artefacts. This is not limited to theatrical contexts, but also encompasses gallery and public art exhibits and then out into our built environment. The second notion of performance relates to emergent behaviour of situated agents through their embodied, embedded, extended and enactive relationship to their environment. This thesis does not relate to J. L. Austin's "speech act" notions of relationships between language and action, nor Judith Butler's use of Performativity in the construction of gender. Richard Schechner's notions of ritualized performance that codify human hierarchies and other relations addresses issues of performance at societal scales and is therefore omitted.

Robotics

Robotics is an interdisciplinary field primarily situated in the intersection between computational, mechanical and electrical engineering. It encompassed the design, assembly, operation, and use of robots. The field emerged out of developments in industrial automation, advanced by Cybernetic control systems in the mid-twentieth century to build machines capable of sensing and purposefully responding to their environment through

physical motion. Mobile robotics are built to negotiate environments using a combination of sensing, information processing and actuation and will behave differently depending on input stimuli. Manufacturing robotics by contrast are often employed to perform repetitive tasks and are limited in their responsiveness to their environment. Types of sensing, actuation and information processing widely differ depending on application, and approach. Certain sub-fields of robotics research such as social robots that deal with human machine interaction also draw upon fields such of psychology. The word robot comes from R.U.R. (Rossum's Universal Robots), a 1920 play by the Czech writer Karel Čapek. The story tells of artificial workers, "roboti" being the Czech *serf labor*. These machine slaves, with human-like bodies left a lasting impression on popular conceptions of robots as humanoid, and have been reinforced particularly by Science Fiction. In reality, most robots bare little physiological resemblance to human beings. To name just a few, autonomous cars, vacuum cleaners, responsive building facades, cruise missiles, harness robotics to do a variety of tasks without taking on anthropomorphic form.

Interaction

Academic definitions of interaction are widely inconsistent. But some principle characteristics are shared in literature. Communication of two-way or multiple directions exists through media, potentially multi-sensorial. The role of the messenger and receiver can shift between interacting agents. These can be human, or machine. The feature of Interactivity grew as a buzz word quickly in the 1990's, both in popular, industry and scholarly press. This led to uncritical use of the term, with little reflection for example on difference between reactivity and interactivity. Cybernetics pioneered machines with adaptive communicative behaviours. This is early work is exemplified by Ross Ashby's Homeostat and Gordon Pask's Coloquy of Mobiles, both discuss in this thesis. Their model contrasted with master-slave models of control, popular in computing that favored one way control rather than circular feedback loops of interacting agents. Interaction, as a continuous and adaptive exchange, places interactivity between participants rather than a property of any one machine. Work presented in this thesis features both reactive and interactive modes of behaviour.

1.2 Robotic Art Installations

Contemporary robotics are the progeny of a remarkable history of theatrical automatons, from the earliest mechanical birds of Archytas, hydraulic orchestras of Al-Jazari, to the Francini Brother's kinetic grottoes, von Kempelen's Chess playing *Turk* and Vaucanson's illustrious *Canard Digérateur*. These spectacles were the wonders of their time, both

artistically and technologically. Driven, I believe, by some irresistible mimetic impulse to remake life, the great automaton artists not only produced theatrical innovations, but also built the first cogs of the industrial and computing revolutions. More profoundly, their machines shaped the intellectual discourse of their time, on the very nature of life itself. Today, questions of what distinguishes the inanimate from animate seem all the more challenged by the emergence of robotics, artificial intelligence, and synthetic biology. Robotic art is a descendent of the performing automaton of the ancients, the modern kinetic art movement and the brief but captivating cybernetic arts of the mid-twentieth century. Jack Burnham in *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century*[21] described kinetic sculpture as "the unrequited art". Robotics suffers from the same status, remaining on the periphery of the arts, though recognition is growing with major retrospectives taking place, such as at the *Artists and Robots* exhibition at Grand Palais, Paris (2018), some 50 years since Jasia Reichardt curated the *Cybernetic Serendipity*[22] exhibition at the Institute of Contemporary Art, London.

Artist Eduardo Kac argues there is no narrow definition for robotic arts, apart "perhaps, for the principle of giving precedence to behavior over form". Within robotic arts we find a widely divergent field of exploration, ranging from anthropomorphic sculptures in the work of Chico MacMurtrie, or 'Cyborgian' prosthetics of Stelarc, to the autonomous, zoomorphic agents of Ken Rinaldo and the artificial ecosystems of Philip Beesley's responsive installations. What brings these works together is no single technology, but rather purposeful behaviour that imbues an irresistible sensation of animacy. This makes them quite unlike the work of artists, such as Jean Tinguely, whose 'Meta-Mechanical' sculptures furiously perform random motion, or the mechanical automaton of Arthur Ganson, that perform pre-choreographed routines.

As robotics become pervasive features of the built environment, 'robotic art' or 'robotic architecture' may become an anachronistic term in a similar way that 'digital media' or 'digital architecture' has. However, as artificial intelligence increasingly mediates our lives and recognition grows of its rather mercurial nature, and as robotics exhibit more sophisticated behaviour, the public's interest in these new forms of agency, is growing quickly. Questions of what constitutes life, and the ethics of AI and robotics have entered public consciousness. Leading robotics artists throughout the 20th century were often pioneers in critically exploring technologies considered benign by the scientific community.

> *"The fascination robots exert on the population at large has unexplored social, political, and emotional implications. These implications must be coupled, if they are to be properly understood in the contemporary art context, with the new aesthetic dimension of modeling behavior (the artist creates not only form but the actions and reactions of the robot in response to external or internal stimuli) and developing unprecedented interactive communicative scenarios in physical or telematic spaces."* [23] *(Kac, 1997)*

As an artist myself, working with robotics, particularly with custom assembled robotics, I am continually negotiating the relationships between computational control systems and a wide range of material systems. Artists working with robotics also often hybridise technology with a variety of other media, contexts and living systems. Bill Vorn, for example, describes his robots, coupled to lighting, projection and audio outputs, as "Theatrical Machines". The landscape of behavioural art forms, be they robotic and/or other emerging media, are characterised by innovative new methodologies of production that challenge normal disciplinary boundaries between arts and sciences.

Whereas scientific research into the communicative possibilities of human robotic interaction has developed around representational schemas that have emerged from established computational models of intelligence, arts practice has circumvented the need for such frameworks, focusing instead entirely on the problem of experience, namely how to create a coherent experience for people encountering work. While scientific research is assembled upon the technological apparatus that builds up around their representational schemas, artists, free from methodological rigors draw upon the widest sources of behaviour, be they analogue or digital, physical or virtual, centralised or distributed, organic or synthetic.

This freedom affords fast, cheap, direct routes to manifesting behaviour that may be accused of taking 'short-cuts' around the 'state-of-the-art' in robotic research. But an artist's work is not subject to criticism if, in achieving an intended behaviour, it circumvents established methods or scientific theory. The work is ultimately judged on its performance –its ability to compel an audience's emotional and intellectual engagement and, in the case of interactive work, draw them into forms of extended exchange that leave lasting impressions. It finds it easier to admit the intelligence or life of its machines are illusions, unlike the engineers and scientists practicing in artificial intelligence.

However, the value of such work should not be framed as seeking aesthetic goals alone.

This experimental work can often be theoretically and technically pioneering. Take Edward Ihnatowicz's *Senster*, to robotics, or Myron Krueger's Videoplace, to computer vision. Robotics and new media artists have advanced enquiries into areas of communication and behaviour generations ahead of scientific study, just as visual artists explored the perceptual experience of abstract stimuli decades before psychophysical and cognitive researchers. Arts practice can not only can precede scientific enquiry, but also escape the inherent reductivism of lab experimentation. Concept and embodied practice are integrated together rather than making and performing, serving theorising. Artistic practice acknowledges the complexity of the environments in which interactions exist beyond spatial cues, within rich cultural spaces whether galleries, public spaces, or places of work, and wrestles with its heterogeneous nature.

> *"Innovation in the field of robotics could well come from art as well as from industrial robotics because the goals of art are not clearly defined and most intangible problems could lend themselves to its ad hoc methods. Whereas industry may find solutions to numerous finite problems through the use of multipurpose robots, it will not deal with effects, illusions or emotive principles which belong to art."* [24] *(Reichardt, 1978)*

Through built works, I have examined how a deeper understanding of the perceptual factors that determine the qualities of animacy, and endow it with emotional, visceral and aesthetic potency, can be usefully applied in design practice. It will become evident that the literature from visual perception, behavioural and social psychology, puppetry, animation, cybernetics, robotics and interaction research have all influenced the conception of the work, however, they were not the sole influences. All the works described were site-specific, responding to the time and place of their realisation. The very collaborative nature of designing and building performative machines has meant that friends and colleagues brought valuable contributions that have enhanced the work immeasurably. Some of these contributions are highly relevant in the context of this thesis and are discussed.

Others, although in some cases critical to the success of the work, are omitted. Here I provide only a limited description of the technical systems employed. I will resist the temptation to talk about the challenges faced in building the world's largest delta robot or the trials and tribulations of installing a kinetic installation within a collection of Picasso's Master Pieces.

> *"The fear of tiring you, Gentlemen, has made me pass over a*
> *great many little circumstances, which tho' easy to suppose*
> *are not so soon executed." [25] (Vaucanson, 1742)*

Successful exhibitions of the work have led to increasingly larger commissions and budgets, that have allowed me to build larger and more agile machines, and deal with the ever-greater technical complexities that inherently emerge. In stark contrast to the growing complexity of realising the installations, the visual and formal aspects of the work have become simpler – some have called it minimal.

This undoubtedly reflects a growing understanding in my practice that, from the perspective of the observer, the way things may move is far more important than the way they may appear, and that the careful mastery of motion and behaviour was enough to elicit complex and engaging responses in the public. Each project will be introduced with a summary of the context of its realisation, and an overview of physical design. Details on behaviour will be revealed in discussing the work in the context of theories I introduce in later chapters.

Performative Ecologies

Performative Ecologies is an investigation into the design of embodied interactive agents. It is made up of four autonomous attention seeking robotic 'dancers' which search out people using cameras in their 'heads' and orientate to face inhabitants and begin performing using their 'tails'. The body of each robot is assembled from 3mm thick aluminium sheet, waterjet cut into parts and slot fitted together. Each robot features two Hitec HS-805BB Servos for orientation and tail motion, two Hitec HS-422 Servos for pan and tilt directional control of the head. The tail made of Perspex acrylic rod catches light emitted from the Kingbright 525 RGB high power LEDs held at its two ends. The head has two forward facing Kingbright 568 white LEDs and a discretely hidden low light sensitive Sony Digital Pin Hole Camera. In its latest incarnation, an onboard ARM-based computer (Raspberry Pi running Linux) executes a genetic algorithm (programmed in openFrameworks 0.9.0.) and facial recognition algorithm (openCV), which send commands to an Arduino Nano microcontroller that manages head direction, body orientation and the performance of the tail's lighting and motion.

Figure 4. Performative Ecologies at the VIDA 11.0 Artificial Life Art exhibition in Madrid

Each robotic agent autonomously manages its own performances, which are generated from a computational gene pool of evolving short 'dances', the 'fitness' of each are measured by how much attention they receive from the public. An on- board camera assesses attention levels based on facial orientation of the audience before and after each short performance. Over time, successful manoeuvres are saved and recombined to produce new performances while less effective ones are discarded. When there are no people around, the robots turn to each other and teach their most successful performances to one another, negotiating new performances together. Over a wireless network the robots communicate with their neighbouring robots, occasionally exchanging data from their individual performance gene pools. If their exchanged data share similarities, then the exchanges are accepted. If they are too different they are rejected due to 'artistic differences'. *Performative Ecologies* has been exhibited at Instituto Itaú cultural in Sao Paulo, Beall Centre for Art and Technology in California, National Art Museum of China in Beijing, Kunsthaus in Graz and as part of VIDA 11.0 Artificial Life Art exhibition in Madrid.

Motive Colloquies

Commissioned by the Centre Pompidou, Paris, *Motive Colloquies* was a collaboration between the Bartlett School of Architecture and the Royal Central School of Speech and Drama, combining expertise in puppetry, performance, robotics and interaction design. The result was a responsive installation and performance held within the Pompidou's Pablo

Picasso Gallery in May 2011. The design was based on parallel robot principles. These are used extensively in the manufacturing industry, but never in a performance context before this work. The final strategy was a novel kinetic structure combining two delta robot mechanisms. A delta robot is a type of parallel robot, kinematically assembled around two equilateral triangles: a 'base' triangle and 'end-effector' triangle. The two triangles are connected by multiple kinematic chains, which together give it a range of motion while maintaining the end-effector's orientation.

Figure 5. Install of Motive Colloquies, Picasso Gallery, Centre Pompidou, Paris

Built from aluminium box and tube sections, an inverted 2m tall delta robot was developed giving the appearance of three legs which met at an elevated end- effector which became the platform to suspend a second smaller lighter delta robot whose end-effector held a folded aluminium sheet 'head'. I describe this unorthodox mechanism as a "Double Inverted Delta Robot", and is the first of its kind. The base on the ground sat on a triangular plinth where three industrial NEMA 42 worm-geared stepper motors actuated the legs. The suspended delta robot was actuated by spur-geared Hitec HS-785HB servos, and the head's pan and tilt mechanism were driven by a pair of Hitec HS-422 servos.

Sensing of inhabitants of the gallery visitors was achieved using three Microsoft Kinect Xbox 360 Sensors hidden in the base of the plinth. Together these depth sensors continually scanned the gallery and when visitors came into range they triggered a reactive 'mirroring' behaviour. This primitive reactive algorithm contrasts *Performative Ecologies* adaptive ability to interact. The complexity of *Motive Colloquies'* behaviour was a direct reflection of the complexity of the environment it was sensing.

Fearful Symmetry

Commissioned by the Tate Modern for the Cultural Olympiad that accompanied the 2012 London Olympic Games, *Fearful Symmetry* is the major piece of work synthesising the theoretical matters addressed in this thesis. The commission was a result of the success of *Motive Colloquies* at the Centre Pompidou and shares the same approach of using a delta robot. The challenge of the commission was the scale of the site. The Tate's cavernous South Tank, 32m diameter, 7m tall, was adjacent to the Tate Modern's Turbine Hall. The space had previously lain dormant for decades cloaked in darkness. In discussion with Curator Mark Miller, the idea of a 'living luminaire' was agreed upon. The installation would reveal the dramatic south tank as it moved through the gallery, interacting with the visiting public.

In form, the luminaire was a primitive tetrahedron, lit by electroluminescent sheet from Lumitec AG, and powered by a Enz Electronic EL-Inverter. The sub-structure for the electroluminescent sheet was assembled from a combination of custom 3D printed and laser-cut plastic parts, and was placed on the delta robot's end- effector. Similarly to *Motive Colloquies*, a pan and tilt mechanism using Dynamixel RX-64 servos orientated the tetrahedral luminaire.

Figure 6. Fearful Symmetry, The Tanks, Tate Modern, London

The delta robot control was managed by Maxon EPOS2 Positioning Control Units that directed three Maxon 200 Watt RE50 DC Servo Motors, and GP 62 Planetary Gearbox. Positioning feedback was provided by Maxon HEDL 5540 encoders. The triangular base of the delta robot was an aluminium and steel custom-built rig that tightly packed the motors and controllers to keep payload weight to a minimum. 5m tall when fully suspended, the assembly was as far as I'm aware, the largest delta robot at the time. Since then, a number of large scale delta robots have been built for additive manufacturing of architectural structures[26]. These however are engineered to move slowly depositing clay and other construction materials whereas *Fearful Symmetry* required a faster moving mechanism to animate the novel luminaire. Weight was minimised using carbon fibre box and tube sections and universal joints were IGUS injection moulded plastics rather than the steel variety more typically used.

The South Tank Gallery's 32m diameter also afforded us the opportunity to install a 21-metre motorised rail on the ceiling that the delta robot was suspended from. A Hepcomotion belt driven linear actuator was chosen powered by a large industrial AC Baldor Servo Motor. The linear rail greatly increased the operating range of the delta robot and variety of behaviour it could exhibit. With the exception of the Dynamixel RX-64 servos, the system ran on a CAN (Controller Area Network) 2.0 bus. The integration software was developed in Texas Instruments LabVIEW system-design platform.

An array of Kinect sensors mounted on the travelling robot built a real-time depth map of its local environment, detected the public and read their individual movements using gesture recognition algorithms. To add a further level of intensity to movement, contact microphones were placed on motors, with high pass and low pass filtering, and other acoustic processing amplifying every gesture it made. The site installation was exhibited in August 2012 and since then has proven difficult to exhibit elsewhere. A smaller tourable version without a motorised rail was exhibited in July 2017 at Instituto Itaú cultural, Sao Paulo, using a Universal Robotics UR10 robot arm as the manipulator.

Happy Accidents

There have been a multitude of small prototypes in my work that are not detailed in this thesis, but it is worth mentioning a couple early 'happy accidents' that revealed to me how 'life' can burst out of machines at the most unexpected of times. The first was a primitive 2 axis robotic armature made of acrylic. Its orientation was set by turning a pair of potentiometers that were wired to an Arduino Microcontroller that converted the analogue signals to digital pulses that steer the armature's Hitec HS805BB Servos. One afternoon in

my basement studio at the Bartlett in October 2006, having assembled the armature, I was moving it into position to film it when it suddenly began furiously swinging its arm around as if it might be trying to beat me away. I manage to pull my head back just as it flew across my face and continued swiping for a few more moments before coming to a halt when I switched off power. Fortunately, my camera captured its wild liveliness and the terrified and exhilarated look on my face, that turned to laughter a moment later. This was my first truly visceral interaction with a robot.

The source of this temperamental behaviour, fighting off molestation, was the accidental disconnection of the two potentiometer circuits to the Arduino controller. The analogue to digital converters on the Arduinos input pins, deprived of clean grounded signals read the static of the room. The chaotic nature of its movements, noisy electrical emissions from heaters, fluorescent lights, mobile phones, laptops all contributing to its personality. This was my first hint that the complexity of an environment was an incomprehensibly rich source of animate stimulus.

A few years later in November 2010, I was teaching students from the Bartlett's MSc Adaptive Architecture and Computing programme. We had built a small Delta Robot actuated again by Hitec servos, though this time the sensing was a Microsoft Kinect, a depth sensing camera that allowed for far greater sensitivity to human gesture. The assembled system allowed us to teleoperate the Delta Robot by moving a hand around in front of the sensor. The aim of the exercise was to manipulate and potentially stack a pile of small cardboard boxes within reach of the Delta Robot.

A collection of a dozen students had gathered around the robot while I user tested some code. When my hand was within the frame of view of the Kinect sensor, the motion of the Delta Robot was consistently smooth. I was in complete control, the robot was an extension of me, rather than having agency of its own. By chance, a student was filming on their phone, at just the moment I tried to pick up one of the cardboard boxes beneath the robot. As I reached in to pick up the box, the Delta Robot swung down seeming to intercept my hand and protect its pile of boxes. I pulled my hand back and froze still. A moment later the students burst into laughter. The cause of this sudden and unexpected protective behaviour was my hand disappearing outside of the sensors frame of view and it returning to its home position rapidly. The irresistible impression was that the robot had successfully deterred my predatory behaviour.

1.3 Structure

Animating Discourses

This chapter constructs a critique of Cartesian approaches to problems of life and cognition, and examines alternatives in theories of embodied, embedded, enactive, and extended 4E-cognition that I characterise as neo-cybernetic. I draw an historical arch over animated machines, recognising how the millennial pursuit to imitate life has shaped philosophical discourse between two distinct views on the nature of life and cognition. On the one hand, a Cartesian view inspired by mechanical automata and later reinforced by digital computing, and on the other, an emergent systemic view that became embodied in cybernetic machines. Two machine makers and founders of cybernetics are focused upon, Grey Walter and his robotic tortoises, and Ross Ashby and his *Homeostat*. Andrew Pickering explains in his book *The Cybernetic Brain* (2010) that "One can almost say that everyone can have their own history of cybernetics"[27] and here I attempt to make one that highlights the under-acknowledged role machines have had in shaping cybernetic thinking and, consequently, the neo-cybernetic theories of autopoiesis and contemporary 4E-cognition.

I discuss the discoveries and pitfalls of the digital computing revolution and the formulation of discrete forms of behavioural complexity that replaced their analogue electro-mechanical predecessors. I distinguish between the two by recognising that while cybernetic machines had pursued the manageably complex from the chaotically complex, in contrast, computational attempts at digital life pursued complexity from simple rules. The same contrast is made for the differences between embodied robotics approaches that, again, I would characterise as neo-cybernetic and Cartesian symbolic approaches to artificial intelligence. The chapter outlines fundamental ways to design machines with animate behaviour using primitive sensorimotor reflexes. The central idea of embodied behaviour is discussed and I also argue the importance of acknowledging the environment in co-producing the perceived intelligence of agents, whether human, animal or machine. The implication of this is that designing animate behaviour is, both in the design of an agent and in the design of the agent's environment, a strikingly architectural perspective, under-appreciated in discourse on robotics design.

I follow this by discussing Gordon Pask's work as a machine maker, performer, artist, educator and leader in the epistemological shift from first-order to second- order cybernetics, offering a performative approach to systems research and acknowledging the observer as part of the system. Pask who described himself as a "mechanic philosopher"[28] is most widely

acknowledged for developing automated teaching machines, but he also developed a variety of experimental performative systems designed to interact in a playful open-ended way with musicians and the public. I discuss his *Musicolour* installation that I consider to be the first performative machine that was truly interactive. I make a distinction between two notions of performativity, that of staged and cybernetic.

I introduce my first installation *Performative Ecologies* and describe how my adoption of neo-cybernetic approaches to lively machines has also shaped my conception of human cognition as embodied and situated. Despite understandings of intelligence as embodied being a subject of discourse back to pre-Socratic thought, and found throughout the history of philosophy, such ideas have met continuing resistance to scientific scholars whose intellect is often traded in words and algorithms, rather than in practices, such as making and performance. I conclude by examining neo-cybernetic understandings of aesthetics first from Pask's observation that we are attracted to novelty in our environment compelled to learn how to control it [29].

Life in Motion

When we enter a room, with the quickest of glances, we can tell whether there are living entities present. We are highly attuned to social perception and it is the visual detection of motion that appears to be the primary stimuli for making such judgements. Throughout the animal kingdom, distinguishing between animate and inanimate motion is critical to detecting prey, mates and predators, so our sensitivity to animacy is deep within the primitive architecture of our animal brain. Children under the age of three do not demonstrate a theory of mind, yet they are capable of recognising the difference between animate and inanimate motion, and engaging in a variety of interactions with animate agents. This would suggest – and research in the field of human visual motion perception supports – that our experience of engaging with animate entities is formed not solely by reasoned acts of anthropomorphism, but also powerfully by instinctive, emotional and automatic processes of cognition. However, these matters are sometimes overlooked because of Cartesian modes of thinking that remain dominant in certain fields, including human-robotic interaction (HRI) where design of 'intelligent' behaviour is typically structured from the top-down, through language and other forms of symbolic logic. Theories of human experience in HRI have been built primarily upon the complementary logic of Computational Theory of Mind - the idea that we 'mentalise', or construct rational mental models, of other animate entities, such as animals or robots, in order to hypothesise on their beliefs and motivations. The anthropomorphic explanation is convincing in as much as we all recognise that we enter into these mental processes

naturally when we observe and interact with others. However, such a theory of mind does not give us a satisfactorily complete theory of these experiences.

To address the gap, this chapter takes a counter approach, working bottom-up, beginning with reflexive visual processes of animacy perception that appear to be innate. The automatic nature of these percepts can partially explain how certain vocabularies of motion seem so irresistibly animate. A case study of Edward Ihnatowicz's cybernetic artwork, *Senster* demonstrates how, unknowingly, artists tune their work into these innate psychological responses. Together with a discussion about the neuro-aesthetics of Calder's mobiles, I highlight the role the arts have long played in exploring the hold on our attention and imagination animate motion has.

I identify the primary motion cues that perceptual research has discovered to date and discuss the theories of fast heuristic processing of basic behavioural typologies. Social scientists hypothesise that these may act as an innate structural skeleton for the development of more sophisticated learnt social perceptions. Jean Piaget's studies of young children's primitive distinctions between animate and inanimate objects are an early example of this hypothesis. The naïve connection between motion and life has had a profoundly vitalist impact on conceptions of our world. As American psychologist Julian Jaynes explains, for millennia, motion and life were bound together, creating a wider field of animacy that remain in certain Eastern animist philosophies, but have been largely exorcised in Western Philosophy.

> *"Motion is now the domain of physics but before the seventeenth century,*
> *motion was an all-encompassing mystery… Because [the stars] moved,*
> *the stars were thought by no less a scientist than Kepler to be animated.*
> *Motion perplexed Gilbert who became convinced that magnets had souls*
> *because of their ability to move and be moved. And Campanella in his*
> *Neapolitan prison, when he understood what Copernicus was saying, that*
> *the earth really moved, exclaimed, "Mundum esse animal, totum sentiens!"*
> *In a world so sentient and alive, motion is everywhere."* 30 (Jaynes, 1970)

Complimenting the catalogue of motion cues and behavioural heuristics established by scientific research, I will examine the art of animation, and the established principles of orthodox forms of Western character animation. I discuss Kenny Chow's notion of

'Technological Liveliness' that supports my own view that animation as a field extends out into our built environment and draw synergies with his discussion on the experience of animation being bound to our embodied knowledge of own animate behaviour.

Aesthetics

As I've established, visual perception not only constructs the physical structure of the world, but also the social and causal nature of the world. This is as under- appreciated and under-explored topic, particularly contrasted against the enthusiasm the visual arts have shown to the aesthetic potential of visual ambiguity in static paintings, sculptures and installations. The aim of this chapter is to draw a line between psychophysical understandings of animacy perception and their manipulation in arts, using insights from puppetry and robotic arts to focus on experiences 'in the flesh', whether in a theatre, a gallery exhibition or in the built environment. Notions of the uncanny as a term to describe the visceral affect of ambiguous motion perceptions of animacy in inanimate artefacts' motion, are discussed, distinguishing it from the uncanny in scientific discourse of robotics that focuses on figurative appearance. Over-laps are found between discourses in arts and sciences on the notion of bistable experiences of animate motion. I examine how the essentialist pursuits of modern puppetry and the related avant-garde conceptualisation of machine theatres, tended towards the animation of minimal abstract forms. This also resonates with the techniques employed by perceptual scientists in the decades following, creating a surprising methodological link between these very different modes of investigating animate behaviour. The chapter concludes by examining the role the arts have played in probing the aesthetic field of robotics.

Lively Artefacts

In the formulation of the thesis, a number of robotic prototypes and publicly exhibited installations have been built. This chapter describes a series of experiments synthesising ideas drawn out of artificial life, perceptual psychology, animation, robotics and puppetry. A particular focus has been made on examining how puppetry can offer alternative approaches to robotics design both mechanically and behaviourally. These works demonstrate the practical value of a deeper understanding of the perceptual factors that determine the qualities of animacy, and that endow it with emotional, visceral and aesthetic potency.

2. Animating Discourses

*"It's going to be harder to distinguish: what is alive and what is a machine…
And that boundary may start to become meaningless."* 31 (Brooks, 1997)

2.1 Introduction

At Trinity College Dublin, in 1943, to a packed audience of academics and dignitaries, including the then Taoiseach Eamon de Valera, Austrian physicist Erwin Schrödinger delivered his illustrious lecture titled *What is Life?* Taking principles of his own scientific field and placing them onto the study of cell biology, he proposed the idea of a 'code-script' with all living things holding the "entire pattern of the individual's future development and of its functioning in the mature state."[32] Within a decade Watson and Cricks confirmed his hypothesis, describing the double-helix structure of DNA – the hereditary mechanism of all biological life and the foundations of the science of genetics. In honour of Schrödinger's contribution, in 2012, Trinity College Dublin hosted another packed audience, including standing Taoiseach Enda Kenny for a follow-up lecture, again titled *What is Life?* The appetite for answers was clearly undiminished. Its speaker, American geneticist, J. Craig Venter, offered his definition.

*"All living cells that we know of on this planet are DNA software driven
biological machines comprised of hundreds of thousands of protein robots,
coded for by the DNA, that carry out precise functions."* 33 (Venter, 2012)

In May 2010 researchers at the J. Craig Venter Institute had sensationally announced to the world they had successfully constructed the "First Self- Replicating Synthetic Bacterial Cell." By substituting the genome of a host bacteria with a fully synthesised genome they had, in effect, created the first synthetic life form. To distinguish their computer programmed DNA from the original genome it was copied from, they encoded the names of the authors of the research, a website address, and for good measure, three quotes touching upon the

significance of their endeavour. "To live, to err, to fall, to triumph, to recreate life out of life" was chosen from James Joyce's, *A Portrait of the Artist of a Young Man*[34] and from *American*

Prometheus, the biography of Robert Oppenheimer, "See things not as they are, but as they might be"[35].

The third and final encoded statement "What I cannot build, I cannot understand"[36], attributed to physicist Richard Feynman, transpired to be a misquote of "What I cannot create, I do not understand." Regardless of this minor but somewhat embarrassing error, the quote touches on the underlying reason for perhaps humanity's greatest technological and philosophical project. Motivated by questions, both metaphysical and scientific, on the origins of life and consciousness – with ever greater resolution – man has mimicked the forms and behaviours of life to better understand them.

Venter's view of life is unapologetically mechanistic. His code instructions programme protein automaton, just as a roboticist may engineer a servomotor mechanism. His work, and that of his team, is the latest step in a long and extraordinary history of machine making. Of artistic and scientific enquiry that with every step has further dissolved distinctions between natural and artificial, animate and inanimate, animal and automata.

Today's notion of a machine, and terms, such as autonomy and emergence have developed in unison with technologies that shed increasing light on life itself. As theoretical physicist Werner Heisenberg recognised "What we observe is not nature itself, but nature exposed to our method of questioning"[37]. Conflicts naturally arose between the human tendency towards Vitalism and modern science's tendency towards reductive mechanism. Neither have provided entirely satisfying answers to the question of What is Life? However, the friction between the two has inspired great inventions, art, technology and thought, that continue to inspire discourse.

2.2 Machine Life
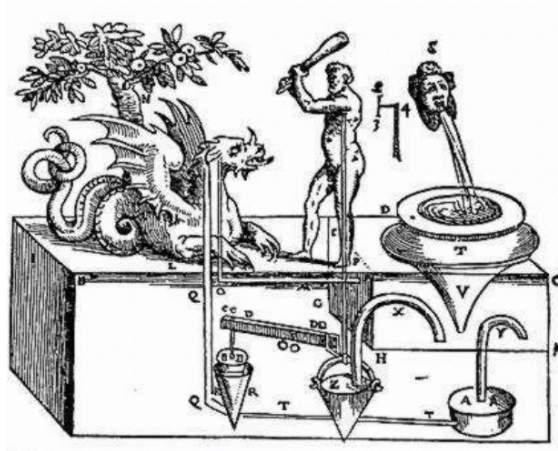
Figure 7. Heron's 'Hercules and the Dragon', illustrated by Giovanni Battista Aleoti (1589)

Automatic Life

From the legendary mythological automaton makers Daedalus and Pygmalion, to the early inventors Ctesibius (285–222 BC) and Heron (10 - 70AD), and the illustrious Ismail al-Jazari (1136–1206AD), there is a fascinating, and fragmented record of the ancient history of the human project to make life through imitation. The translation and dissemination of ancient texts in the renaissance, such as architect and stage designer Giovannie Battista Aleotti's reinterpretation of Heron's *Pneumatics* in 1589, have been instrumental in renewing interest in theatrical automaton[38]. Similarly translated in the 16th century, Marcus Vitruvius Pollio's *de Architectura* – the only treatise on architecture to survive from antiquity – featured a tenth book dedicated to mechanical devices including hoists, cranes, catapults, sundials, water clocks, and the first recorded steam engines. It also included descriptions of mechanical figures that drank and moved, alongside water organs and "other things that are found to be pleasing to the eye and the ear"[39]. Architecture and the art of machine-making have a relationship reaching back to the foundations of architectural theory, in which the aesthetic potential of animated space is acknowledged. In 1598, Florentine architect Tommaso Francini, accompanied by his brother Alessandro, arrived at the gardens of the royal chateau of Saint-Germain-en-Laye, to begin building what are considered the high point of Renaissance automata[40].

Hydraulic statues enacted mythological tales, danced, played music and even spoke in what must have been for visitors of the time, an extraordinary, perhaps even supernatural, experience. In 1614, a young man recovering from the first of several breakdowns hid himself

away in Saint-Germain for two years. So fascinated by automata, records suggest he built his own[41]. However, it was not so much what he made, but how these animated machines shaped his way of thinking that was to cause perhaps the greatest epistemological shift in the Western world, towards a way of looking at the world that exorcised science of its animist tendencies.

> *"Revolutions in thought are usually steady maturations suddenly completed. In emotional moments the gathered ideas of one mind decisively collect into a single vivid intuition. In such a moment of the year 1619 the Angel of Truth announced to the dreaming Descartes that the material world was geometrical. In that moment of insight Descartes beheld a physical world of extended things with figures and motions. The vision perpetuated a permanent conviction that the material world was a vast assemblage of figured bits of extension in motion, or with relative rest... Versions of physical nature provided by the animate model, by the analogy of the living thing, gradually waned, and then dramatically succumbed, before the mechanical philosophy of the geometric ideal."* [42] *(Gregory, 1927)*

Life was motion itself, and its truths could be found in an idealised mechanical model of the world. The influence of Descartes' division of the material and mechanical human body on one side, from thinking mind and soul on the other, presented God as the architect of a marvellous automaton. Minsoo Kang notes in *Sublime Dreams of Living Machines*[43] that Descartes, in effect, appropriated automata "conceptually wrenching them out of their original context of magical enchantment"[44] into a new age where the physical world was rationalised so that living things and their behaviour, with study, could be mechanically explained and replicated.

The dawn of the enlightenment saw automata flourish, epitomised by the artistic and scientific invention of Jacques Vaucanson, a trainee monk, born in 1709 in Grenoble, France. Vaucanson developed an interest in mechanics by making flying automaton angels. Finding his Jesuit superiors disapproving of his hobby – so much so that they destroyed his workshop – Vaucanson left the church and began a career that earned him the reputation, as Historian Silvio Bedini described it of "Unquestionably the most important inventor in the history of automata, as well as one of the most important figures in the history of machine

technology"[45]. Vaucanson first made his name with a series of life size flute playing androids, but it was the infamous *Canard Digérateur*, or *Digesting Duck* (1739), that secured his name in the history of performing machines.

The life size automaton would eat, drink, stamp its webbed feet in water and, most momentously, digest food and excrete much like a living duck might do. It was a phenomenon, touring internationally, performing to enchanted crowds and bringing Vaucanson wealth and notoriety. His interest in replicating digestion had, however, begun before his musical automata. A student of anatomy, with an interest in medicine, he had earlier tried unsuccessfully to build a working imitation of a functioning human body. His failure to have achieved this overly ambitious goal would, it seems, to have provided the necessary lessons to allow him to accomplish his comparatively simpler, but nonetheless critically acclaimed automaton.

"All the movements and attitudes of this automaton faithfully reproduce nature, copying it to the life even down to the tiniest detail, so much so that for a moment we are tempted to believe that there is a real duck before us… we have no doubt that the discoveries of this master mind will make his name immortal." [46] (Chapuis et al, 1958)

Great automata makers including Leonardo da Vinci, Wolfgang von Kempelen, James Cox, Pierre Jaquet-Droz and his son Henri-Louis, dazzled the world with performative machines, driven by ambitions to imitate life. Their automata played a theatrical role in the exorcism of Vitalist science, embodying the mechanical logic of astronomy, mathematics and physics, of Copernicus, Kepler, Galileo, Bacon, Descartes and Newton. Too often though, historical accounts of their machines portray them as merely playful curiosities. Vaucanson, for example, made improvements to machine tools decades ahead of their time, and while trying to replicate vocal cords discovered a way of making flexible tubing from Indian rubber that found countless applications in industry and medicine. Undoubtedly, it is for his invention and refinement of an automatic weaving machine erroneously attributed to Jacquard, that he deserves greatest recognition. For it was the genesis of programmable machines and the foundations of modern computing.

Cybernetic Life

When in 1780, Italian physician Luigi Aloisio Galvani discovered the muscles of dead frogs' legs jumped when stimulated by an electric charge, he was the first to identify the animating power of electricity that famously inspired Mary Shelley's Frankenstein[47]. Galvani's experiments saw a wide variety of other theories of animation loose favour, including deflating the ideas of the Balloonists, who believed muscle contraction involved fluids or gases – not a surprising theory, in the age of steam engines. By the 20th century, the making of lifelike machines would shift from pneumatic and hydraulic mechanisms towards electromechanical brains and servomechanisms, in the perennial search for ever-more lifelike forms of behaviour, and it was the new science of cybernetics that would focus most intensively on the relationships between living and lifelike machine behaviour.

"Our terrestrial world is grossly bimodal in its forms: either the forms in it are extremely simple, like the run-down clock, so that we dismiss them contemptuously, Or they are extremely complex, so that we think of them as being quite different, and say they have life." [48] *(Ashby, 1960)*

In the 1930s, psychiatrist W. Ross Ashby's studies of the underlying organisation of the nervous system led him to develop a general theory of complex regulating systems, hypothesising that a system of unorganised interacting elements, each with their own adaptive mechanisms, through circularities of stimulus exchange, could find dynamic equilibrium. His proto-cybernetic theory accounted not only for the effects of stimulus within a system, but also for the added complexity of unpredictable external environmental stimuli. He called this 'ultrastability', and in 1946 he began building a machine to test and embody his theory that he called the *Homeostat*. In Ashby's essay *Adaptiveness and Equilibrium* [49] he had earlier recognised that regulatory mechanisms are not solely a feature of biology.
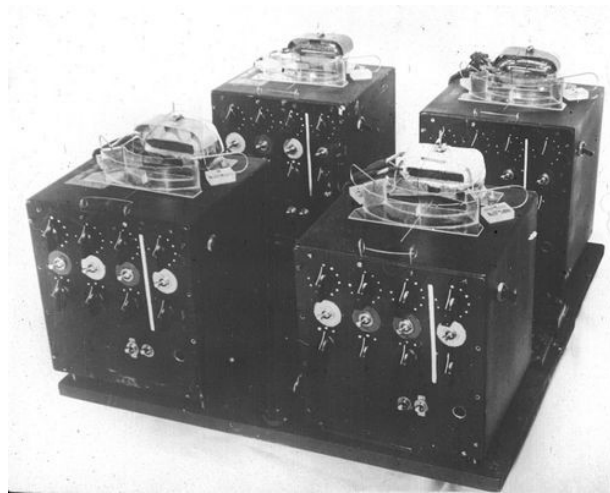
Figure 8. Ross Ashby's Homeostat cybernetic machine (1948)

Throughout the 19th century, the automation industry had harnessed steam power with James Watt's invention of the Governor. There was, however, a fundamental difference between the use of regulatory systems in biology and in machines of the time. An entire steam engine could operate on a single governor. A factory may use more, but nonetheless economically. Conversely the natural world, Ashby explained, was made up of systems far more "complex and composed of almost unaccountably many parts"[50]. To test his theory of complex regulating systems, he was to build a machine quite unlike any machine before it – an apparatus that contradicted the pre-programmed, automatic and, consequently, predictable behaviour of early machine paradigms. In the December 1948 issue of the journal Electronic Engineering under the conspicuous title *Design for a Brain* [51], Ashby presented *Homeostat* consisting of four sub-system units each networked together with input and output connections, through which they exchanged electrical stimuli.

> *"Ashby understood these currents as the homeostat's essential variables, electrical analogues of blood temperature or acidity or whatever, which it sought to keep within bounds—hence its name".* [52] *(Pickering, 2010)*

Each *Homeostat* unit could be in one of 25 internal states – each state, an electrical configuration would change to another state if input stimulus thresholds were triggered. Regardless of having 2 x 25 x25 x 25 x 25 (781,250) combinatorial states within the *Homeostat*, it was successfully able to self-organise into a stable system, without any overarching control mechanism.
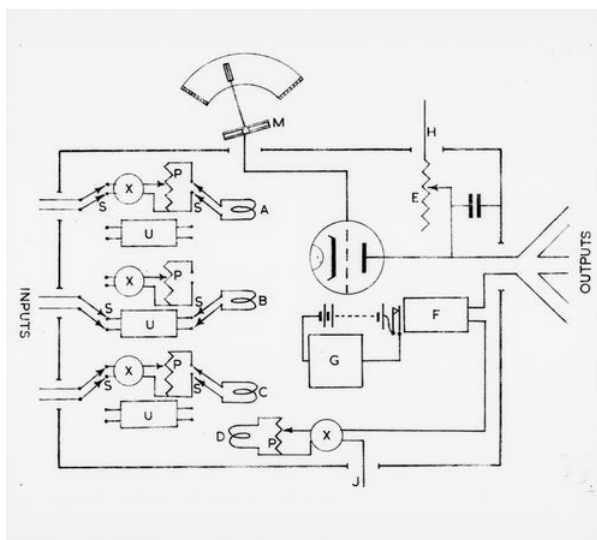
Figure 9. Circuit diagram of a single one of Ross Ashby's Homeostat devices

Regulation was distributed and proved robust enough to also handle external perturbations Ashby electrically introduced into the system. Norbert Wiener, the father of cybernetics, heaped praise on this radical reformulation of the machine's behaviour describing it as "one of the great philosophical contributions of the present day"[53]. Time magazine described it as the "closest thing to a synthetic brain man had made so far"[54]. Ashby, as a psychiatrist had built a machine to better understand how we organise thought. However, he had not only built a microcosm of a brain, but also of the living world. He argued provocatively in his later book, also titled *Design for a Brain (2013),* that if such organisation could come out of chaos, "the development of life on earth must thus not be seen as something remarkable. On the contrary, it was inevitable" [55]. Such ideas of emergent life from self-organisation were decades ahead of the later work of complexity theorists, such as Stuart Kauffmann, Stephen Wolfram and Fritjof Capra.

Similarly to Ashby, the neuroscientist Grey Walter came to develop an interest in cybernetics, recognising that negative feedback control processes in machines were analogous to those found in biological nervous systems. The dynamic stability of sensory-motor systems was, as Grey Walter pointed out, something that physiologists had a head start on studying before engineers began formulating their own principles of control. Machines provided a necessary means of physically modelling sensory-motor behaviour, that Walter hoped might uncover some of the many mysteries of the human brain. He built a series of electro-mechanical animals called *Machina Speculatrix*. Due to their domed shell body and slow pace they were often affectionately called 'tortoises' and among some of the earliest autonomous robots built.
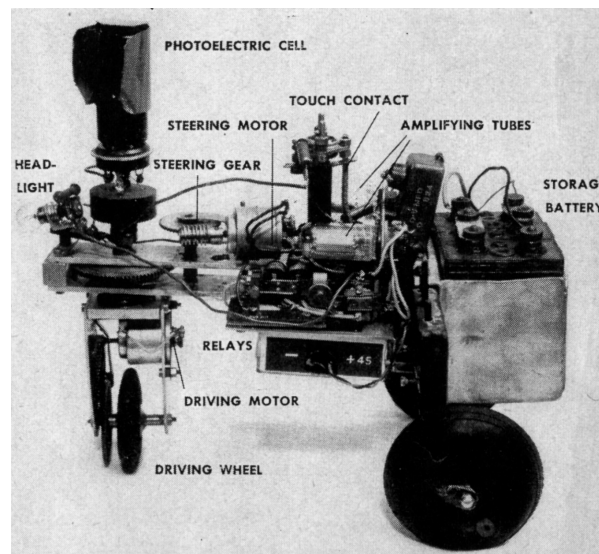
Figure 10. William Grey Walter's, cybernetic tortoise, (1950)[56]

Each tortoise consisted of a pair of electrical circuits, built to simulate nerve cell functions coupled to motor functions. A photo-electric receptor enabled the tortoises to sense and steer motion towards light. The second receptor, an electrical contact switch, sensed collision with obstacles altering direction of travel. The robots would continuously explore their environment, attracted to light sources until a threshold of light exposure would be met, at which point they would turn away and the process would begin over again. A recharging hutch with a light above it assisted the tortoises in finding their way to a source of energy, giving them the ability to sustain continuous activity, with some autonomy. These robots, even by the engineering standards of the day, were electro-mechanically primitive. The "extreme economy" of design as Grey Walter described it, did not however lead to an economy of behaviours, with his primitive robots performing a variety of complex patterns of movement. Most compellingly, these behaviours were "remarkably unpredictable" with a "strange richness … [found in] animal behaviour– and human psychology". A quality of "uncertainty, randomness, free will or independence" Grey Walter remarked, "so strikingly absent in most well-designed machines."[57]

These were the successors to life imitating automatons, representing a radical shift in approach. Whereas Pierre Jaquet-Droz's *The Writer* (1772), consisted of 6000 exquisitely crafted mechanical parts, Walter had built his from only a handful of electro-mechanical components. Whereas programmable automatons were completely predictable and repetitive, 'tortoises' *Elmer* and *Elsie* would never repeat the same exact behaviours twice. Neither entirely consistent nor random in motion, they seemed to operate on the threshold

between order and chaos, performing qualitatively differently to anything built to imitate life before them.

The sensorimotor nervous system of the animal brain now had an electro-mechanical simulacrum in machines. Unlike the animal brain however, it consisted of only 2 analogous cells rather than the billions of cells of a human brain. Nonetheless, to observers, the volitional behaviour of these tortoises was compellingly intelligent. They also had a particular liveness from their explorative behaviour, unlike Ashby's earlier *Homeostat* which was immobile, and virtually silent once in a stable configuration. Walter later dubbed Ashby's electro- mechanical device, *Machina Sopora* likening it to a "fireside cat or dog which only stirs when disturbed, and then methodically finds a comfortable position and goes to sleep again"[58]. While Ashby's *Homeostat* attempted to find stability within itself, Walter's tortoises attempted to find stability through their interaction with their surrounding environment. By modifying the environment, such as the location of sources of light or obstacles, a surprising variety of patterns of behaviours would emerge.
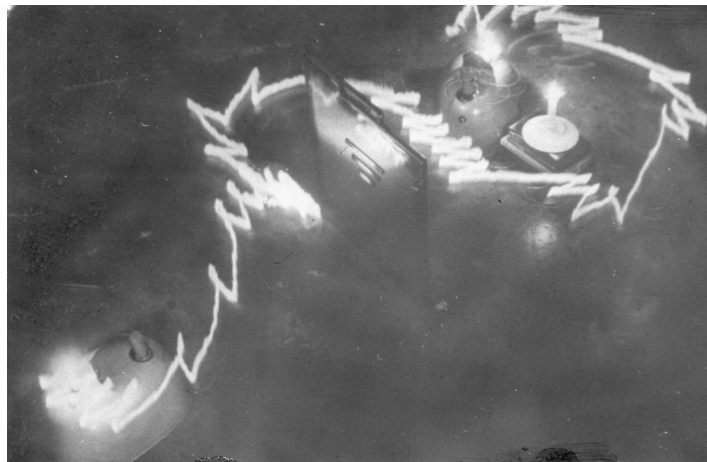
Figure 11. Elsie the robotic tortoise distracted by the reflection of its own candle in a mirrored screen before eventually finding a candle light source behind it

One of the most interesting examples given by Walter, was noted when a tortoise passed in front of mirror. An on-board indicator light – intended only for Grey Walter to observe the machine's internal state – was detected by the tortoise's own photocell, causing an unexpected flickering behaviour. The light sensed by the photocell activated a change in state in the robot which in turn switched off the light. This in turn changed the state of the robot back to its original light on state, which in turn switched the light off again, leading to an oscillating motion and corresponding flickering light. Walter quipped, such a behaviour could even be (mis)interpreted as form a self-recognition. When *Elmer* and *Elsie* were observed close to one another, a similar but distinctive pattern of behaviour would occur.

Each attracted by the light of the each other, would enter into a reciprocally oscillating motion. Author of *The Cybernetic Brain,* Andrew Pickering, likened it to a "tragic mating dance"[59], a lively and seemingly creative higher-order behaviour emerging from the interaction of a pair of robots, each endowed with only a couple electro-mechanical nerve cells. Of course, such interpretations were not beyond dispute, raising questions of where indeed the intelligence and novelty lay in the behaviour of these machines.

The tight-coupling between the features of the environment and the tortoise's behaviour presented Walter with the opportunity to study his *Machina Speculatrix,* by modifying the environment they inhabited, rather than tampering with their internal electro-mechanical composition. This approach was strikingly similar to the deductive study of animal behaviour exemplified by Pavlov[60], Thorndike[61] and Skinner[62], where the inner workings of the brain are inaccessible, so environmental stimuli are modified and resulting behaviour observed. Alongside Ashby and Walter, early cyberneticians including Norbert Wiener and Claude Shannon, built electro-mechanical models to study self-organising behaviour. Though the singular Watts Governor may have symbolised the cybernetic principle of circular feedback control, it was multiplicities of interacting feedback mechanisms, and their emergent self-organising behaviour, that captured the pioneers' imagination.

Emergence and self-organisation are interchangeable terms in cybernetics. While Self-organisation sees less use beyond the field, Emergence has a wider, although somewhat notorious, philosophical position within the arts and sciences. From the Latin verb 'emergo' to arise, to rise up, to come up or to come forth – discourse on emergence developed within a fractious debate on the nature of life in the 19th century. The rise of a mechanical worldview – established by the achievements of Copernicus, Galileo. Bacon, Descartes, and Newton – advocated a view of life as reducible to physical processes. In opposition, the Vitalists argued that such reductivism failed to explain the phenomenal qualities of life and consciousness, favouring the proposal of a metaphysical substance – a soul, or Aristotle's and Hans Driesch's entelechy – that differentiated the inanimate from the animate. "May God us keep, From single vision and Newton's sleep"[63] lamented romantic artist and mystic, William Blake.

Avoiding the vitalist disposition towards the spiritual, while maintaining the need to recognise a property greater than the material parts, a third way was proposed by the *British Emergentists,* including philosopher Samuel Alexander who encapsulates their perspective in his 1920 book *Space, Time, and Deity.*

> *"Physical and chemical processes of a certain complexity have the quality of life… The higher quality emerges from the lower level of existence and has its roots therein, but it emerges therefrom, and it does not belong to that lower level, but constitutes its possessor a new order of existent with its special laws of behaviour. The existence of emergent qualities thus described is something to be noted, as some would say, under the compulsion of brute empirical fact."* [64] *(Alexander, 1920)*

The recognition of the limitations of reductive methods, and the embrace of unpredictable and emergent phenomena, became central interest for pioneering cybernetic practices. The electro-mechanical machines of Ashby's *Homeostat* and Walter's tortoises representing the first electro-mechanical embodiments of emergent artificial life. Whereas the prior age of industrial automation had seen machines limited to repetitive and predictable motion, the cybernetic revolution unlocked the potential for unpredictable, yet purposeful, emergent behaviour. Machines with an aesthetic potential that captured the public's imagination, would have likely entertained William Blake with their ability to bring out the vitalist tendencies of their spectators. The environmental stimuli of mirrors, light sources and obstacles, that Walter's tortoises encountered, shaped their animate emergent behaviour without the need for sophisticated electronics or computing power. Through Walter and Ashby's machines, we see from its foundations, that cybernetics recognised behaviour of a physical agent-system being inseparably coupled to its environment. Whether it is in the study of the brain, or social or economic systems, behaviour does not occur within a vacuum, but rather is a continuous embodied exchange with an environment. Though environment as a term is often used loosely to describe a subject's general surroundings, in cybernetic it should be understood as specific to "all objects a change in whose attributes affect the system and also those objects whose attributes are changed by the behavior of the system"[65].

> *"There can't be a proper theory of the brain until there is a proper theory of the environment as well… the subject has been hampered by our not paying sufficiently serious attention to the environmental half of the process… the "psychology" of the environment will have to be given almost as much thought as the psychology of the nerve network itself."* [66] *(Ashby, 1953)*

This is one of early cybernetics' key contributions to understanding the source of emergent life and intelligence. It encourages us to rebalance our attention to design problems between agent and environment, whether one is engaged in designing the behaviour of common robotic typologies or exploring non-standard applications in architecture, arts and performance. In my own practice, working between robotics and architecture, and making semi-autonomous machines to behave in spaces, it has become apparent to me that this is essential. I have found the 'environmental half' – which I believe has been understudied – remains in much need of deep consideration.

Defining an environment, particularly one that is highly dynamic creates considerable challenges for designers. The *Smart Geometry: Constructing for Uncertainty* conference which I chaired at the Bartlett in 2013 addressed these issues at a variety of scales. When trying to understand the environment in which an agent-system is intended or observed to exist within, two observers may well have different ideas about what constitutes a given agent-system's environment. Heinz von Foerster puts its plainly, stating that "the environment as we perceive it is our invention." Further Ashby's notion of the 'Black Box', warns us that there may be things that are 'out of view', and these may be of greater importance than we fully anticipate or appreciate.

Neo-Cybernetic Life

Heinz von Foerster, the secretary of the early Macy Conference proceedings, which brought together the founders of cybernetics, had presided over developments in the field that, in the following decades, saw 'hard' and 'soft' camps emerge. On one side the mathematical and engineering concerns towards computing, communication technologies, robotics and artificial intelligence developed the foundations of today's ubiquitous digital infrastructure. On the other, the 'softer' philosophical concerns of social systems, psychotherapy, cognition and ecology were developed. As Bruce Clarke explains "Few persons besides von Foerster could be said to have had a foot in both camps"[67], allowing him to explore a complete vision for cybernetics that might consolidate some of the field before it otherwise separated entirely into independent specialisms.

Primed by Ashby's understanding of the 'Black Box', alongside contemporaneous work in fields of mathematics of George Spencer Brown's *The Laws of Form*[68] that examined the act of making distinctions, von Foerster harnessed the language of control feedback (of first-order cybernetics) to examine a second-order of circularity for the field. This was a conceptual leap in which the observer not only stipulates the purpose of the system, but also, as Heinz von Foerster explains, enters that system by stipulating his or her own purpose[69].

This has been described as the cybernetics of cybernetics, second-order cybernetics or more recently neo-cybernetics. This 'meta' cybernetic framework is an epistemological shift away from scientific traditions of objectivity and reductive rationality, towards radical forms of constructivist and ecological thinking. Ranulph Glanville describes "Von Foerster's significance/role in second-order Cybernetics is without equal"[70].

> *"The relationship of first order Cybernetics to second order Cybernetics is like the relationship between the Newtonian view of the universe, and the Einsteinian. Just as Newton's description remains totally appropriate and usable in many instances (including flights to the moon), so first order Cybernetics also retains its value and frequently provides us with all we need (for instance, in many control arrangements). And just as the Newtonian view is now understood to be a special, simplified, restricted (and slow) version of Einstein's view, so first order Cybernetics is a special, simplified, restricted (and linear) version of second order Cybernetics."* [71]
> *(Glanville, 2002)*

This critical maturing step in cybernetic thinking acknowledged the observer was an essential part of all systems. Von Foerster's papers *Notes on an Epistemology for Living Things*[72], *On Constructing a Reality*[73] and *Cybernetics of Epistemology*[74] and *Objects: Tokens for (Eigen-) Behaviour*[75] made the case that to live within an environment is to be an epistemologist, presenting with persuasive style, the circular feedback mechanisms that enable cognitive systems to construct stable realities (continuously re-distinguishing the distinction). His argument is based on an understanding that knowledge of an environment is dependent on the system that observes it, that "form and content interrelate, in much the way Gregory Bateson talked of the unity of the mind and body"[76], and that a systemic reality of an environment is both the precondition and product of an observing system.

Where early first order cybernetics provided a means to understand regulatory processes, such as homeostasis, habituation and adaptation, the second-order provided a framework to tackle processes of cognition, bound between living things and their environments in continuous interaction. As von Foerster concludes in his 1973 paper, *On Constructing a Reality,* "If you desire to see, learn how to act."[77]
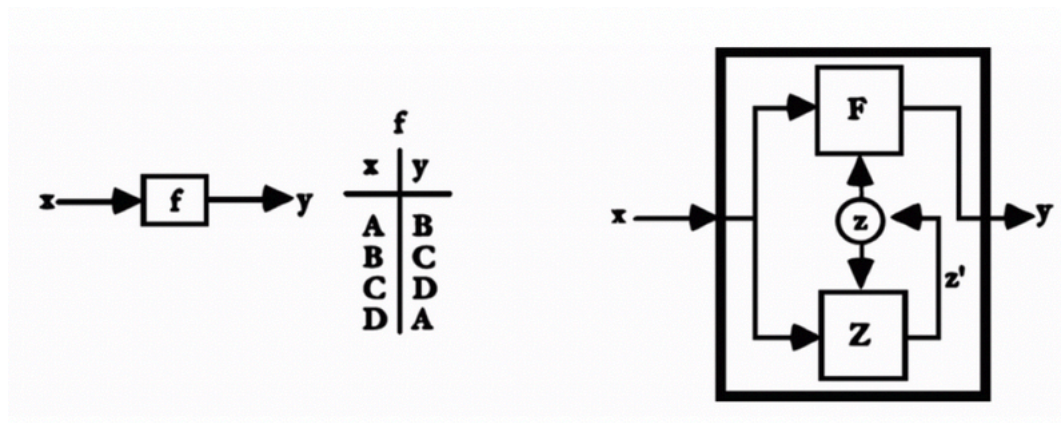
Figure 12. Trivial machine with truth table (left) and non-trivial machine (right)

Heinz von Foerster unlike other cybernetic pioneers such as Wiener, Walter, and Ashby, was not a machine maker. He instead would use the word 'machine' in terms of conceptual mechanisms for discussing input and output relationships in systems. He distinguished two fundamentally different types of machine, trivial and non-trivial. The trivial machine is a simple, limited and predictable system, best described by von Foerster himself.

> *A trivial machine is characterized by a one-to-one relationship between its "input" (stimulus, cause) and its "output" (response, effect). This invariable relationship is "the machine." Since this relationship is determined once and for all, this is a deterministic system; and since an output once observed for a given input will be the same for the same input given later, this is also a predictable system. (Von Foerster, 1972)[78]*

Importantly the trivial machine is a personal construct of the observer, not a first- order cybernetic system diagram. With observation of input stimuli and output behaviour, clear causal relationships can be constructed and a "truth table" drawn up to refer to. A trivial machine will repeat behaviours predictably to repeated stimuli input without change. By contrast, non-trivial machines will not exhibit completely predictable behaviour because its internal mechanism, are subject to change due to its history of previous inputs.

Ashby's *Homeostats*, are clear examples of non-trivial machines with their internal transformations in signal processing that lead to adaptive behaviour. In networks of other machines the interaction of multiple machines lead to non-linear self- organising behaviour that are complex but capable of dynamic stability. While Trivial machines represented a

primitive reactive model of behaviour, non-trivial opened up the possibilities for behaviour adaptive to changing conditions over time. Though most technology we encounter is designed to act as a trivial machine and operate predictably, cybernetics was far more interested in non-trivial mechanisms as they seemed to hold the key to understanding the recursive and continuous performance of complex living systems.

Knowledge, far from being passively received, is actively and continuously constructed by a cogniscant observer, and the function of cognition is adaptive to its environment, serving an observer's experiential world, not the discovery of an ontological reality. The cybernetics of cybernetics took what Ernst von Glasersfeld coined as a radical constructivist position arguing that, "Those who ... do not explicitly give up the notion that our conceptual constructions can or should in some way represent an independent, 'objective' reality, are still caught up in the traditional theory of knowledge" [79]. The use of 'radical' was in order to emphasise that this epistemological perspective had to be total in its rejection of a "correct" observable world, ensuring that no lapse back into the fantasy of realism should ever occur. Radical constructivism did not however deny an objective reality exists, only that we have no way of knowing what that reality is.

> *"Radical constructivism itself must not be interpreted as a picture or description of any absolute reality but as a possible model of knowing and the acquisition of knowledge in cognitive organisms that are capable of constructing for themselves, on the basis of their own experience, a more or less reliable world."* [80] *(Watzlawick, 1984)*

Though epistemological concerns were often directed to issues of human cognition, the foundations of these understandings had emerged from general studies of simpler behaviours and the organisation of primitive nervous systems. In the foundational years of cybernetic research, Warren McCulloch and Walter Pitts' neurophysiological studies led to the development of the first mathematical model of neural networks [81] that continue, today, to be the principle reference for the computation of artificial neural networks. McCulloch and Pitts joined MIT, under the invitation of Norbert Wiener, where they worked with Jerome Lettvin and Humberto Maturana on the publication of *What the Frog's Eye Tells the Frog's Brain*[82], the paradigmatic study on visual perception that demonstrated that retina was not merely a light receptor that sent signals to the brain for interpretation, but that it also performed 'feature-detection', with neurons responsive to specific features of a visual

stimulus, such as edges, changes in light levels and movement. Famously, they identified a feature detector that they called the 'bug detector' - specialised cells in a frog's eye that responded when small, dark objects enter the visual field, stop, and then move intermittently.

> *"The eye speaks to the brain in a language already highly organized and interpreted, instead of transmitting some more or less accurate copy of the distribution of light on the receptors"* 83 (Myhrvold 2013)

So radical an idea was it that Lettvin tells the story of when they tried to present the study to the American Physiology Society, were laughed off the stage and had their research funding threatened. The paper has since gone on to be one of the most highly cited papers in perceptual and cognitive science. The paper characterises the eye far from being a passive camera receptor of an external reality, but rather an active and specialised interface for the frog's own purposes within its world – one that is highly attuned to its own survival with reflexes for social perception and responsive behaviour.

> *"A frog hunts on land by vision... The frog does not seem to see or, at any rate, is not concerned with the detail of stationary parts of the world around him. He will starve to death surrounded by food if it is not moving. His choice of food is determined only by size and movement. He will leap to capture any object the size of an insect or worm, provided it moves like one. He can be fooled easily not only by a bit of dangled meat but by any moving small object."* 84 (Lettvin et al, 1959)

While the frog is easily fooled into false detection, it has evolved and thrived with these relatively simple object motion-detection capabilities. The eyes of other more advanced predators have far sharper and longer-range vision, capable of detecting the animate motion of potential prey from great distances. The visual-cortex of social animals including human beings are also understood to be highly attuned to detect not only life, but also gender, and emotional cues from even limited visual motion information[85]. Jerome Lettivin, and his colleagues at MIT, demonstrated in compelling fashion that the optic nerve was less like a transmission cable and much more like a neural computer, processing information and parsing features from the retina into meaningful information, and triggering responsive

behaviour. The Frog's eye not only detected bugs but it automatically triggered a jumping reaction. Far from the eye being an 'input' sensor, it is understood to be tightly coupled to behavioural response. Such automatic responses are found throughout the animal kingdom and, in the following chapter, I will examine how this understanding has been extended to studies on how the human eye automatically constructs not only spatial, colour and motion information, but also the causal and the social structure of its environment. I will also describe how, today, some of the most sophisticated research into deep neural networks is discovering the power of binding perceptual and motor control together, to solve the most challenging of problems in robotic behaviour.

The collaboration of Jerome Lettvin, Humberto Maturana, Warren McCulloch and Walter Pitts was a moment of convergence in the careers of four eminent scientists, working with the characteristic disregard for disciplinary boundaries that cybernetic practice embodied. First-order cybernetic concerns of purposeful (goal- directed) behaviour were deepened by second-order study of the purpose of purpose, and the regulation of regulation, implicitly raising 'big questions' about the self-organising systems that lead to cognition, and life itself. Seeking to understand "the characteristic organization of living systems", Maturana's early work on the *Biology of Cognition* was further developed with his student Francisco Varela, into their theory of *Autopoiesis* [86] - auto meaning "self" (i.e. autonomy of self-organising systems) and poiesis, meaning making, formation or creation.

"An autopoietic machine is a machine organised (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which: (i) through their interactions and transformations continuously regenerate and realise the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realisation as such a network." [87] *(Maturana and Varela, 1980)*

A system was autopoietic if the structure of parts interacts in such a way as to self- organise the production of further parts and interactions that maintain its self- organisation. Maturana and Varela's neo-cybernetic theory was developed as an abstract model of cell metabolism - not defined by the presence of a particular material substance, but rather a set of dynamic relations. Central to their theory is the concept of autonomy, but not in the naïve sense of

absolute self-sufficiency. Rather, it acknowledges that the organism or agent-system is organisationally closed, while paradoxically bound to its environment.

> *"The result of structural coupling is an autonomous and strictly bounded system, that has nevertheless been shaped extensively by its interactions with its environment over time, just as the environment has been shaped by its interactions with the system."* [88] *(Quick, 2003)*

Autopoietic theory comprises two key reciprocal features - the maintenance of organisation (dynamic interactions), and regeneration of structure (network of parts) to remain autonomous. The complexity of an environment can 'perturb' the autopoietic system and stimuli can even trigger it to restructure itself, however, the system's boundaries are organisationally closed.

> *"The self-transcending movement of life is none other than metabolism, and metabolism is none other than the biochemical instantiation of the autopoietic organization. That organization must remain invariant – otherwise the organism dies – but the only way autopoiesis can stay in place is through the incessant material flux of metabolism. In other words, the operational closure of autopoiesis demands, that the organism be an open system."* [89] *(Thompson, 2009)*

For an autopoietic system to perpetuate itself within an environment, it must be responsive to that environment, with an organisation that seeks to increase its potential to survive and thrive. Evolutionary biologists and psychologists examine how the behavioural organisation of living organisms are shaped over generations – from their ability to sense external stimuli, to their articulation of a response – and that, significantly, this occurs in the context of their environment. Over generations, perceptual capabilities to detect salient stimuli, while ignoring aspects of their environment that are irrelevant, develop. Evolutionary 'knowledge' is embodied in these perceptual systems (detecting predators, for example), and suitable response mechanisms have also developed.

In *Life and Mind: From Autopoiesis to Neurophenomenology*, Evan Thompson describes the autopoietic (and neo-cybernetic) understanding of cognition as simply "the minimal sense of

viable sensorimotor conduct"[90] found in the most primitive of living organisms. The autopoietic view of life is one where life and stimulus exchange with an environment are necessarily bound to one another, as Maturana's is often quoted, "to live is to cognize", a shortening of his earlier statement "Living systems are cognitive systems, and living as a process, is a process of cognition"[91]. The life of a species, in its structure and organisation, holds a deep evolutionary knowledge, where each instantiation of that species embodies that perceptual knowledge, which, in interaction with an individual's lifetime of experiences, shapes an individual's reality.

Whether we are discussing a human being, a frog, or a single cell, homeostasis is not simply the maintenance of biological operation. Understood through the cybernetic entrainment of mind, body and environment, autopoietic systems are continually in a process of constructing their own stable reality or "cognitive homeostasis", as von Forester put it. And so, as Varela asserts, our deep knowledge of our constructed world, and how we interact with it, is not "as a representation of the world 'out there', but rather as an ongoing bringing forth of a world through the process of living itself"[92].

> *"Autopoiesis entails emergence of a self. A physical autopoietic system, by virtue of its operational closure, gives rise to an individual or self in the form of a living body, an organism. Emergence of a self entails emergence of a world."* [93] *(Thompson, 2009)*

Autopoiesis, as an abstracted description of autonomous living systems, attracted the attention of the social sciences as well as organisation and information system theorists. German sociologist Niklas Luhmann's use of the metaphor of autopoiesis to describe whole social systems immaterially mediated by communication, is the most prominent example of the transferability of cybernetic models to other domains. Luhmann argued that all higher forms of life, consciousness and social communication behavior were necessarily non-trivial machines.[94] He explained that Social systems were – like living organisms – self-referential. "The system continuously refers to itself by distinguishing itself from the environment"[95]. The self-referentiality allows the social system to distinguish itself as a system from its environment, without the material boundaries we can more easily distinguish in biological cells, for example.

"A social system comes into being whenever an autopoietic connection of communications occurs and distinguishes itself against an environment by restricting the appropriate communications. Accordingly, social systems are not comprised of persons and actions but of communications." [96]
(Luhmann, 1989)

Zeleny points out that, in fact, one can also see "(...) all biological (autopoietic) systems are social systems. They consist of production, linkage, and disintegration of related components and component-producing processes. An organism or a cell is, therefore, a social system"[97]. He also points out that while there have been many successful examples of defining all biological systems as autopoietic, there has been less success at demonstrating all autopoietic systems are living ones.

The epistemological focus of neo-cybernetics that enabled an autopoietic view of life and cognition is not without critique. Ontologist Andrew Pickering warns the "endless agonizing about the observer's personal responsibility for his or her knowledge claims"[98] detracts from the "performative materiality" of the field. He views cybernetics, embodied in the performance of the machines of Ashby, Grey Walter and (later) Pask, amongst others, as providing a lasting contribution, by grounding a nonmodern ontology through performativity. He maintains behaviour does not require an observer – although it might have one – rather, "behaviour is that part of the functioning of an organism which is engaged in acting upon or having commerce with the outside world"[99]. I find both the performative nonmodern ontology of Pickering, and the epistemological emphasise of Glanville, von Foerster, and Pask to be, in practice, very similarly useful. They both share the metaphor of a dance of agency which implies a continuity of adaptive exchange, and embodied interaction.

The complexity of emergent interactions in social systems, the emphasis on the irreducibility of those system-observer exchanges, and the inherent subjectivity of modelling, led neo-cybernetic research to dispense with formal mathematical modelling, in favour of philosophical discourse. This, it has been argued may have insulated its impact from concurrent mathematical and computational discourse on the design of artificial 'intelligent' systems. For those in fields of applied sciences, the second-order passion for the self-referential and philosophical detached cybernetics from concrete phenomena. Yet, as Bruce Clarke and Mark Hansen make the case in *Emergence and Embodiment, New Essays on Second-Order Systems Theory,* "Some of the most important theoretical and critical

conversations going on today in cognitive sciences, chaos and complexity studies, and social systems theory stem from neo-cybernetic notions of self-organisation, emergence and autopoiesis" [100]. I would add to that statement, that cybernetic machines – particularly early analogue homeostatic contraptions – are commonly left unrecognised for their foundational role in the development of those theories, though their embodiment performance of these ideas.

Digital Life

The dawn of digital computing granulated the previously continuous interface between machines and their environments. And, with the digital turn, the discrete computational biology of von Neumann came to dominate approaches to replicating life-like behaviour in machines. In 1970, when John Conway published his binary state cellular automata, famously titled the *Game of Life*[101], it became the defining example of the enormous emergent potential of even the simplest of rule bases. Further studies revealed it capable of building of a universal Turing machine, offering a way to build a mathematical universe from the ground up. William Gosper, a leading programmer at MIT's AI Lab described it as giving "the ability to do everything from animal husbandry to recursive function theory"[102], and Conway himself believed the *Game of Life* might support the emergence of any known animal, as well as unlimited novel new creatures.

If the grid was large enough to compute the enormous number of infinitesimally small interactions, something may emerge capable of "Evolving, reproducing, squabbling over territory. Getting cleverer and cleverer. Writing learned Ph.D. theses. On a large enough board, there's no doubt in my mind this sort of thing would happen"[103]. For this scale of computation to emerge in a cellular automaton, the computer scientists predicted it to need unfathomably large grids, possibly the size of a universe itself, and it was this sort of equivalency that inspired groups like the Information Mechanics Group at MIT, to explore the possibility of our universe as an enormous automaton – and by implication something fully knowable and simulatable. For the group's founder Edward Fredkin "the basis of life is clearly digital… nothing is done by nature that can't be done by a computer. If a computer can't do it, nature can't" [104]. He wasn't alone in this proposition. Models of the universe as a giant computer had first been explored by Konrad Zuse (1969), and then later by Stephen Wolfram (2002).

"It's interesting what the principle of computational equivalence ends up saying. it kind of encapsulates both the great strength and the great weakness of science. because on the one hand it says that all the wonders of the universe can be captured by simple rules. yet it also says that there's ultimately no way to know the consequences of these rules— except in effect just to watch and see how they unfold." [105] *(Wolfram, 2005)*

In Wolfram's and Conway's automata, there is little means available to calculate in advance how they will behave. One simply has to 'let them run', stepping through discrete units of time, updating their state variables in accordance to the given rules, to see what emerges. Though many rules bases of cellular automaton predictably generated instances of unresponsive and periodic patterns, it was the instances of unpredictable chaotic and semi-chaotic patterns that attracted the most interest. Studying cellular automata, Christopher Langton examined how CA rules – approaching a phase transition between ordered and disordered patterns – were capable of universal (Turing) computation. He identified that between predictable order and chaotic noise, a zone of emergent complexity existed. Langton and other complexity researchers became interested in how certain patterns could remain semi-ordered, yet interact with dynamics of their noisy environment. Mathematician Doyne Farmer coined this the 'Edge of Chaos', an emergent computational space that had properties of living systems interacting with the dynamics of an entropic world.
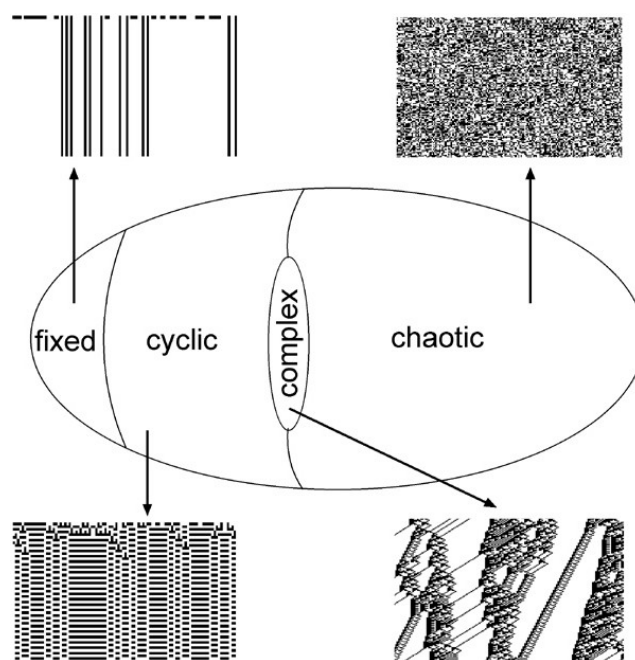
Figure 13. Chrisopher Langton's Life at the Edge of Chaos illustrated using Wolfram's cellular automata

Langton's egg diagram, mapping the mathematical space of his cellular automata, indicates the relative location of periodic, chaotic, and complex transition spaces. To the left, information is frozen entirely, followed by a 'regime' where 'periodic cycles' might be considered like crystal growth. Patterns emerge, yet they are too limited to support life. To the right, information is unstructured, or cannot maintain structure for long. Only within a relatively small 'sweet spot' do we find information with stability, but enough dynamic interaction with its surrounding environment to appear to have life-like behaviour. The responsive emergent patterns of CAs suggested types of phase-transitions of a pre-biotic world, with information processing capabilities that may have formed with other complex structures to become the 'primordial soup' of life. Perhaps unsurprisingly, the emergent qualities of complex animated computer animations encouraged a quiet vitalism to appear in discourse. Leader in parallel supercomputing, Danny Hillis went as far as to describe the soul as being found in emergence.

> *"The soul is the result of taking simple things that you understand the rules of, and applying this emergent behavior that is both a consequence of the rules and also not obviously connected to it. That's to me where the soul is. That's a much more interesting, robust place for the soul to be than off in some little comer of science which we just haven't figured out yet."* [106] *(Hillis in Levy, 1993)*

The artificial life community that emerged in the late 1980s, embracing a bottom-up approach to intelligent machine behaviour, were faced with the immediate problem of definition. The first ALife conference, chaired by Christopher Langton, had promoted itself as "the study of artificial systems that exhibit behaviour characteristic of natural living systems", rather than dare suggest any promises of "real" life in silico. Yet, the diverse crowd of over a hundred scientists and technicians who attended the first gathering in Los Alamos, coming from a diverse array of fields, all had very different ideas about the problem definition for the community. Steven Levy's account of the first meeting describes the "perpetually haunting question: What is life?" that left the community wondering, "How can you create life when no one agrees what that means? How would you know you had done it?"[107]

A similar problem had been faced for decades in the field of artificial intelligence. The solution proposed by Alan Turing, which would come to be known as the Turing test, was an experiment that, in short, asked a human subject to have a text based conversation with another hidden agent, who may be human or machine. The subject would ask questions and receive answers eventually making a judgement call about whether the hidden agent was human or not. In other words, if the subject could no longer determine which respondent was human or machine, the Turing test would be passed and we could attribute intelligence to machine. The delegates at the first ALife conference discussed what an equivalent test might be for a field less interested in imitating human reasoning and, rather, the essential characteristics that we all appear to irresistibly identify as life-like.

"In a coincidental nod to de Vaucanson, some people at the a-life conference began talking about a duck test: if it looks like a duck and quacks like a duck, it belongs in the class labelled ducks. this Vaucanson test was admittedly subjective but ultimately no more so than the Turing test." 108 (Levy, 1992)

With such a variety of software, hardware and wetware approaches to animate behaviours, within the burgeoning community, a general agreement formed that creators should simply aim to satisfy their own criteria for aliveness. This allowed deeper inspection of a multiplicity of types of behaviour, rather than immediately seeking a universal principle, although that remained an ambition. Langton's favourite example of tackling a particular behaviour was Craig Reynolds's 1986 'Boids' program[109]. Boids, short for 'birdoid', referring to something bird-like, demonstrated compelling impressions of flocking behaviour directed by a simple set of three rules of separation, alignment and cohesion, driven by attraction, detraction and velocity parameters.

"The motion of a flock of birds is ... simple in concept yet is so visually complex it seems randomly arrayed and yet is magnificently synchronous. Perhaps most puzzling is the strong impression of intentional centralized control. Yet all evidence indicates that flock motion must be merely the aggregate result of the actions of individual animals, each acting solely on the basis of its local perception of the world." 110 (Reynolds, 1986)

From a primitive set of 'perceptual' rules, a global flocking behaviour spontaneously emerged from local interactions, in a similar manner to cellular automata. So convincing was the performance of the boids, that ornithologists began contacting Reynolds intuiting that real living birds might be using the same perceptual heuristics [111]. Iztok Lebar Bajec and Frank Heppner have described the study of organised flight of birds as "one of the most easily observed, yet challenging to study, phenomena in biology" [112],with computational simulations generating a great variety of striking representation of behaviour and hypothesises about the underlying mechanism. So rapidly that "the ability to test these hypotheses lags behind the capacity to generate them".[113]

The work also attracted the interest of the computer animation industry who would come to be a key financial backer of the ALife movement, deploying the techniques in 1992 for the first time in a feature film to simulate flocking bats in Tim Burton's *Batman Returns*[114]. In this context, the success of these simulated agents is measured by their verisimilitude to an audience's expectations of bat behaviour. This would be at the softer end of the ALife research field. At the other end of the spectrum there were those hard ALifers who maintained that if an organism (usually digital in their research) was self-organising and self-replicating in its (usually digital) environment, they could be considered seriously as alive in every sense.

Langton, a computer scientist argued for a reconceptualisation of life. "The leap you have to make is to think about machineness as being the logic of organization. It is not the material…if you can capture its logical organization in some other medium you can have the same "machine" because it's the organization that constitutes the machine, not the stuff it's made of. That's the leap you have to make. It's a small one" [115]. 'Machineness' is here an expanded notion, beyond mechanical forces, into the realm of systems thinking, with information flow and interaction, representing the fundamental layer. Life, in Langton's view, is not therefore located in the material itself but rather in an ongoing set of relations. "To animate machines… is not to bring life to a machine; rather it is to organize a population of machines in such a way that their interactive dynamics is alive" [116].

Langton's confidence that he could create life, was not universally shared by researchers in the field. While those in the hard ALife camp believe – as von Neumann did – that life was a process that could be abstracted away from any particular medium, soft ALife sees the product of the field as a performative animacy, of life-like rather than living behaviour.

> *"The question "What is life?" is not often asked in biology, precisely because the machine metaphor already answers it: "Life is a machine." Indeed, to suggest otherwise is regarded as unscientific and viewed with the greatest hostility as an attempt to take biology back to metaphysics."*
> *117 (Rosen, 1991)*

Robert Rosen's *Life Itself* [118] delivers a surgical dissection of the shortfalls of modern science's mechanistic conception of life, rejecting them ultimately for their inability to explain the qualities of life. He suggests that to reveal the answers to the mystery of life one must look to the 'oracle' of *Systems Theory* - shifting the question from what is special about life in terms of material, to what is special about life in terms of organisational behaviour. Sympathetic theories can be found in Deep Ecology [119], and intrinsically within cybernetics. Fritjof Capra and Pier Luigi Luisi, in their *Systems View of Life[120],* further the argument for a holistic network view emphasising pattern and organisation. What is so tantalising for me, personally, about this counter argument with modern Cartesians, is its quiet vitalism. Rosen acknowledges the aversion this causes to many in the scientific community.

Philosopher Mark Bedau argues that this "should be considered one of the fundamental concepts of philosophy, but philosophers haven't thought of it much. Nor have biologists. They typically throw up their hands. It is not a natural property like water – you can investigate water and say, 'there's H20, that's its essence.' But life isn't material, it's ephemeral". Elliott Sober contends that, ultimately, the question is not important. "If a machine can extract energy from its environment, grow, repair damage to its body, and reproduce," he asks, "what remains of the issue whether it's 'really' alive?" [121] Physicist Gerald Feinberg and biologist Robert Shapiro have coined a term for those who "believe that all life must be based on the chemistry of carbon compounds and must operate in an aqueous (water) medium" - "carbaquists" [122]. Yet, no one has effectively argued that life could never exist in other forms.

2.3 Models of Intelligence

Cartesian Cognition

In the age of mechanical clocks, Decartes described the world in terms of cogs and levers, and all life as a divinely designed automaton. In an age of digital automaton, computer scientists, in the same manner, theorised of our universe in binary automaton. This modern

Cartesianism, proposing a digital physics or pancomputationalism, met with strong critique for its inability to account for natural emergent phenomena, such as human consciousness[123], nor for free will and various examples of indeterministic randomness[124]. Whereas cybernetic conceptions of cognition were understood as continuous, embodied exchange between autopoietic-systems and their complex environments, artificial intelligence research that emerged out of the establishing of computer science departments, built on the binary logic of digital computing.

What is often called 'Classical', 'Computational' or 'Cognitivist' AI, prescribed to a view of intelligence as a problem of computer software, and the internal manipulation of symbolic representations of an outside world. Software became the focus of AI, relegating hardware to the supporting role of input-output devices and information processors. This Cartesian split came from perceived limitations of analogue computing compared to the discrete logic of binary computing. Marvin Minsky, a leading figure in AI research, argued the limitations of the computer as an intelligence-amplifying machine rested in the capabilities of the programmer alone[125], and a great deal of promise was made in early artificial intelligence research, based on a premise that the brain and the computer were much the same thing.

This approach reinforced the view that intelligence was an entirely rational processing of logical and discrete representations, as opposed to an embodied, complex and continuous exchange with the physical world. To today, the cultural power of computing has had lasting effects on broad cultural conceptions of intelligence, and has reinforced Cartesian conceptions of cognition that continue to relegate bodies and their embodied knowledge to the supporting role of input- output devices and information processors.

After a disappointing start to the new field, Minsky and others recognised what they called the 'common-sense problem', which emerged from designing intelligence from the top - down. The scientists had not fully appreciated that human intelligence was structured upon vast amounts of implicit knowledge, shared between us through experience, but rarely explicated in any logical representation.

> *"An old philosophical dream was at the heart of the problem. AI is based on an idea which has been around in philosophy since Descartes, that all understanding consists in forming and using appropriate symbolic representations. For Descartes these were complex descriptions built up out of primitive ideas or elements. Kant added the important idea that all*

concepts were rules. Frege showed that rules could be formalized so that they could be manipulated without intuition or interpretation. Given the nature of computers, AI took up the search for such formal rules and representations. Common-sense-intuition had to be understood as some vast collection of rules and facts." 126 (Dreyfus and Dreyfus, 1986)

This approach became embroiled in issues about the structure of knowledge representation, for example, how could encyclopaedic databases, such as dictionaries and image banks be organised to enable human machine interaction or autonomous robot navigation of environments? Others explored whether environment could be formulated into hierarchical 'if-else' logics. Without a machine capable of learning common sense facts, scientists resorted to manual input of millions of general knowledge rules, most of which the average human being would take for granted. The largest of these is the CYC Project founded by Douglas Lenat in 1984, with over a million hand-entered facts[127].

Hubert Dreyfus phenomenological critique *What Computers Can't Do*[128] published in 1972, and the brilliantly biting 1992 follow-up *What Computers Still Can't Do*[129]*,* argued that there was a fundamentally flawed assumption in AI that the brain is analogous to computers and the mind to software. As a scholar of French phenomenologist Maurice Merleau-Ponty and the German philosopher Martin Heidegger, he argued that there was an inherent inability for disembodied machines to achieve any of the AI aims their authors set out to achieve. A second assumption he railed against was that there could be no objective set of facts outside of an individual's mind that are continually re-constructed through interaction with the world, and through cultural filters. Classical AI, he argued, would always come up against the common-sense knowledge problem, regardless of attempts at look up tables. "Current claims and hopes for progress in models for making computers intelligent are like the belief that someone climbing a tree is making progress toward reaching the moon," he argued in *Mind Over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*[130].

Regardless of the significant limitations with negotiating complex physical environments, it should be recognised that computational approaches to AI have lead to many important applications in digital environments, such as the internet, where statistical and machine learning techniques have been essential in processing large amounts of text, images and other data. But the Promethean project of making animate machines is one of embodied life, not of informatics and as Rolf Pfeifer and Fumiya Iida argue, "the classical approach has not contributed significantly to our understanding of, for example, perception, locomotion,

manipulation, everyday speech and conversation, social interaction in general, common sense, emotion, and so on" [131].

The critique of Classical, Computational or Cognitivistic approaches to AI, that became known as good old-fashioned AI or GOFAI, was characterised by Stevan Harnad in 1990, as the "Symbol Grounding Problem"[132], where engineers had made great progress in highly structured symbolic environments, such as chess games, but struggled to build computer-controlled robots able to achieve even the simplest of navigational tasks in common day physical environments.

Consequently, examples of where classical approaches to AI in the physical world have been used, have been limited to highly structured physical environments, such as factory assembly lines, where all objects are known, modelled and manipulated in controlled spaces, engineered to segregate human and machine contact until maintenance is required. Industrial robots are mass-produced, general purpose positional machines, typically arms, augmented by custom end- effectors to repetitively automate a single task. Though they are electrically sophisticated and reprogrammable, they are, once running, operationally closed and little different to the classical automaton of pre-electronic mechanical age. Not only do they share the repetitive motion, but built from rigid metal bodies, the mathematics of their kinematic models are fundamentally Newtonian. It would take a paradigm shift to overcome the limitations of GOFAI. And it would be a neo- cybernetic revival that returned to fundamental understandings about animate behaviour that would bring robots out of the lab and into complex environments forging new relationships with emerging theories of cognition that rejected Cartesian dualism.

Embodied Cognition

> *"Embodiment is the method by which situatedness is achieved. It proves the actual functioning of the system in ways that simulation cannot. It is ruthlessly efficient at exposing wishful thinking."[133] (Kruegar 1996)*

Roboticist Rodney Brooks, who had spent the late 1970s working with Hans Moravec on symbolic approaches to AI for mobile robotics, was to have a pivotal role in a revival of the nonrepresentational, embodied approaches to intelligence characteristic of early cybernetic devices. His 1986 internal memo [134] to MIT's Artificial Intelligence Laboratory was one of a growing number of scathing critiques of GOFAI, where Brooks lamented at the inability of

multi-million dollar, state of the art robots to navigate environments with the ease that Grey Walter's tortoises had demonstrated with primitive and affordable sensorimotor systems. The more technologically sophisticated work at MIT involved machines building abstract models of environments, and exploring solutions within the internal abstract model of the environment before executing motion in the environment. Knowledge representation, planning, hierarchical analysis, reasoning, path planning, were all areas of research, reflecting a linear and modular conception of human thinking.

Brooks famously argued "the world is its own best model"[135] and proposed that AI research spend less time trying to engineer simulacra of higher-order human functions, before addressing lower order characteristics of living organisms.

> *"Insects are not usually thought of as intelligent. However, they operate in a dynamic world, carrying out a number of complex tasks, including hunting, eating, mating, nest building, and rearing of young. There may be rain, strong winds, predators, and variable food supplies all of which impair the insects' abilities to achieve its goals. Statistically, however, insects succeed. No human-built systems are remotely as reliable."* [136]
>
> *(Brooks, 1991)*

Embodying a bottom-up approach, which the field called 'behavioural robotics', Brooks built 'robotics insects', such as *Genghis* (1989), demonstrating, just as Grey Walter had done almost half a century earlier, that the qualities of life-like and intelligent behaviour can be abundantly found without resorting to computationally heavy processes. After all, nature was full of intelligent forms of behaviour by animals with minimal neural capabilities. As social scientist Herbert Simon pointed out in *The Sciences of the Artificial* [137], "An ant, viewed as a behaving system, is quite simple. The apparent complexity of its behaviour over time is largely a reflection of the complexity of the environment in which it finds itself". He goes on a page later, to argue that human behaviour is also 'largely' explained by the same principle.
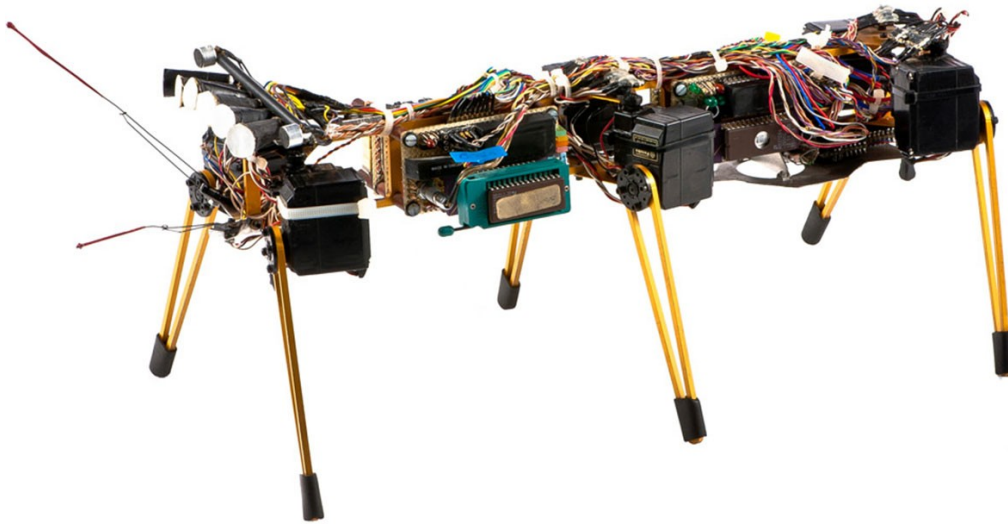
Figure 14. Genghis, an insect-like six-legged robot built by Rodney Brooks at MIT. Complex behaviours, such as 'crawling' emerged from a network of reactive decentralized controllers.

Brooks suggested that many fast and cheap robots could be more effective and far more resilient a strategy, for robotics in hostile environments, than the expensive GOFAI approaches of the time [138]. So frustrated was the research field by technical limitation of the symbolic approach that a substantial segment of the community revisited the sensorimotor cybernetic models of W. Grey Walter.

Bottom-up became the pervasive phrase in the new field of behavioural robotics and artificial life research and nowhere more clearly and concisely is this approach expressed than in Valentino Braitenberg's 1984 book, "Vehicles: Experiments in Synthetic Psychology"[139]. In a series of thought experiments, beginning with the simplest of stimulus response mechanisms, Braitenberg, over the course of short but captivating chapters, takes developmental steps in the complexity of his Vehicles.

Beginning with a single sensorimotor model, Vehicle 1 has one stimulus input and drives a single motor with a linear response. Braitenberg explains, "the more of the quality that the sensor is tuned to, the faster the motor goes".

"As the vehicle pushes forward against frictional forces, it will deviate from its course. In the long run it will be seen to move in a complicated trajectory, curving one way or the other without apparent good reason… Imagine, now, what you would think if you saw such a vehicle swimming

around in a pond. It is restless, you would say, and does not like warm

water. But it is quite stupid, since it is not able to turn back to the nice cold

spot it overshot in its restlessness. Anyway, you would say, it is ALIVE,

since you have never seen a particle of dead matter move around quite like

that." [140] (Braitenberg, 1986)

With a second sensorimotor mechanism introduced, Vehicle 2 is able to steer towards or away from a stimulus. Its behaviour is controlled by both the physical (morphological) arrangement of the sensors and motors, and the location of stimuli in the environment. With a primitive pair of sensorimotor mechanisms, Braitenberg demonstrates the cybernetic principle of goal-directed behaviour, in a similar manner to Grey Walter's tortoises. He also similarly gives accounts of his purposeful machines appearing emotively motivated - driven by fear, love, and other emotions that readers might associate with higher-order cognitive functioning.
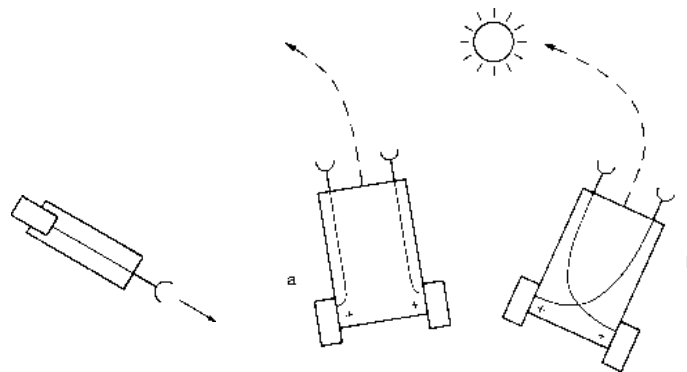
Figure 15. Braitenberg's Vehicles, 1, 2a, and 2b

Increasing again in complexity, Vehicle 3 features a variety of sensors tuned to different environmental stimuli making behaviour far less predictable. Braitenberg attributes the Vehicle as having 'knowledge', or 'knowing' what is best for it - again traits that readers might associate with higher-order cognitive functioning, but that he presents as embodied knowledge held in their morphology.

"You will have no difficulty giving names to this sort of behavior. These

vehicles LIKE the source, you will say, but in different ways. Vehicle 3a

LOVES it in a permanent way, staying close by in quiet admiration from the time it spots the source to all future time. Vehicle 3b, on the other hand, is an EXPLORER. It likes the nearby source all right, but keeps an eye open for other, perhaps stronger sources, which it will sail to, given a chance, in order to find a more permanent and gratifying appeasement."[141]
(Braitenberg, 1986)

Vehicle 4 introduces non-linear relationships between stimulus and response that suggest decision-making and, by Vehicle 5, Braitenberg establishes the idea of inhibitors as the foundations for the logic of a neural networked brain. By Vehicle 6 he discusses chance and its contribution to natural selection, "a source of intelligence that is much more powerful than any engineering mind"[142]. He then goes on to build a primitive eye, for the vehicles to have a picture of their environment, and further features including memory. By his 14th Vehicle, he has described explorer, social and even philosopher Vehicles, suggesting they display free will. A provocation to the reader to consider behaviour and free will not within the machine, but instead in the eye of the observer.

To understand Braitenberg's motivation for this step-by-step assembly to human- like intelligence, we must return to his introduction entitled *Let the Problem of the Mind Dissolve in Your Mind*. After a career in neuro-anatomy, he had come to the view that the problems of intelligent life were not so problematic at all. "While I was counting fibers in the visual ganglia of the fly or synapses in the cerebral cortext of the mouse, I felt knots untie, distinctions, difficulties disappear, difficulties I had experienced much earlier when I still held my first naive philosophical approach to the problem of mind"[143].

For Braitenberg, his Vehicles are intended to carry his readers through a series of insights he had made himself in understanding the building blocks of animate behaviour. A series of thought experiments that start to recognise the role of environment, the knowledge embodied in physical organisation, the intelligence of evolution and, critically, the role of the observer. Braitenberg recognises the difficult distinction between a systemic description and observed behaviour as the "law of uphill analysis and downhill invention" - where we might understand the internal components of an agent, yet not be able to confidently lay claim to why particular behaviours emerge.

"It is pleasurable and easy to create little machines that do certain tricks. It is also quite easy to observe the full repertoire of behavior of these machines -- even if it goes beyond what we had originally planned, as it often does. But it is much more difficult to start from the outside and try to guess internal structure just form the observation of the data. [...] Analysis is more difficult than invention in the sense in which, generally, induction takes more time to perform than deduction: in induction one has to search for the way, whereas in deduction one follows a straightforward path. A psychological consequence of this is the following: when we analyze a mechanisms, we tend to overestimate its complexity." [144]
(Braitenberg, 1986)

Acknowledging Norbert Wiener in his introductory chapter, Valentino Braitenberg's bottom up approach is knowingly cybernetic. Though he makes no mention of Grey Walter, the influence of his tortoises playful disposition to attributing elaborate motivations to his machines is discernible. Brooks and Braitenberg were highly influential in inspiring a new generation of robot makers to animate machines from the bottom up.

As I have mentioned, insects were an early source of study with Brooks arguing that it took evolution far longer to get from nothing to walking insects, than it did to get from walking insects to human intelligence[145]. The provocation to the community was that the hard problem was not human intelligence but getting the fundamental building blocks (technical and theoretical) right. A field of bio-robotics emerged in the 1980s building machines from the bottom up at a fraction of the cost of GOFAI approaches, enabling a proliferation of cheap reactive robots negotiating complex environments that forged new interdisciplinary research.

Taking some of the findings, Brooks' offshoot company Roomba developed a tortoise like robot vacuum cleaner that went gone on to sell more than 14 million units worldwide[146]. But Brooks was indeed right that the building blocks of a bottom-up approach would take time. Brooks somewhat impatient for human level interactions, shifted to a humanoid robot called *Cog*[147]. Continuing to follow principles of bottom-up emergent behaviour, hybridised with some higher-order reasoning capabilities, the childlike robot modelled aspects of infant or primate psychological development through interaction with the physical world, and social exchanges with human beings.

As roboticists Rolf Pfeifer and Fumiya Iida explain, "This was, of course, a happy turn for those who might have been slightly sad or disappointed by the direction the field took – insects simply are not as sexy as humans!"[148] *Cog* and the development of the field of social robotics is discussed in a later chapter. Here, I just wish to point out that in robotics' bottom-up approaches have somewhat diverged between quintessentially cybernetic interests in multi-agent interactions, reframed as the field of embodied artificial life, and humanoid robotics typically focused on one to one interactions, reflecting a predisposition of classical AI to recreate human-like intelligence.

Embodied artificial Life's multi-agent ecological framework, made up of a diverse interdisciplinary community, encouraged holistic approaches that led to a more diverse investigation of behaviour between morphology, materials, control and interaction with the environment. ALife robots were also characteristically primitive in their sensory, motor and (neural) control systems, in the manner of Braitenberg's Vehicles, resisting, for example, the use of high-resolution cameras or complex assemblages of moving parts before attempting to find more computationally and materially economic solutions. Animals, after all, don't have cameras but retinas that perform morphological computations through a non- homogeneous assemblage of the light-sensitive cells.

Sharing the task of designing intelligent behaviour across morphology, materials, control and interaction with the environment, ecologically balanced[149] approaches to robotics provided an essential critical contrast to prevailing Cartesian methodologies. Developments in morphological simulation and digital fabrication have opened up new design practices of programming material behaviour, steered by minimal control systems. A compelling example is the design of passive dynamic walkers[150] that demonstrate the embodied intelligence of bipedal mechanical systems found in nature.

Without the need for powered motors or sophisticated control systems, these mechanical walkers, driven by the potential energy of a shallow slope and the swinging pendulum motion of the legs, move with a balance and grace not found often in robots driven by classical motor control approaches. These machines elegantly illustrate the understanding that intelligent behaviour is not shaped solely by a brain but instead distributed from our heads down to the soles of our feet.

Philosopher and cognitive scientist Andy Clark develops the argument that our minds are inextricably interwoven with body, world and action – an assertation that he acknowledges

has its foundations in Martin Heidegger's *Being and Time*[151], Maurice Merleau-Ponty's *Structure of Behavior*[152], and Maturana and Varela's *Autopoiesis*[153] – by constructing an integrative theoretical framework between robotics, philosophy, and cognitive science. In his 1997 book *Being There: Putting Mind, World, and Body Back Together*[154], he points to the work of behavioural robotics and embodied artificial life research, to support his assertion that we should consider minds not as thinking, but rather as doing, in the world. His 'Extended Mind' hypothesis is characteristically cybernetic, describing mind as not restricted to an agent, but rather bound to its environment through continuous circular interaction. Here interaction is not merely instrumental, but rather it constitutes cognition and life itself.

One might argue that Maurice Merleau-Ponty's 'Phenomenological' cognition is also characteristically cybernetic in its search for stability - a continuous active process in which "our body is not an object for an 'I think'…" but instead, as Merleau-Ponty explains, "…a grouping of live-through meanings which moves towards its equilibrium". His notion of perception is a performative act of bodily- mediated perception coupled to motor-action, "the 'perceptual side' and the 'motor side' of behaviour are in communication with each other"; "every perceptual habit is still a motor habit".[155]

Habits, to Merleau-Ponty, are behaviours that through repeated action construct stability in perception. This performative relationship between the behaving body and the world it constructs he explains as "the relations between consciousness and nature, between interiority and exteriority"[156]. A central discussion in his *Phenomenology of Perception*, is that these relations may not be linear in causation, enabling our embodied experience of our own behaviour to translate into other perceptions of other bodies performing. "Perception does not present itself in the first place as an event in the world to which the category of causality, for example, can be applied, but as a re-creation or re-construction of the world at every moment"[157]. Perceptions of animate behaviour, from a phenomenological perspective, are not reduced to "a certain indescribable state or quale", but rather a means to access the world. Our perception of animate behaviour in our environment is bound to our own embodied animate behaviour. Varela proposes the term 'Embodied Mind', drawing upon the work of cybernetician Gregory Bateson's *Ecology of Mind*, Heinz von Foerster's *Constructed Realities,* and his work with Humburto Maturana on *Autopoesis*. By replacing the word cognition for mind, he attempts to separate from computational cognitivist tendencies, and to ground mind within an embodied dynamical process that he terms "enaction"[158]. This binding together, arguing for organic living structure and the mechanism of cognition are two facets of the same phenomenon of life.

"Organisms do not passively receive information from their environments, which they then translate into internal representations. Natural cognitive systems...participate in the generation of meaning ...engaging in transformational and not merely informational interactions: they enact a world." [159] *(Di Paolo et al, 2010)*

This idea resonates with George Lakoff and Rafael Núñez in their provocative book *Where Mathematics Comes From*[160], where they argue that even highly abstract concepts, such as 'numbers', or 'limits' are concepts that are ultimately a construct that reflects our embodiment and interaction with our world.

Mathematical concepts are based on metaphors, such a point 'moving' towards infinity. Our movement - the interaction and transformation of physical objects - ground these metaphors in embodied cognition. Therefore, they argue, spatial, social cognition and rational problem solving, natural language and other forms of reasoning are also ultimately grounded in embodied cognition.

Evidence of a cognitive architecture for this coupling of perception-action, sensorimotor processes in the context of social interaction has been identified in neurological research by Rizzolatti and Luppino. They describe it as the "execution/observation matching system", popularly termed 'Mirror Neuron System', which is involved in both perceptual and motor behaviour. Vittorio Gallese suggests that this region, involved in controlling our own body movement through space, may also shape our understanding of the agency[161] of other animate bodies. By being not only able to guide our embodied motor action, but also our embodied simulation of action, he suggests that Mirror Neurons may provide a neurological explanation for how we emotionally empathise with the performance of other bodies. Gallese and Freedberg argue that processes of embodied empathy have aesthetic qualities[162] that are universal and essential in appreciating static imagery, sculpture or dance.

Antonio Damasio argues forcefully for the importance of embodied thinking in Descartes' *Error: Emotion, Reason, and the Human Brain*[44], examining how, alongside the perceptual cues that are acknowledged to shape cognition, the body murmurs with emotional information, that are essential parts of cognition but remain under examined, in part because of their appearance of irrationality. Damasio's critique is that cognitive science which, like AI research, tends towards rational and computation approaches to mind, have been reluctant to acknowledge that feelings exist and are important. His critique in particular takes aim at

cognitive science's reductive approach to discussing human experience, namely rationality of Cartesian 'Theories of Mind'.

2.4 Cybernetic Performativity

"The entire task of cybernetics was to figure out how to get along in a world that was not enframable, that could not be subjugated to human designs—how to build machines and construct systems that could adapt performatively to whatever happened to come their way." [163] *(Pickering, 2010)*

Coming to understand the emergence of meaning through a temporal process of embodied interaction with things and other agents in our environment, is to engage in what Andy Pickering has called a 'Performative Ontology'. Pickering's notion of performative behaviour is embodied and adaptive, emerging from circularities of interactions between agent-systems and environments - a situated sensorimotor action in which the brain is a "performative organ rather than a cognitive one"[164]. This is an understanding rooted in the central discourse of cybernetics that, as I have discussed in chapter one, was shaped by the embodiment of theories of life and cognition within animated machines.

"To some, the critical test of whether a machine is or is not a 'brain' would be whether it can or cannot 'think.' But to the biologist the brain is not a thinking machine, it is an acting machine; it gets information and then it does something about it." 165 *(Ashby, 1948)*

In opposition to Cartesian modes of dualist thinking, the emergent performance of embodied machines resisted the reductive and symbolic, instead steering their paths through the complex and continuous. As I have emphasised this is a fundamentally cybernetic approach, but to portray the discipline as being entirely antirepresentational would be a mischaracterisation. Cybernetic textbooks filled with mathematical equations, and logic diagrams, pursued a common language. Yet, we see the practices of the founders of the field showed an intense suspicion of making representations of the world, instead approaching problems through embodied behavioural artefacts. Besides the aforementioned

work with analogue electronics, the Chemical experiments of Gordon Pask and the extensive work of the Biological Computing Lab founded by Heinz von Foerster, demonstrate a resistance to symbolic reductivism, even though it remained useful within the axioms of established scientific practice. Even Ashby's 'Black Box', which describes the construction of conceptual apparatus to interact with the world, is a performative representational construct, rather than a symbolic representational one, as a 'Black Box' is a responsive acting thing, that one acts upon, and the 'Black Box' acts back - entering into an adaptive exchange that Pickering has called a "dance of agency"[166].

> *"As ontological theater, then, a multihomeostat setup stages for us a vision of the world in which fluid and dynamic entities evolve together in a decentered fashion, exploring each other's properties in a performative back-and-forth dance of agency."* [167] *(Pickering, 2010)*

This metaphor of a dance is one of negotiating adaptive embodied actions in search of stability, as Ashby's *Homeostat* had first demonstrated. Pickering's choice of the metaphor of a dance also alludes to the latent theatricality of observing the indeterminate unfolding of interactions. Rather than predictable or pre-choreographed, cybernetic machines displayed a 'life of their own'. It is my opinion, that the animate behaviour found in cybernetic Machines encouraged their designers, to view their machines as life-like agents, and that this inspired circulatory and participatory models of interaction that were creatively surprising, and aesthetically richer than models based on reductive and linear control.

Gordon Pask's Musicolour

Gordon Pask was the first cybernetician to recognise and explicitly harness the theatricality of these Lively Artefacts in a series of staged performances. As a Cambridge undergraduate Pask, and his friend and long time collaborator Robin McKinnon-Wood, took an interest in building novel machines, by repurposing bits of bombsight computers and musical instruments[168], fashioning together various curiosities including a musical typewriter and a self-adapting metronome. Inspired "by the concept of synaesthesia and the general proposition that the aesthetic value of a work can be enhanced if the work is simultaneously presented in more than one sensory modality"[169], Pask presented for the first time, in 1953,

his *Musicolour* live performance machine.
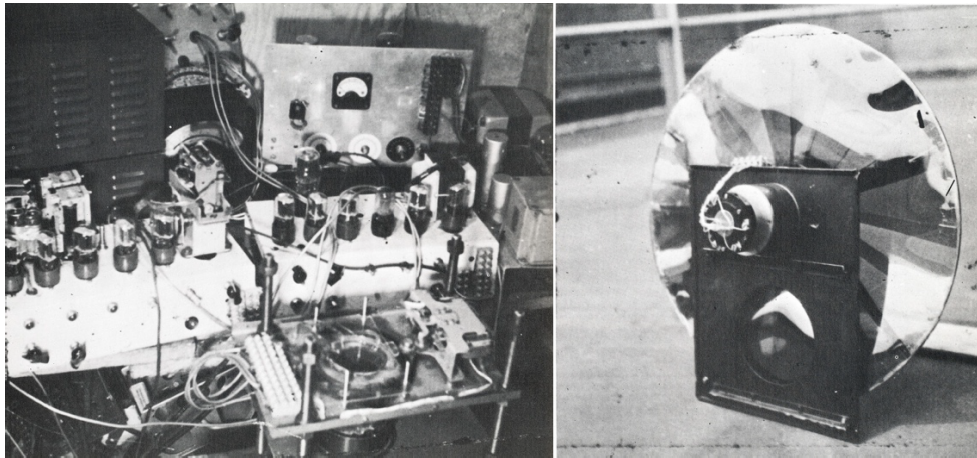
Figure 16. Gordon Pask's Musicolour (1953-57), Left: Experimental electrical control rig, Right: Servomechanism driven projection wheel[170]

A touring rig of coloured lights that responded to audio input from human musicians, it travelled with Pask around England performing at many cabaret and night clubs, while modifications were made to its design. Pask's account of this period of experimentation, described in *A Comment, a Case History and a Plan*[171], tells how, as these performances developed, his interest turned away from synaesthesia and towards adaptive learning behaviours. Unlike modern disco lighting systems that are typically pre-programmed and predictable in their behaviour, Pask was interested in the possibility of *Musicolour* as a performer itself, in co-operation with musician performers. His approach was to make its responses less predictable by giving it the capacity to get bored, dimming its lights and becoming less responsive, if its musical partners played a rhythm that was too static or the frequency range was too consistent. This would, in turn, encourage the musicians to continually perform something novel.

> *"The result (at least when the performer cooperated) was a continuous flow of improvisation; a "conversation" where the performer and apparatus flowed into the other with action and response...At another level it is dialogue without a set script; an unfolding of events delimited by the range of the performer." [172] (Pangaro ,1993)*

Musicolour was presented in a wide range of contexts to different audiences, some engaging in it more than others. It was through these valuable staged experiments that Pask was able

to observe its effects on both the audiences observing, and performers interacting with, it. This theatrical period in Pask's development of a cybernetic practice sowed the seeds for his development of theories of human- machine interaction based on models of messy conversational exchange. An approach to machine behaviour starkly in contrast to the linear master-slave models of von Neumann's models of computing, that have become doctrine for so called interaction design and user interface design today. As Paul Pangaro, a student of Pask and scholar on interaction design models argues, "Most modern interface designs… do not involve 'interacting' very much at all. They are more like command-line instructions dressed up in drag"[173]. Pask's models of interaction explored multiple participants, human or machine, each with their own goals searching for stability (control) of their environment. By coupling the musicians' purposeful actions and *Musicolour's* purposeful responses, a dynamic stability was created that neither could predict or produce without the other. Both human and machine were adaptive to each other leading to a truly open-ended and emergent space of performative possibilities.

With every different musician or different audience, the criteria of stability would change, and so too would the emerging music and light show. This had clear aesthetic advantages, but also created new challenges compared to the use of predictable pre-choreographed lighting systems. Pask described the feedback loop as leading to "an almost hypnotic effect upon the performer"[174], though not always leading to as compelling and experience for its audiences. While musicians could construct an understanding of *Musicolour's* behaviour through purposeful musical inputs into the system, and observe the resulting responses, audiences would require a sensitive enough ear to recognise those inputs and connect them to resulting outputs. It is likely that such a new genre of performance would have been particularly challenging for even the most avant-garde of audience to find legible, at least enough to construct their own understandings of the ongoing exchange.
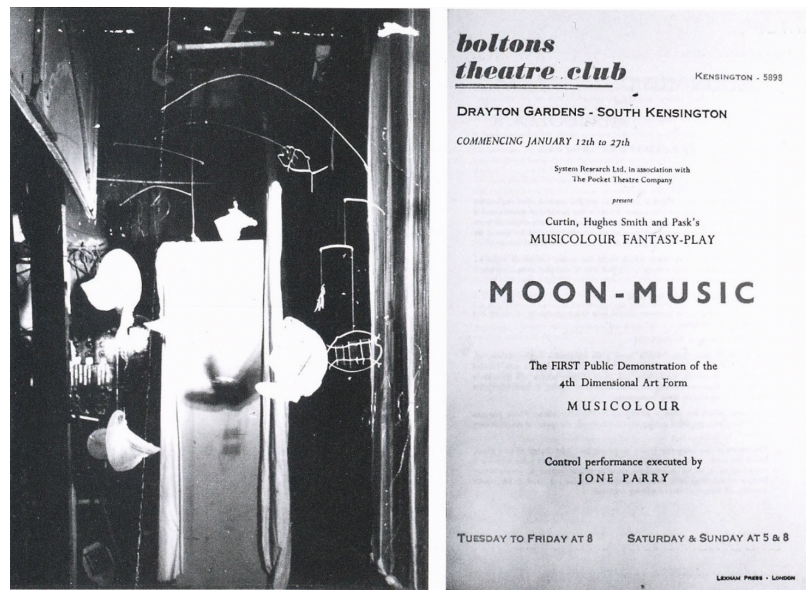
Figure 17. Records from Musicolour presented at Boltons Theatre Club, South Kensington in 1954.

Left: Stage with projection screen for Musicolour. Right: Event poster[175].

Musicolour satisfies Pickering's notion of performative behaviour as embodied and adaptive, emerging from circularities of interactions, but there is another distinct notion of performative in the work. That, of staging a multi-sensory performance between human and machine, as an aesthetic act. I will hereon in describe the first notion as 'Cybernetic Performativity', and the later as 'Staged Performativity'.

Musicolour satisfies both of these descriptions, Ross Ashby's *Homeostat*, would only meet the first. Grey Walter's tortoises were perhaps built to engage in a study of Cybernetic Performativity but their compelling animacy led to multiple appearances on television and at many expos turning them into minor celebrities. In their staging to delight audiences, we can say that they also satisfy the later notion of performativity*.*

Behaviourist Art

From the 1960s, artists began to take an interest in these new aesthetic possibilities. British educator, artist and theoretician Roy Ascott was one of the earliest and most influential practitioners to build a theoretical framework for the production of what he called 'behaviourist art'[176,] which brought together elements of the avant-garde with the systemic "spirit of cybernetics". Ascott argued that a cybernetic form of art would free itself "from the modernist ideal of the perfect object". An ideal already under sustained critical attack from the participatory art of Fluxus Happenings, and the dynamic, unstable, ambiguous and polemic works of kinetic, optical, and conceptual art. Ascott explains, "The vision of art has shifted from the field of objects to the field of behaviour and its function has become less

descriptive and more purposive" [177]. His choice here of the word purposive, points to the fundamental cybernetic principle of feedback control. He goes on to say, "The participational, inclusive form of art has as its basic principle "feedback," and it is this loop which makes of the triad artist/artwork/observer an integral whole" [178].

Describing such feedback systems as a common feature of computer-based art today, artist and educator Golan Levin discusses how a "feedback loop can be established between the system and its user(s) — allowing a user or visitor to collaborate with the system's author in exploring the possibility-space of an open work, and thereby to discover their own potential as actors"[179]. These systems produce aesthetic work, but unlike mere instruments of production, they are in themselves aesthetic works. Artists exploring these types of systems are often process orientated[180], and less concerned with the aesthetic value of what's produced than they are with the aesthetic experience for the performers and audiences of these open-ended exchanges.

Figure 18. Myron W. Krueger's VideoPlace "An artwork that happened to be interactive, but to raise interactivity itself to the level of an art medium."[181]

With video and audio processing available on increasingly affordable, and miniaturised computing devices, the past couple of decades have seen an explosion in installation art that uses camera and sound input to gather data about human behaviour in space. A field that pioneer Myron Krueger called "responsive environments"[182] has emerged, not only leading to work for art galleries, but increasingly in public space and on commercial media displays from the scale of advertising signage, to architectural facades. Myron Krueger's work between 1969 and early 1990s was decades ahead of its time and continues to be sadly under- acknowledged for its foresight, and technical sophistication. His *VideoPlace* installation is an example of a continuously iterative experimental practice in which he would

develop its behaviour, invite people to explore the responsive environment, observe its aesthetic successes and failures and develop further versions, finessing its behaviour over time. Feedback-response was in this sense the medium of the work, and his writings on his observations about the immediacy of feedback response remain important.

> *"It is the composition of these relationships between action and response that is important. The beauty of the visual and aural response is secondary."* [183] *(Krueger, 1977)*

Krueger and the participants who perform with his responsive environments share in "an aesthetic experience on the boundary between the aesthetics of production and the aesthetics of reception"[184], and the possibility of meaning being constructed in unexpected ways through this exchange. This Staged Performativity transfers creative control to participant performer(s) away from the artist, and may also involve the transfer of control to participant machine performer(s), but does not satisfy the definition of Cybernetic Performativity. Pask's *Musicolour* was the first such example of a machine that had a degree of control that was adaptive to an ongoing exchange, getting bored and less responsive if human performers were repetitive. Its adaptive behaviour was shaped by a history of interactions, distinct from Krueger's work that, while unquestionably ground breaking, was not adaptive to input stimuli, limited to pre-configured responses. *Musicolour* was, by contrast, capable of novelty, beyond a catalogue of pre-choreographed routines, in the open-ended exchange of performer and machines. Today, with an enormous variety of responsive environments being produced in artistic and commercial contexts, I would argue that contemporary work remains limited to reactive models of 'Staged Performativity' that, on aesthetic grounds, without 'Cybernetic Performativity' miss opportunities for novelty.

To make the case for the potential pitfalls of reactive models, we can look to a commonly cited example of a responsive environment, David Rokeby's installation *Very Nervous System* (1986-1990). Rokeby was an artist whose discontent with the limitations of computer interfaces, led him to develop an installation to "draw in as much of the universe's complexity into the computer as possible"[185]. For its time, it was a sophisticated computer vision system detecting accurate location and movement information, which was then interpreted, and mapped to a bank of sounds and instruments.
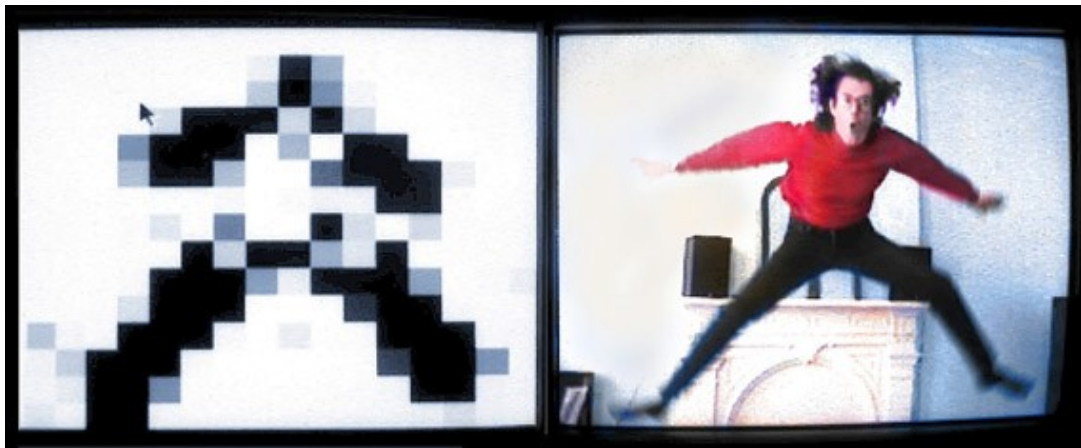
Figure 19. David Rokeby's Very Nervous System, computer vision sensing

The system constructed by Rokeby comprised video cameras, image processors, computers, synthesisers and a sound system. He personally developed and mapped out the sounds through his own experimentation in front of the camera and, as a result, was able to achieve a considerable level of control, much like a musician using his own musical instrument, so that "that every 'pixel' of the space corresponds to a sound"[186]. In a metaphorical sense, he knew what keys to press. When *Very Nervous System* was first presented in Vancouver, Rokeby was surprised by how difficult other people found it to use. Over time, however, people began to play with the space, become aware that the system was reacting to even very subtle gestures, and started to build mental maps of the spatialised instrument. The complexity and surprising musical expressions that came out of this system were, however, not of the machine's doing, rather the result of the complexity of human movement within space.
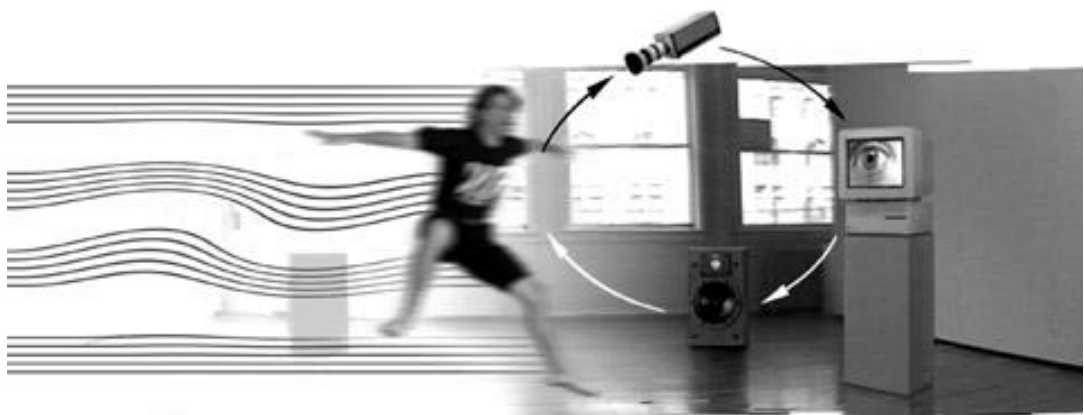
Figure 20. Illustration by David Rokeby of the reactive feedback loop.[187]

Scholar Luísa Ribas defines work in this genre as interactive performativity, and Rokeby himself describes the work as an interactive environment. However, I would argue the artist's systemic description, could be better described as a reactive environment, or constructing a reactive performativity. *Very Nervous System*'s behaviours are not adaptive to an ongoing exchange but are rather fixed, so that a particular, sensed gesture will trigger the same audial response. *Very Nervous System* is an open-end space for exploration of sounds mapped into space, not dissimilar to the mapping of tones to keys on a keyboard. It is not, however, designed to act as a performer itself, but rather as an instrument to control. In an interview Rokeby described how he wished to create systems of "inexact control" and this is a common ambition of artists in the field, but the lack of criticality on what constitutes interaction, I believe, limits this work from achieving his intended goal.

> *"I think that the computer is the result of a fetishization of control and so I like, in my contrary way, to work against that dominant paradigm. Control is over-rated...or perhaps it is better to say that we need to learn to balance control which is very useful in surgery or driving, with other sorts of engagements with other things and otherness that are looser than control relationships where we allow ourselves to be open, engaged and willing to be surprised. Otherwise life is dead."* 188 (Rokeby, 1998)

The desire to make artworks that not only surprised the audiences, but also the artists themselves, became a notable characteristic of mid to later 20th century time-based art practice. John Cage, a leading figure of the post-war avant-garde, experimented with computer music using randomisation or chance within parameters defined in the ancient Chinese book 'I Ching', as a generator for constructing musical scores for performances. The use of random, provided a degree of indeterminacy that was aesthetically appealing, though the possibility for novelty was limited to results within a range algorithmically defined by the artist, falling some distance short of generating the type of novelty that might be possible, for example, between two improvising dancers.

2.5 Performative Ecologies

With the metaphor of an improvisational dance in mind, *Performative Ecologies* is an investigation into the design of embodied interactive agents. Made up of four autonomous attention seeking robotic "dancers" which search out people and begin performing using their

illuminated "tails". Each robotic agent autonomously manages its own performances which are generated from a computational gene pool of evolving short "dances" whose fitness are measured by how much attention they receive from the public. The on-board camera assesses attention levels based on orientation of the audience before and after each short performance.

Over time successful manoeuvres are kept and recombined to produce new performances while less effective ones are discarded. The robots also are capable of sharing performances with each other so they have competitive and collaborative behaviours with their neighbours. They compete for the attention of human spectators, and share performance data when there are no spectators around.
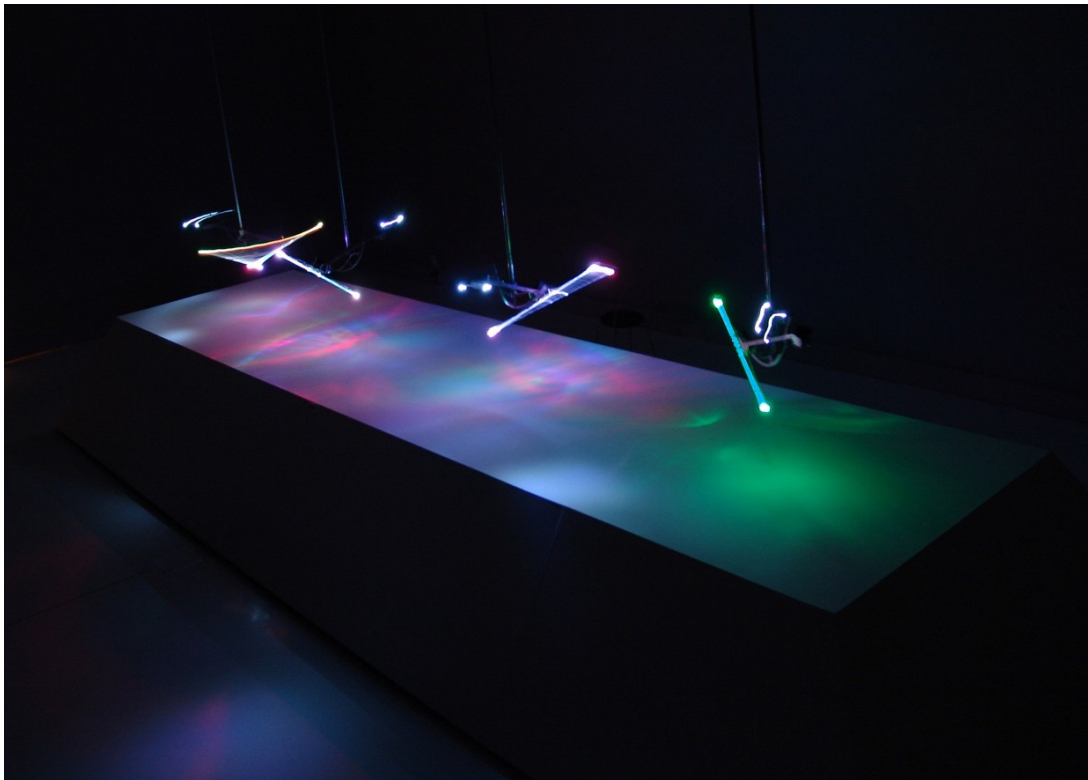
Figure 21. Performative Ecologies exhibited at Instituto Itaú Cultural, Sao Paulo (2008)

The term ecology is used here in two ways. One is the idea of multiple classes of agency, with varying goals and behaviours in a shared environment. The robots perform with their 'tails' to the human audiences. In return the human beings gesture interest with their gaze and proximity. Human spectators also perform to other human spectators in a variety of social forms. The robots also perform to each other when sharing performance data. So, this notion of ecology touches on the rich web of communicative exchanges that occur in complex interacting systems. The second important idea that is central to ecological theory is

adaptive behaviour. Ecosystems, and the agents within them are adaptive to changing circumstances. Ernst Haeckel coined the word 'Oecologie', referring to the study of the relationship of organisms to their surroundings. In his popular 1876 English edition *History of Creation*[189], he noted that Darwin's doctrine of adaptation provided the law-like nature to explain ecological relationships.

Genetic Algorithm

These ideas have become influential in design. Architect John Frazer's early work in harnessing evolutionary processes, had the goal of not merely copying the work of nature in architectural form, but through adaptive behaviour, "relating architecture to the new holistic understanding of the structure of nature" [190]. Frazer's ecological approach was not to replicate "natural ecosystems, but the general principles of interaction". This could be described as a soft artificial life strategy, Frazer himself exploring the behaviour of cellular automata with genetic algorithm (GA) evolved rule sets. Pask, in his foreword to Frazer's book *An Evolutionary Architecture*, suggests that working with these life-like behavioural systems changes the role of the architect, "to not so much […] design a building or city as to catalyse them; to act that they may evolve" [191]. This notion of emergent co-creation has precipitated an enormous field of computational design techniques. A critique of the current state of evolutionary inspired computational design I have is that, whilst generally highly adaptive and responsive in the digital design space, the realisation of this evolutionary architecture in the physical world is largely static and unresponsive, seemingly frozen in a form of cryogenic stasis. *Performative Ecologies* was an effort to explore what an ecological architecture could be, where ecological processes (like evolution) could go beyond the digital design phase and enter into the operation (even life) of built environments.

> *"When man wanted to fly, he first turned to natural example--the bird-to develop his early notions of how to accomplish this difficult task. Notable failures by Daedalus and numerous bird-like contraptions (ornithopters) at first pointed in the wrong direction, but eventually, persistence and the abstraction of the appropriate knowledge) resulted in successful glider and powered flight. In contrast to this example, isn't it peculiar that when man has tried to build machines to think, learn, and adapt he has ignored and largely continues to ignore one of nature's most powerful examples of adaptation, genetics and natural selection?"* [192] *(Goldberg, 1986)*

Genetic Algorithms is a method of search and optimisation, following evolutionary concepts and inspired by the chromosomal processes of genetics. A GA starts with gene pool of random solutions, typically stored in binary strings. In the case of *Performative Ecologies*, its genotype was 14bit string that can be broken down as follows.

6 bit Colour   Colour Range of 64 RGB combinations, 2 bit per colour

3 Bit Speed   8 Speeds (applied to lighting pattern and tail motion)

3 bit Tail Swing   8 swing ranges from possible

2 bit Lighting   4 lighting effects (pulse, flash, on, off)

Each generation of phenotypes, which encoded a short dance would be performed and a facial recognition algorithm would measure attention and proximity. The 'fittest', highest ranked dances are retained as "parents" for the next generation of dances. The weaker die out. In pseudocode this can be understood as follows

```
BEGIN

INITIALISE Population (gene pool) with random phenotypes (dance)

LOOP START

IF(Face Detected)

ACTIVATE phenotype (dance)

EVALUATE fitness of solution IF(All Phenotypes Evaluated)

SELECT fittest phenotypes as "parents"

RECOMBINE pairs of phenotypes

MUTATE the phenotype of offspring a percentage REPEAT FROM LOOP
START
```

A GA works in generations, using three operations: reproduction, crossover and mutation. In GA algorithms, there is typically a termination criteria to be satisfied. In the case of *Performative Ecologies* the machines continue to perform endlessly. GA's are a widely utilised search and optimisation technique first developed by John Holland in 1965 and published in 1975 in *Adaptation in Natural and Artificial System: An Introductory Analysis with Applications to Biology, Control, and Artificial Intelligence* [193]. They have since become

hugely popular, primarily because of their simplicity, but also their capacity for parallel computing. Many phenotypes can be evaluated against fitness criteria, over many parallel processing units, allowing for thousands, or millions of combinatorial solutions to evaluated quickly. Another feature of GA is their 'global perspective', which means that a very wide net is cast with the random seeding of generation zero. Classical methods for search and optimisation often converge on local solutions and therefore struggle to have the breadth to solve complex problems efficiently.
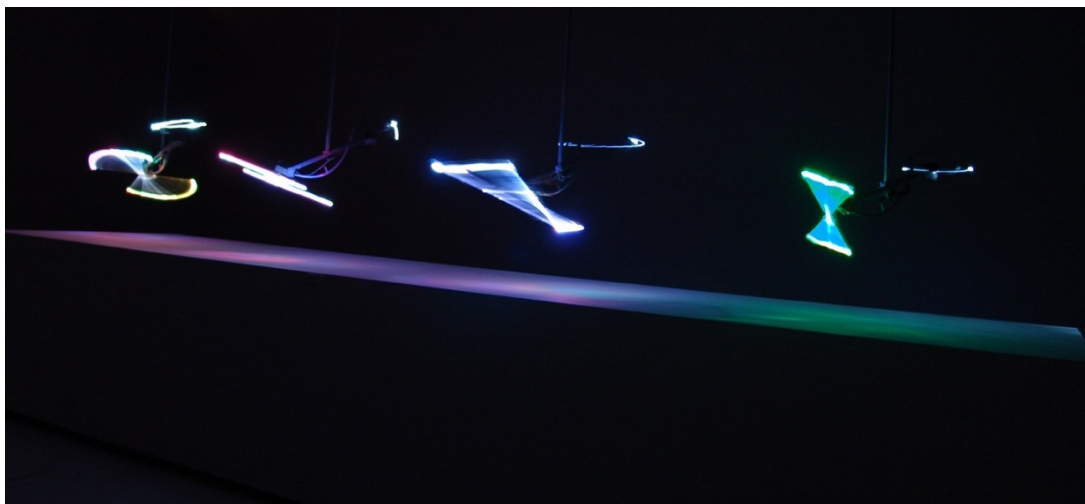
Figure 22. Each robot autonomously test out their own continually evolving performances.

GA's attraction was their capacity to arrive at novel solutions that were tricky to reverse engineer, making the results mysterious and, at times, pleasurably surprising. Karl Sim's evolved virtual creatures are perhaps one of the best known and loved examples of their application to create artificial life within an arts context. However, the use of GA for the adaptive behaviour of physical objects has the challenge of testing solutions in a physical world, which takes time - a lot of time if there are many possible solutions. A dance, for example, took between five and 15 seconds. Holland and collaborator Goldberg commented that "genetic algorithms... have often been attacked on the grounds that natural evolution is simply too slow to accomplish anything useful in an artificial learning system; three billion years is longer than most people care to wait for a solution to a problem"[194]. To address this issue I took advantage of the parallelism of GA methods. Four autonomous robots were built, each evolving performances in parallel and exchanging data at intervals. Still, with a genotype of 2^{14} (16384) combinatorial possibilities, the search space remained large enough to require thousands of performances over the course of a number of gallery exhibitions.

Figure 23. Exhibition of Performative Ecologies at the VIDA 11.0 Exhibition in Madrid (2009), robots perform while observing the success of their performance on the public.

Installation

At each exhibition, the robots were installed in different formations, and randomly seeded at the opening. This meant that in the first few days, performances were very unpredictable. Patterns were found to emerge only after weeks or months of performance. The waiting game was a curiously pleasing aspect of the project. During the 3month exhibition at Instituto Itaú Cultural in Sao Paulo, where they performed to tens of thousands of visitors, each robot developed distinct characters. On my return to the gallery to de-install the work I was amazed to find the gallery attendants responsible for taking care of the robots had individually named each robot, and could speak at some considerable length about their individual personalities. This was unexpected, as the impression of these robots as living creatures had not been in the work's original design intent, however, it quickly became its key talking point. Meanwhile my interest in discussing embodied and adaptive behaviour would at times be overlooked. The hook was the animacy, and the intellectual pursuits of the project became secondary in conversation. This was a useful lesson, and also seemed to be advantageous in public galleries, where audiences are often seeking playful and intuitive interaction first, and challenging ideas later.

> *"Performative Ecologies moves beyond more simple reactive paradigms which have become standard fare in interactive installation, but which amount, most commonly, to little more than virtual button pushing. Here Glynn succeeds in three related goals which together are something of a holy grail for researchers in robotic arts - to develop a system in which agents change and develop as a result of their experience; to share their knowledge with each other; and to make that learning and exchange directly and immediately sensible by humans."* [195] *(Penny, 2009)*

My motivation for *Performative Ecologies* was not to achieve life-like behaviour, it was to question interaction models, particularly what differentiated reactive from interactive behaviour. The cybernetic and ecological notion of adaption seemed most important. Embodiment was not necessary, but the potential for what Pask called a "prevailing mode of discourse" to develop, seemed essential. The issue of long periods of time required in an environment for *Performative Ecologies* to adapt was not in my mind a problem. The work in the context of its production at the Bartlett made me comfortable with change occurring potentially over months, seasons, or even the life time of a building, rather than over the course of brief interaction encounter, such as in a gallery environment. The true spectators of the interaction were the gallery staff and they developed the strongest sense of these machines' 'lives', with a rich account of the robotic dancers development and emergent eccentricities. For the public visiting the gallery, there is still a simpler but nonetheless irresistible sense of life without the need to witness or appreciate their adaptive behaviour. The robots purposeful motion, orientating their heads towards inhabitants, and then aligning their bodies once 'eye-contact' had been established, created the immediate sense they were actively observing and performing to visitors.

2.6 Aesthetics of Cybernetic Life

A decade after *Musicolour*, Pask developed his *Colloquy of Mobiles* installation. The "socially orientated reactive and adaptive environment"[196] was presented at the *Cybernetic Serendipity* exhibition (1968) curated by Jashia Reichardt, and his paper *A Comment, a Case History and a Plan* was published as part of the exhibition publication *Cybernetics, Art and Ideas*[197]. In it he discusses the properties of "aesthetically potent environments" designed to encourage pleasurable interactions. He gives such an environment four key attributes:

It must have sufficient variety to provide the potentially controllable novelty required by a man (however, it not swamp him with variety - if it did, the environment would merely be unintelligible).

It must contain forms that a man can interpret or learn to interpret at various levels of abstraction.

It must provide cues or tacitly stated instructions to guide the learning and abstractive process.

It may, in addition, respond to a man, engage him in conversation and adapt its characteristics to the prevailing mode of discourse." 198 (Pask, 1971)

In particular, it is in the final attribute that Pask describes the potential for interaction with an aesthetically potent environment. His use of the term conversation, predating his formulation of 'Conversation Theory'[199], points to exchange between participants, rather than top-down master-slave control. "Close participant interaction" develops, through a circularity of communication, as both human and the machine adapt and learn about each other. He rather modestly states that his own work only goes "some way" towards satisfying attribute (d) and makes the point of asserting that machine interaction is not a necessity of an aesthetically potent environment.

"A painting does not move. But our interaction with it is dynamic for we scan it with our eyes, we attend to it selectively and our perceptual processes build up images of parts of it... Of course, a painting does not respond to us either. So once again it seems deficient with reference to

d. But our internal representation of the picture, our active perception of it does respond and does engage in an internal conversation." 200 (Pask, 1971)

His discussion of the experience of paintings as similar in some respects to the dynamics of

cybernetic artworks, is a clear attempt to bridge two disparate cultures of designing machine behaviour, and the production and reception of the arts. Pask's notion of an internal dialogue, constructing experience, emerging from active perceptual processes, is quintessentially cybernetic. His contribution to the field is to recognise that this internal dialogue can be considered aesthetic, and that the dialogue can be shared between the artwork and audience. A new domain of aesthetic dialogue created between the performative agency of the artwork and performative agency of gallery visitors.

"Man is prone to seek Novelty in his environment and having found a novel situation, to learn how to control it...These propensities are at the root of curiosity and the assimilation of knowledge. They impel man to explore, discover and explain... they lead him into social communication, conversation and other modes of partially co-operative interaction... My contention is that man enjoys performing these jointly innovative and cohesive operations. Together they represent an essentially human and inherently pleasurable mode of activity."[201] (Pask, 1971)

For Pask, who explored behaviour through a performative lens, the social and exploratory behaviour that came from encountering novel situations, driven by an unquenchable human curiosity, supported learning. The impulse to learn, to take control of one's environment, is pleasurable. Aesthetics might, within a cybernetic lens, be considered a feedback reward, towards control. These highly novel experiments challenged preconceptions of the art objects. With their lively behaviour, at an anthropomorphic scale, they would have trigger ambiguous perceptions of animacy that encouraged audiences into participatory interaction to make sense of these experiences.

By contrast, Herbert Franke's *Cybernetic Approach to Aesthetics*[202] follows the informational model of Claude Shannon, and tackles aesthetics as a mathematical theory of communication. This leads to reductivist and contentious statements, such as "a new guideline for making artworks can be proposed: artists should provide a flow of information of about 16 bits/sec. If this is done, one might expect feelings to be stimulated that are associated with beauty, harmony, etc."[203] Franke's version of cybernetic aesthetics attempts to reach a more "objective means of evaluating the effectiveness of artworks", but finds itself raising more questions than it answers, not least because of the implausible challenge of measuring the 'amount of information' in an artwork at any one moment. Similarly, the

'Information Aesthetics', of Max Bense draws influence from cybernetics, though again leaning heavily to Shannon's computational communication theories and David Birkoff's mathematical theory of aesthetics (1928-33).

> *"Today we have not only mathematical logic and a mathematical linguistics, but also a gradually evolving mathematical aesthetics. It distinguishes between the 'material carrier' of a work of art and the 'aesthetic state' achieved by means of the carrier. The process is devoid of subjective interpretation and deals objectively with specific elements of the 'aesthetic state' or as one might say the specific elements of the 'aesthetic reality'. These elements are pre-established and their appearance, distribution and formation is described in mathematical terms. Thus this new aesthetics is simultaneously empirical and numerically orientated."* [204]
> *(Bense, 1971)*

Bense's rationalist theories of aesthetics were quintessentially Cartesian, and it is striking that they appear in *Cybernetics, Art and Ideas*[205], alongside Pask's paper *A Comment, a Case History and a Plan*. As a field, cybernetics had already begun bifurcation into new disciplinary fields, adopting particular features of its progenitor. The rise of digital computation, encouraging rationalist aesthetics, to match the media of enquiry. As he was head of the Stuttgart school[206], Bense's 'Aesthetics'[207] were influential on the first wave of generative computer artists, including Frieder Nake and Georg Nees. Their means of production was based on the algorithmic use of simple rules, to generate complex aesthetic results. By contrast, Cybernetic art embodied in Pask's *Colloquy of Mobiles*, pursued the manageably complex from the extremely complex. A similar comparison, I would argue, could be made between Cartesian Computationalist, and embodied cybernetic, approaches to understanding aesthetic experience.

The dichotomy of Cartesian and embodied forms of aesthetics can, in part, be attributed to rationalist discourses of the Enlightenment. Immanuel Kant's claim that, "a judgment of taste is not a cognitive judgment and so is not a logical judgment but an aesthetic one" has the effect of devaluing questions of aesthetics to a murky domain of subjectivity, discouraging scientific study and placing it in the domain of art history and criticism. This led to the bourgeois notion of aesthetics, disconnected from daily existence. Philosopher of aesthetics Mark Johnson gives an example of this transcendent attitude to aesthetic experience from

English art critic, Clive Bell[208].

"For, to appreciate a work of art we need bring with us nothing from life, no knowledge of its ideas and affairs, no familiarity with its emotions. Art transports us from the world of man's activities to a world of aesthetic exaltation. For a moment we are shut off from human interests; we are lifted above the stream of life." [209] *(Bell, 1914)*

Kantian Aesthetics were fundamentally Cartesian, drawing distinction between perception and conception, reasoning and emotion, and relegating aesthetics to non-cognitive, non-rational and private judgments of feelings, separated from the rational construction of meaning. Contemporary embodied theories of aesthetics promoted by Mark Johnson, however, present the opposite notion, that in fact aesthetics, in the everyday, is "at the heart of our capacity for meaningful experience"[210]. Aesthetic conditions are not solely found in the hallowed halls of galleries, palaces and museums, or on stage in theatres. Rather aesthetic experience is pervasive, constituting our "visceral, emotional, and qualitative" [211] relationships to our world.

Johnson's notion of embodied aesthetics builds upon the biologically grounded discussion of John Dewey's *Art as Experience[212]* that describes man, whom he calls the "Live Creature", actively constructing his experience situated and physically bound to his environment. He states, "An experience is a product, one might almost say bi-product, of continuous and cumulative interaction of an organic self with the world. There is no other foundation upon which esthetic theory and criticism can build" [213]. Dewey's call for a 'pragmatic aesthetics' dissolving the notion of aesthetics theory as a separate subject to that of our everyday lived experience of the world. Recent neuro-scientific studies of aesthetic experience also support the understanding that there is "no specific neural network dedicated to aesthetics"[214]. Aesthetic discourse in the context of the arts practice represents an intensified focus on the daily processes of constructing meaning, heightening particular qualities that might otherwise be difficult to articulate in words or concepts.

"Reasoning must fail man—this of course is the doctrine long taught by those who have held the necessity of divine revelation...ultimately there are but two philosophies. One of them accepts life and experience in all its

uncertainty, mystery, doubt, and half knowledge and turns that experience
upon itself to deepen and intensify its own qualities—to imagination and
art." [215] *(Dewey, 1934)*

Johnson picks up on Dewey's continuity between mind and body, placing the body at the centre of mediating 'meaning-making', in interaction without environment. Meaning emerging bottom up from qualitive sensory motor sensations, our emotions, and our imaginative ability to synthesise experience. Johnson argues, "qualities provide the most primordial meaning available to us prior to, and underlying, any conceptual abstraction or conscious reflection we might engage in"[216]. An embodied aesthetics focuses attention, therefore, on these percepts that interact to create emergent phenomenal experience. It also recognises the importance of emotions in particularly memorable aesthetic experience, and their role in decision-making.

As Antonio Damasio points out, "emotions provide a natural means for the brain and mind to evaluate the environment within and around the organism, and respond accordingly and adaptively"[217]. Instinctual emotional responses, positive and negative, are the result of evolutionary development of tendencies to avoid threats, or be drawn to favourable features of our environment. Deep-rooted survival responses can trigger visceral neural and chemical bodily responses to basic fears of predators. Sudden unexpected motion in an environment, or unfamiliar, uncanny encounters can trigger a release of adrenaline, sometimes referred to as the 'fight or flight' hormone, raising our heart rate and sharpening our mental focus. An embodied aesthetics, attends to these non-conscious psychophysical responses to animate life in our environment, which seem essential to better understand our experiences of Lively Artefacts, such as cybernetic arts.

"Once we realize that works of art do not re-present objects, events,
meaning, knowledge, or experience, but instead that they present and
enact possibilities for meaning and value in an exemplary manner, only
then will we understand the significance of art." [218] *(Johnson, 2015)*

New media artist and academic Simon Penny's recent publication of the "rudiments of an aesthetic theory" [219] of behaviour, was motivated by his view that new art forms of automation presented a new aesthetic realm that, "Conventional art theory or art-historical approaches

are of scant value"[220]. Penny constructs an overarching framework from a constellation of critical histories of technology and cognitive theory, some aspects of which I have also touched on in this chapter.

However, in an effort to encapsulate the heterogeneous qualities of interactive new media art forms within a unifying 'Aesthetics of Behaviour', Penny does not address any specific quality of an 'Aesthetics of Behaviour' in any great detail. As I have stated, I believe the results of this thesis contribute toward the pervasive and critically important quality of animacy or liveliness often found in behavioural artefacts.

2.7 Conclusions

Grey Walter's tortoises demonstrate that even an 'extreme economy' of design does not have to lead to an economy of behaviour when one conceives of animate behaviour, as bound between agent and environment. This is a simple but immensely important point to recognise for designers of animate artefacts. One might choreograph animacy through the design of an agent, but equally through the design of that agent's environment. Cybernetics encourages us to balance our attention to problems of behavioural design between agent and environment. An immensely architectural idea that is yet to be appreciated in fields of robotics.

Margaret Boden notes that, "During Grey Walter's lifetime, his tortoises—like Vaucanson's flute player, which in fact had also been theoretically motivated— were commonly dismissed by professional scientists as mere robotic 'toys'" [221]. She attributes this to the "vulgar publicity they'd attracted in the mass media around 1950", diminishing its theoretical importance for furthering a model intelligent machine behaviour grounded in continuous interaction with its environment.

"In fact, his anticipatory work is now sometimes praised as the pioneering effort in 'Real Artificial Life'. One might quibble about the laudatory definite article. For his fellow Ratio-member William Ross Ashby, inventor of the— much less entertaining—Homeostat machine, arguably has an equal right to the accolade. That, however, is a different story. What's not deniable is that Grey Walter's engaging little tortoises had a serious scientific purpose that's widely recognized today." [222] (Boden, 2007)

The ability for Walter's robot tortoises to steer towards light and avoid obstacles gave them a compelling appearance of animacy, not previously available in predictably performing automaton. Their balance of purposeful, yet somewhat unpredictable movements, created an impression of free will that would lead to even the most serious of observers turning to psychological explanations of behaviour where there were none. Braitenberg would later note that making such machines is a pleasurable pursuit and from my own experiences, I would wholeheartedly agree with him.

I have sought to demonstrate in this section that machines have long shaped our conceptions of the nature of life and intelligence. Cybernetic's homeostatic machines and the robotic artificial life work that followed them have played a pivotal and provocative role in shaping today's *embodied, embedded, enactive,* and *extended* (4E-cognition) theories, that contrast the Cartesian nature of classical computational cognitivist models. It is however rarely recognised. One explanation for this comes from a favourite quote from Gregory Bateson.

"I think that cybernetics is the biggest bite out of the fruit of the Tree of Knowledge that mankind has taken in the last 2000 years. But most such bites out of the apple have proven to be rather indigestible – usually for cybernetic reasons." [223] *(Bateson, 1966)*

I have presented behavioural robotics, embodied artificial life, and the cybernetic machines that proceeded them, as pursuing the manageably complex from the chaotically complex in contrast to Cartesian attempts at artificial intelligence and digital life that pursue complexity from simple rules. Cybernetic bottom-up approaches to machines seem to easily 'come to life', while top-down methods at intelligent behaviour can struggle to negotiate complex, natural and built environments. Despite an awareness of intelligence as embodied being a subject of discourse back to pre-Socratic thought and found throughout the history of philosophy, such ideas have met continuing resistance to scientific scholars whose intellect is often traded in words and algorithms, rather than in practices, such as making and performance. I have addressed how embodied practices of machine makers and artists working with cybernetic machines and new fields of behavioural arts have led practitioners to question Cartesian doctrine and its implications for the design of human-machine interaction.

Rodney Brooks' bottom-up robots encouraged him to argue that 97% of human intelligent

behaviour is non-representational. David Kirsh proposes a less radically behaviourist position, arguing human thinking should be charted along a continuum where walking occurs[224] at one end of the gradient and intensive cerebral pursuits – what Clark calls "representation-hungry activities"[225] – such as writing appear, at the other end. It is certainly hard to argue, engrossed in writing a doctoral thesis, that the brain does not trade in representations, but the notion of representations as discrete symbolic tokens is becoming increasingly untenable, though still common in an age where digital computers shape the popular conception of the brain. Second-order cybernetics, in acknowledging the observer, demands we ask questions about the observer as well as the observed system.

Central is the idea that a system is a personal construct - that our reality is personally constructed and a construct of our embodied cognitive apparatus within our environment. Autopoietic theory explains that any organism from bacteria to human beings have a cognitive apparatus developed to perpetuate itself within an environment. For life to exist, it must be responsive to its environment, with an organisation that seeks to increase its potential to survive, and so this shapes the way, for example, the eye processes visual stimuli. The eye of the frog is an active and specialised interface for the frog's own purposes within the frog's world. The human eye, as I will discuss, is also an active and specialised interface for human purposes, including the perception of animate life for social interaction and other purposes of survival. This point is discussed in detail in chapter three. I raise it here to emphasise that to reach a deeper understand of our lively animate behaviour, reductive models of human reasoning fail to recognise the fundamental cognitive reflexes that foundationally construct these experiences. And any aesthetics that does not acknowledge this remains tied to limited Cartesian modes of discourse.

"By virtue of evolutionary selection, there is direct cognitive correlation between the world and the bodily experience of it. This results in a kind of (performative) knowledge and (non-)cogitation irreconcilable with the cognitivist 'physical symbol system hypothesis'. But it is this embodied, situated knowledge which provides the basis for precisely such cogitation, and for introspection. This is the lived solution to the symbol grounding problem." [226] (Penny, 2013)

3. Life in Motion

"If asked what aspect of vision means the most to them, a watchmaker may answer 'acuity,' a night flier 'sensitivity,' and an artist 'color.' But to the animals which invented the vertebrate eye, and hold the patents on most of the features of the human model, the visual registration of movement was of the greatest importance." [227] (Walls, 1942)

3.1 Introduction

When we enter a room, with the quickest of glances, we can tell whether there are living entities present. We are highly attuned to social perception and it is the visual detection of motion that appears to be the primary stimuli for making such judgements. Throughout the animal kingdom, distinguishing between animate and inanimate motion is critical to detecting prey, mates and predators, so our sensitivity to animacy is deep within the primitive architecture of our animal brain. Children under the ages of three do not demonstrate a theory of mind, yet they are capable of recognising the difference between animate and inanimate motion, and engaging in a variety of interactions with animate agents. This would suggest - and research in the field of human visual motion perception supports - that our experience of engaging with animate entities is formed not solely by reasoned acts of anthropomorphism, but also powerfully by instinctive, emotional and automatic processes of cognition. However, these matters are sometimes overlooked because of Cartesian modes of thinking that remain dominant in certain fields including human-robotic interaction (HRI) where design of 'intelligent' behaviour is typically structured from the top down, through language and other forms of symbolic logic.

Theories of human experience in HRI have been built primarily upon the complementary logic of Computational Theory of Mind - the idea that we 'mentalise', or construct rational mental models, of other animate entities, such as animals or robots, in order to hypothesise on their beliefs and motivations. The anthropomorphic explanation is convincing, in as much as we all recognise that we enter into these mental processes naturally when we observe and interact with others. However, such a theory of mind does not give us a satisfactorily complete theory of these experiences.

To address the gap, this chapter takes a counter approach, working bottom-up beginning

with reflexive visual processes of animacy perception that appear to be innate. The automatic nature of these percepts can, in part, explain how certain vocabularies of motion seem so irresistibly animate. A case study of Edward Ihnatowicz's cybernetic artwork *Senster* demonstrates how, unknowingly, artists tune their work into these innate psychological responses. Together with a discussion about the neuro-aesthetics of Calder's mobiles I highlight the role the arts have long played in exploring the hold on our attention and imagination animate motion has.

I examine the motion cues that perceptual research has identified to date and discuss the theories of fast heuristic processing of basic behavioural typologies. Social scientists hypothesise that these may act as an innate structural skeleton for the development of more sophisticated learnt social perceptions. Jean Piaget's studies of young children's primitive distinctions between animate and inanimate objects are an early example of this hypothesis. The naive connection between motion and life has had a profoundly vitalist influence on conceptions of our world. As American psychologist Julian Jaynes explains, for millennia, motion and life were bound together creating a holistic field of animacy that remains in certain Eastern animist philosophies, but have been largely exorcised in Western philosophy.

"Motion is now the domain of physics but before the seventeenth century, motion was an all-encompassing mystery… Because [the stars] moved, the stars were thought by no less a scientist than Kepler to be animated. Motion perplexed Gilbert who became convinced that magnets had souls because of their ability to move and be moved. And Campanella in his Neapolitan prison, when he understood what Copernicus was saying, that the earth really moved, exclaimed, "Mundum esse animal, totum sentiens!" In a world so sentient and alive, motion is everywhere." [228] *(Jaynes, 1970)*

Complementing the catalogue of motion cues and behavioural heuristics established by scientific research, I will examine the art of animation, the established principles of orthodox forms of Western character animation. I discuss Kenny Chow's notion of *Technological Liveliness*[229]*,* which supports my own view that animation as a field extends out into our built environment and draw synergies with his discussion on the experience of animation being bound to our embodied knowledge of own animate behaviour.

3.2 Visual Motion Perception

Motion perception is critical to essential tasks involving spatial navigation and the registration of depth and separation of form, from predicting collisions and making judgments of motion direction and speed, to perceptions of surrounding animate activity. Motion perception often allows us to compensate for deficiencies in other forms of visual information. For example, the following four images (Figure 24) show frames from a video where a person is performing a common action. No single frame conveys sufficient spatial structure to permit recognition that a person is present, let alone recognition of what the person might be doing. However, the complex patterns of visual motion generated when these frames are displayed as part of a video convey immediately that a person is present and that the person is in the process of sitting down.
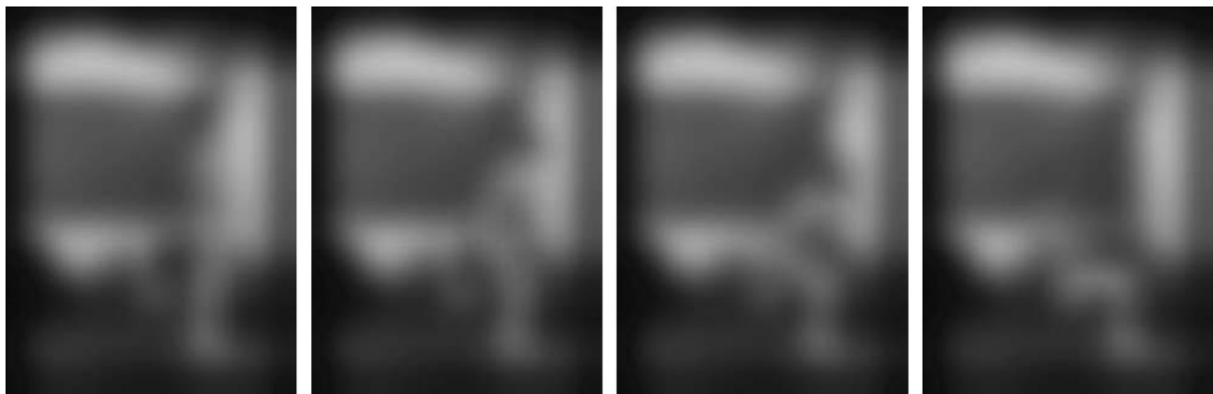
Figure 24. Four still frames cut from a video by Bobick and Davis[230]

Another example is found in physiologist and experimental photographer Etienne- Jules Marey's illumination of limbs in motion, conveying vivid and compelling impressions of human animation which disappear into a muddle of meaningless lights if the walker stands still. People are remarkably adept at recognising the actions performed by others, even when the kinematic patterns of their movements are portrayed by nothing more than a handful of light points (Figure 25).attached to the head and major joints of the body [231]. The information is sufficient to discriminate the sex and other details of the walker, and can be interpreted by young infants [232]. What these experiments demonstrate is that, contrary to any notion that we need detailed visual information to recognise animate behaviour, our visual system can discriminate features of motion essential to social perception and interaction, with even the most limited of stimuli. Detection of the point light walkers, what Johansson called 'Biological Motion' are detected quickly – within 200 milliseconds [233] – demonstrating how highly attuned the human visual system is to motion information that supports social perception.
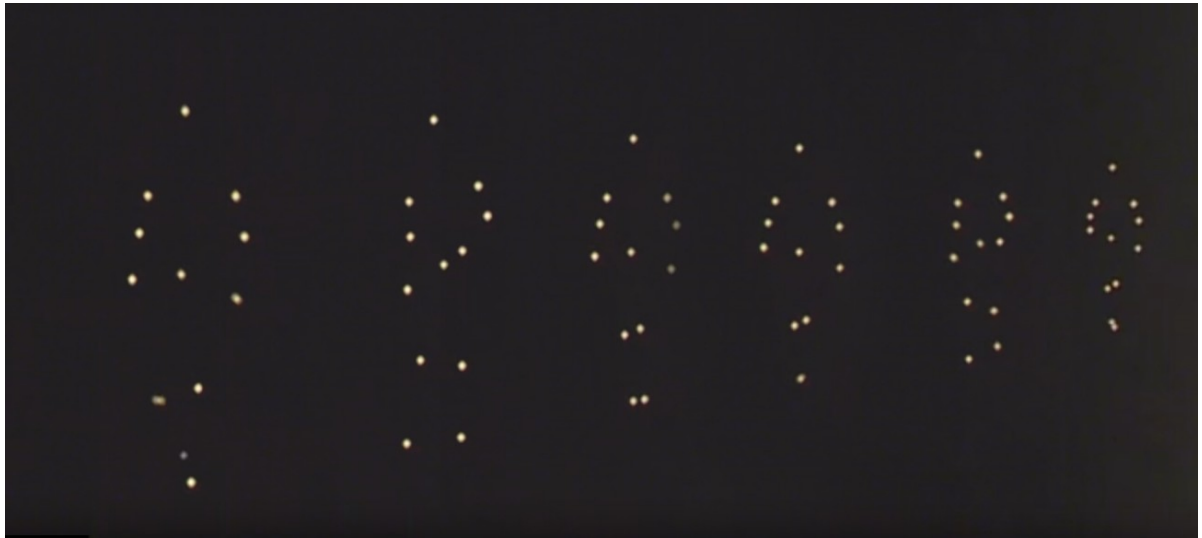
Figure 25.Composite image from screenshots of 1971 movie of Swedish Psychologist Gunnar Johansson's point light experiments with perception of biological motion[234]

From birth, motion innately attracts our attention [235] [236]. Before the evolution of colour or form recognition in the animal eye, motion recognition motivated the development of vision. Virtually all animals use motion detection to evade predators and seek out prey. Very few can retrieve information from static visual stimuli [237]. Motion is the cornerstone of communication and interaction between animals. Courtship displays throughout the animal kingdom feature sophisticated body movements, demanding sensitive visual processing mechanisms to assess potential suitability. In human communication, language can mask our true intentions, but our bodies often 'give us away'. Our physical gestures, less subject to conscious control, convey the unconscious, emotional, embodied "truth" of ourselves. In theories of social interaction, verbal rather than body language is often prejudiced, though our perceptual systems are acutely attuned to the unconscious messaging of the subtlest of body movements.

It is useful to note some of the principles that shape the working methods in psychophysics that sit between neurological and perceptual science.

"In a sense there is only one problem of psychophysics, the definition of the stimulus. . . The complete definition of the stimulus to a given response involves the specification of all the transformations of the environment, both internal and external, that leave the response invariant. This specification of the conditions of invariance would entail, of course, a

A highly controlled environment and repeatability of stimuli have been essential to experimental methods in psychophysics. Contemporary techniques often use computer generated animations, where parametric control allows for the careful manipulation of form, colour, motion and other variables. Earlier methods have included cell based animations[239] and mechanical contraptions[240]. The recurring challenge of work in this field is to isolate stimuli. Take, for example, the variable of velocity. It can be dissected into time and distance, but intervals between stimuli and repetition may also factor in. An extensive review of these challenges can be found in Croner and Albright's *Seeing the Big Picture: Integration of Image Cues in the Primate Visual System*[241]. What is useful for the purposes of this thesis is to characterise how researchers in the field minimise environmental noise, carefully isolate visual stimuli and modify parameters to study changes in cerebral responses.

Using electrodes embedded into the visual cortex of monkeys, David Hunter Hubel and Torsten Wiesel's 1968 landmark study[242] of stimulus-response mechanisms in single cells found visual information from the retina of the eye to be topographically mapped onto the visual cortex. Neighbouring cells represented neighbouring regions in the visual field and these cells were found to be differentially 'tuned' so that one cell in a neighbourhood may respond strongly to vertical edges, while others were responsive to horizontal or other orientations. These so called 'simple cells' are commonly found throughout the visual cortex. Hubel and Wiesel were also able to identify 'complex' and 'hyper-complex' cells that responded to more elaborate combinations of the simple features, for example, two edges intersecting at right angles to one another. These observations suggested that a hierarchy of feature detection took place, with higher level features triggered by patterns of response in lower level cells. As these patterns of response travelled up to higher level cells, more sophisticated perceptions were possible.
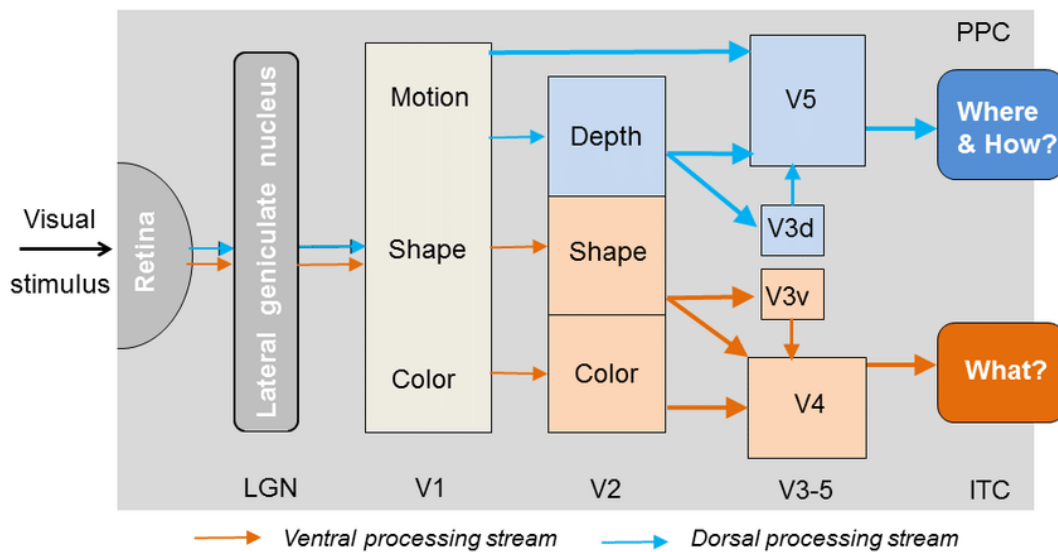
Figure 26. "Visual processing-streams in the primate cortex. Simplified diagram; bidirectional pathways not shown. LGN, lateral geniculate nucleus; V1-V5, visual cortical areas; ITC, inferior temporal cortex; PPC, posterior parietal cortex."[243]

Signals from the retina arriving at the primary visual cortex V1 are generally subdivided into two streams of processing: one for colour and form, the other for motion and location. These are called the ventral and dorsal streams, and due to their functioning sometimes called the 'what' and the 'where and how' pathways [244]. The ventral pathway V4 processes the form and colour of objects and is largely insensitive to the motion of those objects. The dorsal pathway in the V5 region or MT (middle temporal), responsible for motion detection [245][246], is largely unresponsive to static visual stimuli or the shape of objects.

Travelling up the pathway of the ventral and dorsal streams, the receptive fields of the neurons increase, responding to larger fields of view. At the same time, the hierarchical and functional organisation increases, so cells become less attuned to local stimuli but rather to emerging global patterns [247]. Advances in brain imaging techniques, particularly functional magnetic resonance imaging (fMRI) have allowed for more precise recognition of regions associated with these stimuli. A growing body of research has identified more than a dozen regions where neurons are stimulated by motion, revealing that V5 does not process motion information alone [248][249][250]. The interconnected relationships are complex, including back-projection of V5 onto V1 [251] that may be important for conscious awareness of visual motion [252], and exercises to map the region are ongoing. The key principles to recognise are that there is specialisation of function in the visual brain. These are hierarchical and operate

parallel to one another. As the processing time of signals can vary, processing is "massively asynchronous" [253].

Applying understandings of the modular functionality of the visual cortex to aesthetics, Zeki and Lamb's 1994 paper, *The Neurology of Kinetic Art*[254], offers a behaviourist interpretation of our cognitive experience of the work of artists, such as Alexander Calder and Jean Tinguely. Though the field of neuroaesthetics has received considerable critique for its reductive, rationalisation of complex aesthetic experiences, this does not disqualify the value, in my view, of interpretations of work through different (sometimes narrow) disciplinary lens. A bottom-up approach to cognition will inevitably involve the layering of stimuli, some stimulus response, and then increasingly higher orders of complexity, reaching conscious awareness. Zeki and Lamb's key observation is that the artists appeared to be seeking to "obtain aesthetic effects by stimulating optimally only a limited number of visual areas in the cerebral cortex"[255]. These artists were not just creating work that emphasised motion, but were equally de-emphasising of other qualities, such as colour and form.

They suggest the artists' practices unknowingly exploited the organisation of our visual system, driven by a deeper artistic awareness of their aesthetic potential. They theorise that Tinguely's 'Métamatiques' stimulate regions of the visual cortex in V3 and V5. Meanwhile the limited use of colour would minimise responses in V4. The formal simplicity of Calder's mobiles, go a further step, they argue, reducing form sensitivity, focusing cerebral responses even more. The presence in both works of orientated lines or edges is believed to maximise V3 stimulation.

They stipulate that additional factors, such as attention are likely to play a role. Evidence of attention modulating activation of cells in V4 [256] [257] and V5 [258] [259] again raise interesting open questions of the degree of top-down control the viewer immediately has on aesthetic experience. Zeki and Lamb's paper is speculative, but grounded in established neurological understandings of the architecture of the visual brain. They point out that V5 is not a terminal station for motion perception, but rather connects onto many cortical areas that will likely perform roles in the aesthetic experience. Evidently V5 is essential to motion perception and without it we would not see, let alone appreciate, kinetic art.

Creating a plausible neurological discussion of the brain experience of kinetic art, it raises more questions than it answers, revealing a field of study rich in potential. The opportunities for the arts to provide useful insights for the scientific study of motion perception and, reciprocally, for neuroscience to offer potentially useful insights for artistic practice are growing with the advances in medical imaging and physiological sensing technologies.

Perhaps one of the most interesting open questions left unanswered relates to the possibly innate foundations of our aesthetic responses.

"The early maturity of the cortex of V5 probably indicates its importance in early vision. Is it any wonder that babies should find mobiles, a central feature of kinetic art, so attractive? In fact, motion is one of the most primordial of all visual percepts; even animals with more primitive visual systems have a well-developed system for detecting visual motion." [260]
(Zeki and Lamb, 1994)

The popularity of Calder's mobiles to audiences of all ages suggest they must stimulate an innate, non-cognitive processes of perception. Something distinct from an aesthetic engagement of intellectual, higher-order forms of cognition. To better understand these cerebral mechanisms is essential to better understanding the effects of movement in everyday objects, as much as in works of art.

Figure 27. Alexander Calder. Antennae with Red and Blue Dots c.1953

Calder's mobiles are passive, driven by their surrounding air currents. This dynamic external energy source, coupled with the many degrees of freedom inherent in the mobiles construction, precipitate a highly unpredictable performance. Chance movements were a central feature of Calder's work and its success. It broke away from the history of automaton art that he had earlier explored, giving the work a greater autonomy. However, surprisingly, and sadly, many Calder works hang in galleries motionless or only ever so slightly trembling. At the recent show at the Tate Modern[261] signs on the walls instructed viewers "not to blow"

on the art. A kind of communal mischief emerged that Calder would have likely enjoyed, when visitors – myself included – pretended not to see those signs. All too easily art critics and historians talk about kinetic artists bringing 'sculpture to life', yet for all of the visceral qualities of seeing Calder's work in motion, the one quality undoubtedly missing in the installation was any sense of animacy in the mobiles.

3.3 Animating Sculpture

Perhaps one of the most celebrated early cybernetic artworks was *Senster* (1970) by Edward Ihnatowicz, developed as part of Philips' Evoluon exhibition space in Eindhoven. Ihnatowicz (1926–1988) was an artist first and for most, practicing as one for almost two decades before he engaged in cybernetics. He, like Ettiene Jules Marey, had taken and studied many time lapse photos of animal movement, developing a sensitivity to the qualities of animate motion.

> *"The Senster's behaviour is completely unexpected because it is so close to that of an animal that it is difficult to keep in mind the fact that one is in the presence of a machine. It is as if behaviour were more important than appearance in making us feel that something is alive."* [262] *(Reichardt, 1978)*

Senster, built at the University College London's department of Mechanical Engineering, was the first example of a digital, computer-controlled, robotic artwork. Once built and installed at the Evoluon, Ihnatowicz spent time sitting in the exhibition hall making modifications to its code while observing the unfolding behaviours occurring between the machine and the public. Visitors to the Evoluon were very quickly and willing to imbue *Senster* with life. The 2.4m tall steel armature structure, moved smoothly and silently, with a barrier around it keeping excited children at arm's length, helping to create an atmosphere of a zoo. Alex Zivanovic, while visiting Scholar at the Lansdown Centre for Electronic Arts, has exhaustively researched Ihnatowicz memoirs, and also the hardware and code that shaped the behaviour of *Senster*.
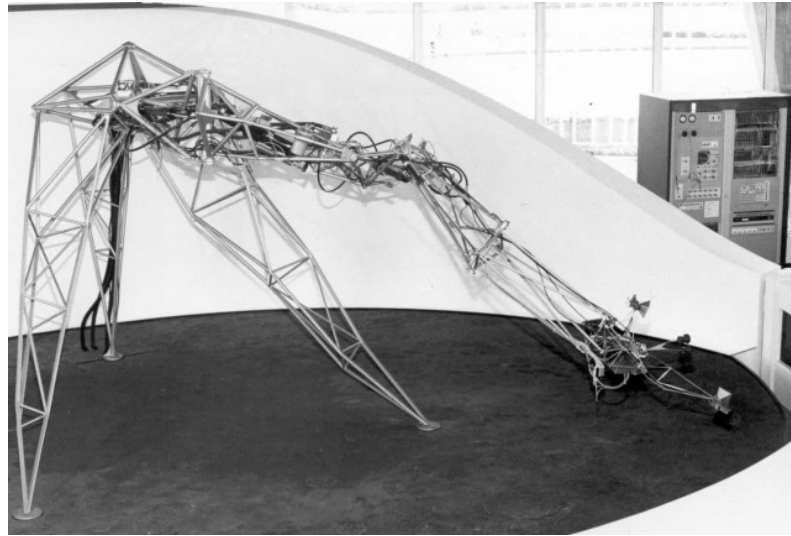
Figure 28. The Senster, installed at the Philips Evoluon (1970-74). The artwork was controlled by the Philips P9201 computer seen on the right.

Zivanovic identifies that part of the robot's success in appearing so life-like, came from Ihnatowicz's choice of actuators. Each of the six joints in the armature had 32 discrete positions controlled by a Philips P9201 digital computer, with 8k core memory. The output from the computer was latched as sixteen data bits. The 16 bits were split into two sets of five bits, which represented the next required position for an actuator, thus each joint had 32 (2^5) discrete positions. This was a very low position resolution but was overcome by the use of a circuit called the predictor. Each set of five bits was passed to a digital to analogue converter and then to the predictor. The predictor was a sophisticated arrangement of op-amps, which operated as a second-order low-pass filter, setting the time by which all the joints had to reach the next set positions, so that they all arrived at the same time to make the movement look natural.
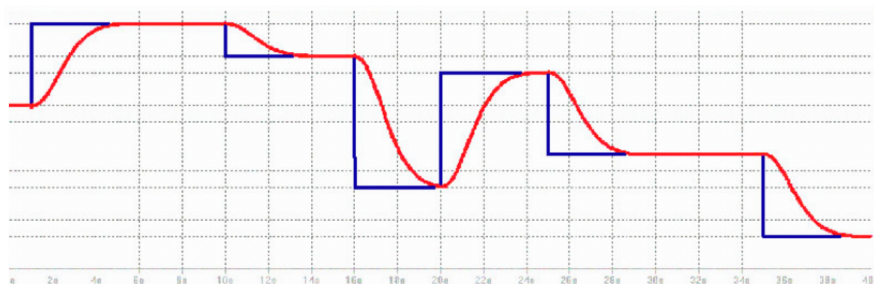
Figure 29. Senster smoothed output simulated by Alex Zivanovic[263]

Today, with many orders of higher-resolution computing, this smoothing can been replicated digitally through a second order low pass filter algorithm. The most efficient (least expenditure of energy) motion can be shown mathematically to be when velocity has a parabolic profile. As Zivanovic points out, the actual shape produced by *Senster* was not the ideally efficient motion found in modern robotics. It was asymmetrical (the peak velocity occurring before the half-way point) and tailing off gradually.
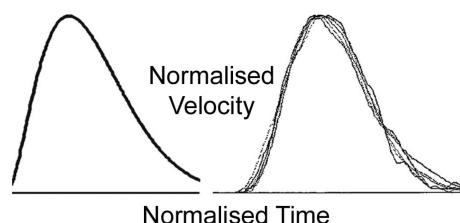
Figure 30. Left: Senster's smooth motion simulated, Right: bio-mechanical smoothing of human arm[264]

The comparison in Figure 30 shows *Senster*'s movement profile (normalised velocity against normalised time) compared to the profile of a tracked human arm.[265] We can see they compare well and as Zivanovic suggests, this smoothing implementation was perhaps the key reason why the movement of *Senster* was regarded as looking so natural, and capable of eliciting perceptions of animacy.

Ihnatowicz, as an artist understood there was aesthetic potency in drawing an audience's attention to animate motion, while minimising attention to other visual cues. His practice of crafting specific qualities of motion sits alongside the work of Calder and Tinguely in this respect, and can be read in the context of Zeki and Lamb's theory of artists unknowingly exploring the perceptual, instinctive reflexes of our human visual experience of motion.

"I can be very precise about when I discovered technology - it was when I discovered what servo systems were about. I realised that when I was doing sculpture I was intrigued or frustrated, because I was much more interested in motion, I was trying to make my figures look as if they were about to take off and start doing something. We respond to people's movements to a much greater extent than we are aware of." [266]

(Smith, 1984)

There is a further feature to *Senster*'s motion that makes it distinct from the work of Calder and Tinguely, and this was the responsive and purposeful nature of its behaviour. Cybernetic

machines were by definition, purposeful. Grey Walter's tortoises, were first to demonstrate how goal directed behaviour, visibly responsive to an environment through their motion, appear life-like. Walter's tortoises moved without the smooth motion control achieved by Ihnatowicz, yet were still irresistibly animate. While smooth motion may be a cue for judgements of animacy, it does not appear to be essential.

Working with students using robotics for the first time, I have found that even quite crude motion can elicit irresistible impressions of life when behaviours appear responsive to their environment, and especially when these motions are responsive to people or other agents. Questions about the saliency of particular motion cues is an ongoing subject of discourse in the science of visual motion perception and specifically within social perception, where researchers seek to quantify and catalogue the relative importance of cues for animacy, and finer grain perceptions of typologies of animate behaviour, such as chasing or playing.

3.4 Social perception

An Experimental Study of Apparent Behaviour

Fritz Heider and Marianne Simmel's 1944 landmark study in perception of social behaviour was the first work in experimental psychology to demonstrate that objects with simple geometric appearances could trigger strong impressions of life in observers through motion alone, but only when these movements have particular characteristics.

> *"When the perception of movement is investigated, it is with the purpose of finding out which stimulus conditions are relevant in the production of phenomenal movement and of determining the influences of the surrounding field. Only when we attempt to answer these questions can we hope to deepen our insight into the processes of perception, whether of movement or of other human beings."* [267] *(Heider and Simmel, 1944)*

Their study consisted of a two and a half minute animation (Figure 31) shown to undergraduate students, who were asked questions about one circular and two triangular black figures, moving at various speeds and directions around a flat 2D world. A further figure, a large hollow rectangle also features in the film, but is motionless. At points in the film, the hollow rectangle is entered by the circle and triangles through what appears to be a latched door.
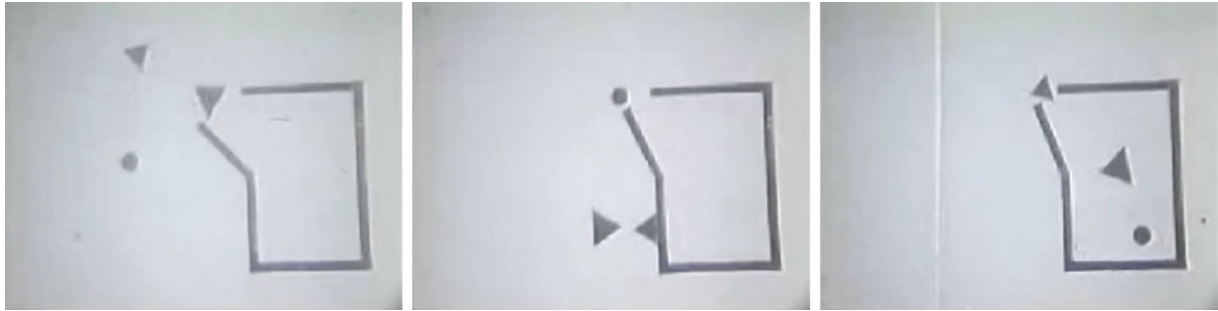
Figure 31. Screen shots from Heider and Simmel's experimental film, 'An experimental study of apparent behaviour.' (1944)

Virtually all the students perceived the figures as animate beings. In most cases they were perceived as persons, in two cases as birds. Although differing in detail, participants interpreted a narrative with surprising uniformity as a succession of motivated actions and reactions. What was interesting was the way students attributed complex personality traits, such as shyness, bravery, irritability or aggressiveness and changing emotional states, such as frustration and anger, to simple geometric figures, without any figurative cues. Here are excerpts from three of the student's descriptions that reveal the complexity and creativity of interpretations when faced with nothing but motion to make sense of social behaviour.

"The first man goes back and tries to open his door, but he is so blinded by rage and frustration that he cannot open it.

Lovers in the two-dimensional world, no doubt; little triangle number-two and sweet circle. Triangle-one (here- after known as the villain) spies the young love. Ah! ... He opens his door, walks out to see our hero and his sweet. But our hero does not like the interruption […] he attacks triangle-one rather vigorously.

Man (T) finds himself in chaos, which finally resolves itself into a sort of cell representing Fate. He is able to free himself (but only temporarily), when Woman (c) accompanied by Evil (t) comes upon him, and disrupts

his momentary peace. He feels called upon to rescue her, but Evil imprisons them both by Fate, from which Man escapes, leaving the woman there for safe-keeping. " 268 (Heider and Simmel, 1944)

Heider and Simmel's view was that perception of animate social behaviour was fundamentally determined by the "temporal succession and spatial proximity" of the figures. The characteristics of movements, and the kinetic relations between movements, were critical to stimulating perception of animate behaviour. This view has stood the test of time, with Philippe Rochat, a half century later, reasserting that "Phenomenal social events and social attribution are thus shown to depend on particular dynamic stimulus configurations"[269]. As this chapter will examine, specific perceptual cues from these experiences, and a review of the latest research offers useful understandings for how we experience and consequentially design animate encounters.

Although the study by Heider and Simmel is over seventy years old – and for a moment putting aside the veracity of their original observations – I am struck by how compelling the animation is to audiences when I share it in lectures. Without giving it any introduction I have many times enjoyed playing the film and watching how people's attention becomes acutely fixed on the geometric objects' motion. Smiles grow on people's faces, nervous giggles, gasps and laughter are often heard. With little more than a series of movements, a dramatic aesthetic experience is often enjoyed by its audiences.

At the time of the research, Heider and Simmel were motivated by what they saw as a lack of understanding of the fundamental stimulus conditions that lead to the perception of our social world. Perception in their use of the word covered all cognitive processes beginning from the bottom-up stimulation of visual receptors. Their critique of the perceptual research of the time, had been concerned with the issue of 'correctness', that perceptual mechanisms are studied "only so far as they impair the correctness of judgement"[270]. They rejected the premise that there must be a correct understanding, focusing on the observer's relationship between stimulus-configurations and their determining interpretations. While their experiment is seminal in demonstrating the rich unfolding interpretations that motion alone can stimulate – regardless of formal appearance – the sheer variety of movements made by the figures in their animation make isolating specific relations for study impossible.

Perception of Causality

Albert Michotte's studies on perceiving interaction between simple geometric objects[271] were essential in founding a scientific rigor to future research. Michotte contrived a mechanical rig that controlled the movement of two objects projected onto a screen. Each object was independently timed to move in either a right or left direction at varying speeds. By modifying the parameters of the rig, he could observe how small variations in their motion led to large variations in perception.

Like Heider and Simmel, Michotte questioned his subjects on their perceptions. Certain motions routines resulted in mechanical descriptions of causal interactions. For example, one object appears to collide with a static object that immediately begins moving on contact. Other motion routines, however, led to far more animate descriptions, inferring motivations into the causation of their motion.

> *"The little ball is trying to play with the big ball, but the big ball doesn't want to play so he chases the little ball away. But the little ball is stubborn and keeps bothering the big ball. Finally, the big ball gets mad and leaves."* [272]
> *(Michotte et al, 1964)*

Whereas Heider and Simmel's animation has been widely criticised for having too many complex stimuli interacting to be able to draw out which stimulus conditions are most relevant, as it claims to do, Michotte's work isolated individual variables that laid the foundations for empirical methods of study in perception, cognition, developmental psychology and neuroscience.

Michotte was "convinced that we can perceive actions performed by objects or animate beings ("agents") on one another in the same way as we can see simple kinetic movements" [273]. For Michotte, causality was a foundational percept of the human visual system. Developmental studies have since been examining at what stage sensitivity to the phenomena emerge, in infants [274][275][276][277]. A number of researchers have persuasively supported the view that these causal perceptions are developmentally foundational [278][279], that may suggest that perception of causality is innate [280].

In a similar fashion to other specialised mechanisms in the core visual system, there have been a number of suggestions made that our mechanisms for causal perception may be evolved rather than learnt [281][282][283], as the ability to recognise agency would be an evolutionary advantage. There is still, however, considerable uncertainty in the field, and definitive evidence for or against Michotte's claim that the causal perceptual mechanisms are innate. There is, nonetheless, wide recognition that by the ages of six to seven months, young infants are able to perceive and interpret causal motion, indicating these abilities are developed early to form a skeleton for more sophisticated social cognition to develop.

It might appear obvious that we recognise cause and effect, for example, when one snooker ball collides with another. The importance of Michotte's work can therefore be easily

overlooked, however, his insight was to look at this seemingly mundane cognitive process and realise that it revealed that the visual system not only recovers the physical structure of the world, but also seeks to recover the causal social structure of the world.

"Before Michotte, nearly all writers had treated causality as a high-level cognitive concept, and tended to think of the currency of perception in terms of only lower-level properties such as color, texture, and motion. Michotte, in this context, demonstrated that even seemingly – "cognitive" properties such as causality may be processed in the visual system." [284]
(Wagemans et al, 2006)

This is a radical idea because social behaviour, which is commonly held to today to be a cognitive process of the higher orders, is far more primitive and automatic than common sense may suggests it is. Michotte's experimental methods are also of great significance. Michotte published more than a hundred studies of stimuli, examining speed and direction, path lengths and angles, the relationships between object sizes, colour and shape, to name a few. His careful separation of variables, using mechanical rigs, provided a scientifically robust means to study phenomenal percepts. His animated displays inspired scientists to develop a variety of innovative parametric systems [280] [285] [286] [287] to study event perception, intentional, biological and animate motion perception.

Primacy of Perception

As cognitive scientist and philosopher Zenon Pylyshyn points out, "although the study of visual perception has made more progress in the past 40 years than any other area of cognitive science, there remain major disagreements as to how closely vision is tied to cognition."[288] He defends the case that 'early vision', the fastest percepts of the visual system, are important and "cognitively impenetrable" from higher-order processing but drawing clear lines is notoriously difficult. The common distinction is that perception is a collection of processes that are relatively automatic and irresistible. On the other hand, higher-order processes involve learning of concepts, and conscious introspection.

Peter White [289] hypothesises that infant perception of continuity and discontinuity of motion originates in the early stage visual processing – namely the iconic region of the visual cortex. Contrary to previous views that this region functioned only to collect and integrate incoming visual stimuli, White argues, and more recent research supports [290] [291], that causal perception

begins within this primary stage, lasting less than 250 milliseconds. As iconic processing is considered automatic, this supports the view that our perception of causality begins with automatic reflexes, before any form of conscious introspection may occur.

Perceptual Knowledge of Animacy

An ongoing and central debate in psychology is the degree to which concepts may exist in some form from birth, and provide the essential scaffolding for cognitive development. Discussing the source of these innate concepts, psychologist Elizabeth Spelke states, "there surely is a time in human development, prenatal if not postnatal, when human beings know nothing" [292]. However, she suggests that as a result of natural selection specific mechanisms could have evolved giving rise to forms of knowledge. These innate mechanisms, she argues, shaped by perceptual systems, may parse the world, structuring the learning capabilities of new-borns.

Innate perceptual reflexes, define entities as domain specific and, in turn, allow structured learning to occur. If an entity in motion fails to conform to particular perceptual cues, it may not be selected for attention in relation to the domain of animacy. If indeed such perceptual mechanisms safeguard particular concepts, then these are difficult if not impossible to be unlearnt or disregarded [293][294]. These perceptual reflexes shape the way we encounter our social world, and develop in sophistication with age, but are, at their core, innate, automatic and irresistible.

Perceptual attentiveness to animacy

From birth, motion attracts attention [295][296], but more interestingly, it appears that there we are born with a pre-conscious bias towards motion stimuli with social cues. Questions of early social cognition are so fundamental to psychology, there is a rich literature on child development, encompassing a variety of theoretical frameworks and methodologies. Non-verbal methods with infants through to interview based studies with older children are used to examine static and dynamic stimuli. Klein and Jenning's 1979 study of infant attention to persons versus a musical mobile [297] found, within weeks, looking time favoured people. This and other studies using props, such as toys [298][299], show signs of person-object distinctions appear soon after birth.

Contrasting with the once cardinal assertions of Jean Piaget that the concept of life developed slowly, research since the 1970s has supported the view that young infants make distinctions between animate and inanimate objects from an early age [300]. *The Origins of Reciprocity: The Early Mother-Infant Interaction* by Brazelton et al [298], demonstrated that by

two months, infants appear to show pleasure, smiling to a responsive adult while not to a static toy monkey. The evident pleasure supports the argument that our evolutionary psychology is positively wired towards attending to dynamic social cues.

Questions remain about the relative importance of figurative cues versus dynamic cues. Figurative research on facial recognition, for example, has demonstrated newborns of less than an hour old are more attentive to faces with eyes and nose features in correct configuration, than those scrambled [301] [302]. The evolutionary roots are primitive with all major vertebrate species appearing reactive to dark eyes or black discs. One of many examples can be found in a study of infant jewelfish that showed that a pair of horizontally aligned black discs triggered an evasive reflex, while other spatial configurations of discs did not [303]. Eyes and gaze detection are widely considered a primary method of predator detection [304].

Such features are important cues in human and other animal social interactions from an early age, and the success of my *Performative Ecologies* installation to trigger impressions of life no doubt was in part elicited by the horizontal arrangement of the illuminated LED eyes. However, as the dynamic motion cues of Heider and Simmel's experiment in *Apparent Behaviour* compellingly demonstrated, perception of animacy can be irresistible without figurative cues.

3.5 Motion Cues to Animacy

Acceleration and change of direction

Just as depth perception emerges bottom up from a range of cues, including motion parallax, occlusion and binocular disparity, animacy too is detected from a variety of cues that have been isolated and studied in recent decades. Patrice D Tremoulet and Jacob Feldman's experiments in motion perception within a featureless environment [305] demonstrate that animacy can be elicited solely from simple motion profiles. Motivated by a critical view of earlier research – including that of Heider and Simmel – that says the motion of their geometric figures too often contained complex trajectories and interactions, they argued these variety of cues made it "difficult to isolate motion factors essential to the judgement of animacy". Tremoulet and Feldman instead constrained their study to the movement of a single figure travelling across an otherwise empty circular display laid on a floor and viewed by subjects from above.

Whereas early experiments in the field had been hand crafted using cell animation, or puppetry techniques, Tremoulet and Feldman used a series of algorithmically generated

motion paths. The use of computational techniques prevented any trace of animacy coming unintentionally from researchers manipulating the stimuli directly. Minimising stimuli, in a similar fashion to psychophysical research, enabled Tremoulet and Feldman to develop a set of primary cues for animacy, and to measure the subtleties with which animacy perception is influenced by each of them. Subjects watched a single figure crossing a display and changing direction and/or speed in a single instance. Direction change ranged from -80° to 80° which was set randomly. Speed changes ranged between a multiplier of 0.5, 1, 2, or 4 of the initial velocity. Change of speed, and change of direction, were the sole motion stimuli. A third factor was the shape of figure, with a circle, dot and rectangle tested. The rectangle was tested as aligned in direction of travel and misaligned.
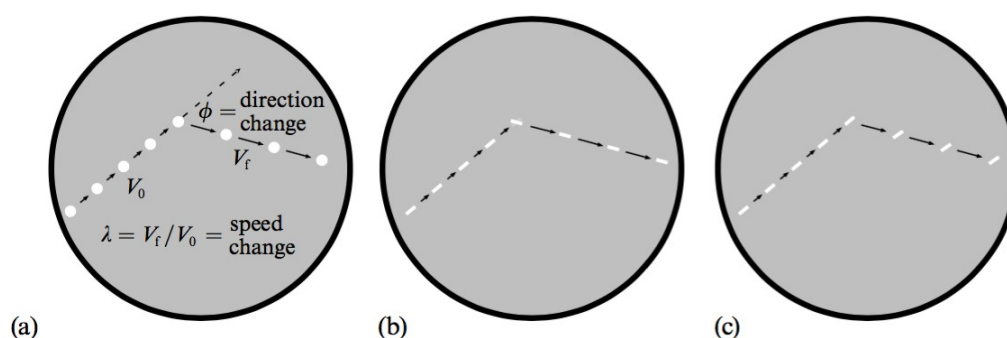
Figure 32. *"Shape/alignment conditions: (a) dot condition (also shown are the motion parameters); (b) aligned condition; (c) misaligned condition."*[306]

The researchers found that all three factors had significant influence on animacy ratings. Figures that accelerated and changed direction the greatest amount, had the highest animacy ratings. Figures that decelerated were rated with the lowest rating below those that showed no change in speed. On the influence of the figures' alignment to direction of travel, they reported, "Animacy ratings were highest in the aligned condition, intermediate in the dot condition, and lowest in the misaligned condition" [307]. As the circle revealed no cues to orientation it was neutral in its effect. Rectangular figures that aligned with the direction of travel were perceived to be the most animate while when misaligned had lowest animacy ratings.

"Some of our subjects informally reported that the object in the misaligned condition appeared to have been `struck' or `kicked.' The apparent passive response to impact (ie failing to align its axis with the new motion direction) might be an example of a positive cue to inanimacy." [308] *(Tremoulet and Feldman, 2000)*

Tremoulet and Feldman make an "energy conservation" argument for the higher animacy ratings of object/figures that accelerate, over those that remained constant or slowed. Figures that accelerate suggest internal energy reserves to self-propel their motion. Acceleration and change of direction both give an impression of 'volitional control', something one would expect typically from living entities. Tremoulet and Feldman are careful to stress that they believe these inferences occur automatically and are perceptual in nature. Recent research studying infants supports this view, finding they look longer at accelerating motions than constant motion[309].

Speed

Perceptual psychologists Paul Szego and Mel Rutherford study in 2007 established animacy ratings could be influenced by speed without acceleration[310]. In a simple experiment, subjects watched two geometric figures simultaneously move across two identical circles, each travelling at different speeds. Again, the screen was presented horizontally so that the observer looked down. They asked subjects to select which of the two figures seemed more alive, finding the relatively faster figure perceived more animate.

Extending this study in 2008, the team demonstrated a "dissociation between perceived speed and perceived animacy, apparently resulting from the human visual system taking gravity into account" [311]. This dissociation occurred when displays were presented vertically upright, as opposed to the earlier mentioned experiments where screens were laid horizontal. Circles moving up the screen were perceived as more animate that those moving down since gravity may account for perceived falling but any rising effect would suggest the entity has an internal energy source of propulsion.

These results they conclude "are consistent with the idea that the human visual system is designed to perceive animacy in a functionally reasonable way, given the terrestrial environment in which it evolved" [312]. Put more plainly, the human visual system has developed within a gravity field where there are evolutionary advantages to distinguishing between jumping prey and falling leaves, for example. Therefore, perceptions of animacy occur within the context of our visual system's embodiment in a physical world, and the observer and observed agent's

relative orientation should be considered in any account. If physical principles are innate in our perceptual processing, it would endorse Stewart's view that motion paths caused by external forces, such as collision or gravity, are seen as inanimate, while motion that violates "Newtonian laws of motion" [313] are seen as animate.

Intention

Following Heider and Simmel's foundational *Study of Apparent Behavior* in 1944, progress with further experimentation was limited besides Michotte's perception of causality work. John Bassili published a 1976 report, *Temporal and Spatial Contingencies in the Perception of Social Events* [314] that reignited interest, pioneering computer animations of circles moving on a featureless background.

Like Heider and Simmel, he found that spatial and temporal contingencies between two geometric figures in motion produced perceptions of intentional and social behaviour. As widening access to computer generated graphics opened up new experimental methods, the ability to not only carefully manipulate animations, but also to code goal-based behaviours between onscreen agents helped researchers to systematically study the stimuli relations between moving, as well as static figures. Studying the relationship between animacy and intention perception, Dittrich and Lea [315] proposed that animacy perception could be understood by bringing together two key factors.

> *That absolute motion kinematics (spatiotemporal trajectories) and relative ones (relations between trajectories) are both likely to be relevant for the interpretation of motion displays as intentional."* [316] *(Dittrich and Lea, 1994)*

If animacy required, both suitable motion profiles and relational motion, then why does Tremolet and Feldman's motion of a single object in a featureless environment trigger animate percepts? Their own explanation is that, when sudden changes of direction or acceleration occur, and there is no evident physical explanation (i.e. collision), the reflex is to attribute an intentionality to that figure's behaviour regardless. Without any visible context in its environment to infer the goal target, the observer appears to infer a goal target beyond his or her own field of view. Dittrich and Lea's own studies of the *Visual Perception of Intentional Motion*[317] support the same view that "The impression of intention depends crucially on the movement being directed towards a goal (…); it is relatively little affected by whether or not that goal can be seen" [318].

Tremolet and Feldman are keen to stress the bottom-up and automatic nature of visual processing of absolute and relative motion stimuli processes while Dittrich and Lea prefer to distinguish between the two emphasising "perception of intentionality is strongly related to observers' use of conceptual knowledge". While this statement suggests higher-order

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reasoning, Tremolet and Feldman point to Michotte's studies to show that fundamental causal processing appears perceptual in nature. Examples include perceiving collisions "launching effect", as well as the avoidance of obstacles. The middle ground may be as Philip Blythe and his colleagues propose – as I discuss later – that innate heuristics could have evolved to process visual information [319] automatically predicting intentions in moving stimuli without the need for conscious reasoning.

A developmental argument supporting this comes from research showing that causal motion draws attention from an early age. John Watson [320] reported that two month old infants were found to respond with similar amounts of cooing and smiling to responsive caregivers and responsive mobiles. This appears to suggest that the contingent behaviour of the mobiles may have appeared social in nature triggering positive social responses from the child without the need for supplementary facial, or otherwise human, visual features.

Context

Understanding the influence between absolute and relative motions has been widely examined, however, distinguishing relative importance of stimuli has been challenging to isolate. Retaining the essential 'minimal' characteristics of their earlier work, Tremoulet and Feldman, in their follow-up research to featureless environments, examined the "influence of spatial context" [321], adding a second geometric figure, first as a static entity and then in later experiments as a dynamic entity. Their aim, as they stated, was to "identify the specific motion/context pairings that produce an impression of animacy" [322].

Repeating their approach of a moving figure accelerating and or changing direction half way along a trajectory path across a circular screen, they placed a second figure they called a 'foil' (a static white dot) in five possible positions (Figure 33), three of which might support intentional explanations (Prey, Predator and Obstacle), and a further two that served as controls (Irrelevant and None). The rate of speed, acceleration and change of direction were varied as in their earlier experiments.
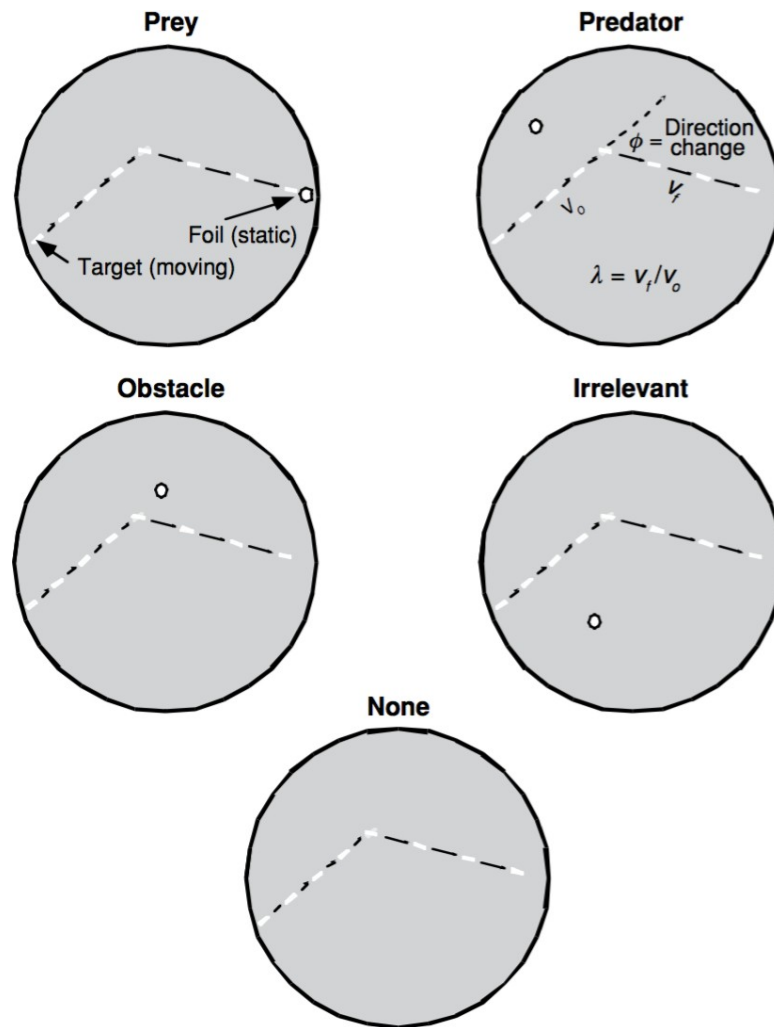
Prey

Foil (static)
Target (moving)

Predator

o
ϕ = Direction change

v_o

v_f

$\lambda = v_f/v_o$

Obstacle

o

Irrelevant

o

o

None

Figure 33. Tremoulet and Feldman, "The influence of spatial context and the role of intentionality in the interpretation of animacy from motion" Experiment 1. Five different environment (foil location) conditions. [323]

Prey behaviour was deemed most animate, followed by Predator and then Obstacle. Lower ratings were given to Irrelevant and None conditions. As they had found in earlier experiments, acceleration and larger changes of direction continued trigger more animate readings. Even a minimal static contextual cue was found to influence the level to which a movement conveys animacy. Not only may it increase animacy ratings where an object approaches another, but where objects are ignored, animacy rating may also be suppressed. They did, however, note that in the first experiment, the effect of the environment (including the static dot), were small compared to speed, acceleration and direction of change factors. They suggest this may indicate that "context generally contributes less to the percept of animacy than motion" [324] leading to a follow-up experiment (Figure 34) where, in two out of four conditions, the moving object collided with a 'paddle' (a static white rectangle).
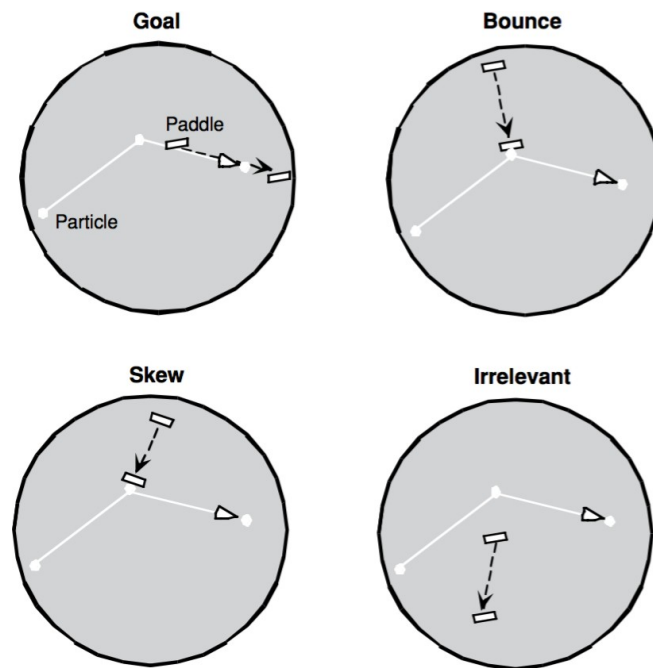
Figure 34. Experiment 2. Four paddle condition

The Goal condition, similar to Prey, was rated highest followed by the Irrelevant condition. Observers would perceive physical causality in collisions (similar to Michotte's early work) in Bounce and Skew. Although the Skew condition did not reflect the moving figure in an accurate manner relative to its orientation, animacy perceptions were suppressed. The impression of a passive change of direction, more or less accurately, follow Newtonian laws. Again, faster movement increases in speed and more dramatic changes in direction were found to have the highest rating.

The researchers concluded that acceleration is "such a compelling cue for animacy that it can significantly increase ratings, even in the presence of at least one cue for inanimacy" [325], which in these cases was a static feature of their environment. The results of these experiments also support the view that static context in an environment can "enhance" the influence of speed and direction changes in animacy percepts.

Their third experiment retained the same four paddles but now moving for the first half of each motion sequence, stopping immediately upon the change in direction of the figure they titled "particle" (Figure 35). The final position of the paddles was identical to experiment 2. The Goal condition, where the paddle appeared to be followed by the particle upon its change of direction and acceleration, making its behaviour appear highly contingent upon the particle's. This spatial and temporal contingency gave the impression of social interaction

between figures.
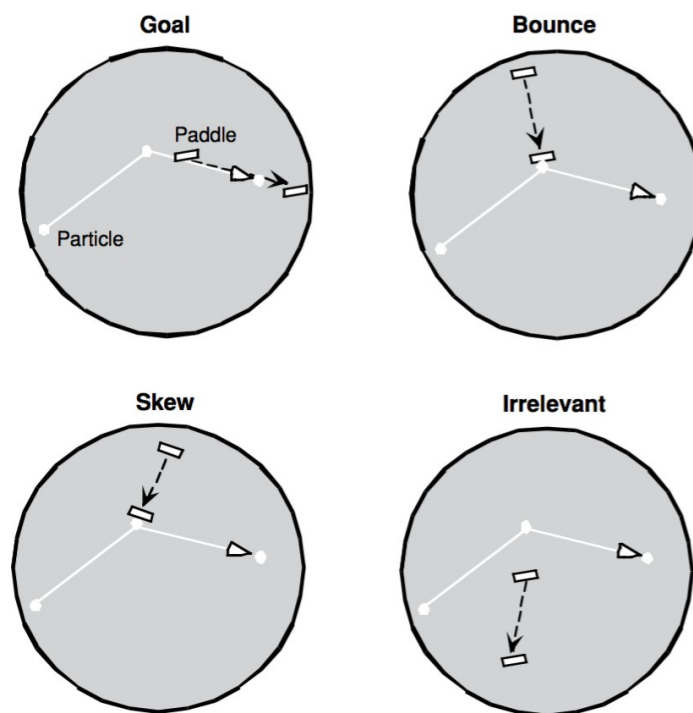
Figure 35. Experiment 3. Four paddles in dynamic conditions.

The Goal condition gives a strong impression of being 'chased', which has been found of the most salient types of animacy perception [326] [327]. Bounce and Skew conditions were seen again as passively obeying Newtonian Laws, the energy of the paddle being transferred into the motion of the particle. Finally, in the Irrelevant condition was perceived with some animacy as its behaviour was temporally contingent upon the particles behaviour, though not spatially contingent. Consistent with all experiments, greater speed, acceleration and change of direction were more highly rated for animacy. Throughout the study, slight manipulation of context was found to significantly change how the motion of a moving geometric figure is perceived. "Spatial context can augment or suppress this impression, depending on how it relates to the target's motion trajectory" [328]. In terms of the relative importance of stimuli, Tremoulet and Feldman emphasise that "the effect of context on animacy ratings was consistently small, compared with the effect of acceleration." However, when motion of an entity is contingent on its environment, static or dynamic, impressions are enhanced. The appearance of dynamic social relations is most animate. By developing a deeper appreciation of these contingency cues, spatial and temporal, impressions of animacy can be predictably manipulated.

Orientation

As we have already seen in *Perception of Animacy From the Motion of a Single Object*, the orientation of geometric object/figure in relation to its path of motion, particularly after a change in direction, can affect perceptions of animacy. Alignment with a path of travel indicates control and purposeful movement rather than, for example, appearing to be blowing in the wind. A compelling and viscerally engaging experiment is titled the 'Wolfpack Effect' [329]. Its authors Tao Gao, Gregory McCarthy and Brian J. Scholl explore the influence of orientation of moving figures to one another through a series of films and interactive studies. The work persuasively argues that animacy perception in itself, is not the end state of perceptual visual processing, and that a richer set of phenomena are available (some of which are still likely undocumented) that powerfully shape our experience and interaction.

> *"The perception of animacy [is treated] as a sort of epiphenomenon, such that there has been a considerable amount of research into the causes of perceived animacy, but very little research on the systematic effects of such processing on downstream perception and action."* [330]
> *(Gao et al, 2010)*

The first thing to recognise about this research is that these experiments are not easily communicated through written accounts or illustrations. Usefully, the authors have shared video documentation of their animated displays online [331], which are essential viewing alongside their report. Their study extensively explores subtle changes in context that I will not review in total, rather I will focus on a few key observations.
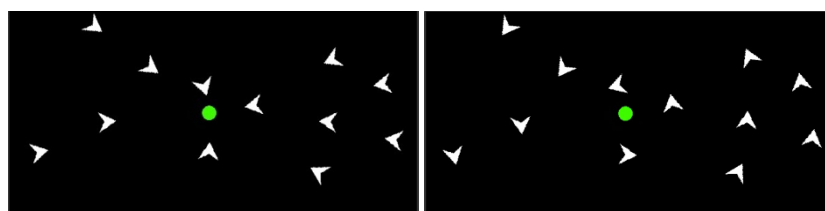
Figure 36. Left: First frame from Animation S1.1: Basic Demonstration of the Wolfpack Effect. Right: First frame from Animation S1.2: Basic Demonstration of the 'Perpendicular' Control for the Wolfpack Effect

The Wolfpack Effect occurs in conditions where a group of figures appear to orientate themselves towards a single figure. In this example (Figure 36), a single green circle is controlled by subjects of the experiment (using a mouse), who move around trying to avoid

collisions. The white arrows, or 'Wolves', did not pursue the circle, rather moving randomly around the screen, keeping their orientation pointed directly at the human controlled figure. Subjects commonly described animate behaviours, such as "Many white arrows were chasing after the green dot", "The triangles . . . follow the green dot wherever it goes", and "There were triangles trying to hit me."

For a comparative experiment, the direction of the arrows was turned 90 degrees, making their orientation perpendicular. Subjects no longer invoked animate behaviours instead describing "arrows that went in random directions", "chaotically floating white chevrons", and "a bunch of white snowflakes or jacks swirling tumultuously around my green circle" [332]. The results indicate that the Wolfpack Effect can overcome what would otherwise appear to be passive motions following Newtonian laws. I would additionally add that watching these two films I found myself more anxious and viscerally engaged in watching the Wolfpack Effect compared to the 'Perpendicular' condition. Although no questions were asked to the subjects on this matter, it would seem likely from their descriptions of the behaviour that impressions of being chased (although motion was in fact random) would heighten the experience.

The researchers followed up on the impression of being chased, in an experiment examining whether the Wolfpack Effect could actually impact a chasing behaviour (Figure 37). For their 'Search-For-Chasing Experiments' they produced a film, with a single randomly moving green rectangle and six white arrows. One arrow was a 'sheep', chased by another arrow 'wolf' and there were four 'distractors'. Both the sheep and distractors moved randomly. Only the wolf moved with purpose approaching the sheep with some deviation rather than a precise 'heat-seeking' trajectory. A series of conditions were tested where all the arrows orientations performed in the same way. In Wolfpack, all the arrows, Distractors, Sheep and Wolf pointed at the randomly moving rectangle, in Perpendicular condition all the arrows turned 90 degrees to their Wolfpack condition, in Match condition the arrows orientated to their direction of travel, and Disc condition showed no orientation.
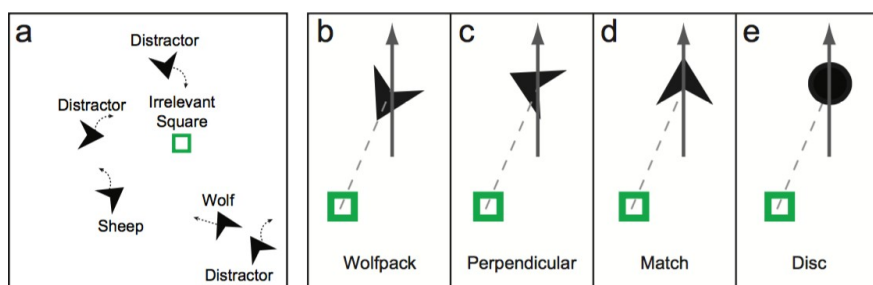

Figure 37. Search-For-Chasing Experiments (a) Sample Display (b-e) Four Conditions tested. Wolfpack prevented detection of chasing, while Match supported motion profiles in detection.

In all conditions, subjects were asked to pick out the Wolf chasing the Sheep. The researchers found that in the Wolfpack condition, its effect impaired the detection of the pursuit. This is a surprising result since chasing is considered among the most salient forms of animate behaviour [333] [334]. In the perpendicular, Match and Disc conditions, detection of the Wolf was considerably higher. Match featured as the condition were detection of the Wolf was easiest with all figures orientated in their direction of travel.

In their follow-up 'Don't Get Caught' experiment (Figure 38), a game version giving subjects control (using a computer mouse input) of the position of the Sheep represented by a green circle demonstrated similar results. The subjects were instructed to detect and evade the Wolf chasing them which they found easier when the arrows were in their Perpendicular condition. They found the Wolfpack Effect clouded the ability to make judgments about the arrows based on motion profiles because of its apparently dominant influence. In crowded kinetic conditions, orientation appears to compete with judgements of intention from motion profiles creating ambiguity. When motion profiles and orientation are in alignment it becomes easier to interpret intention accurately.
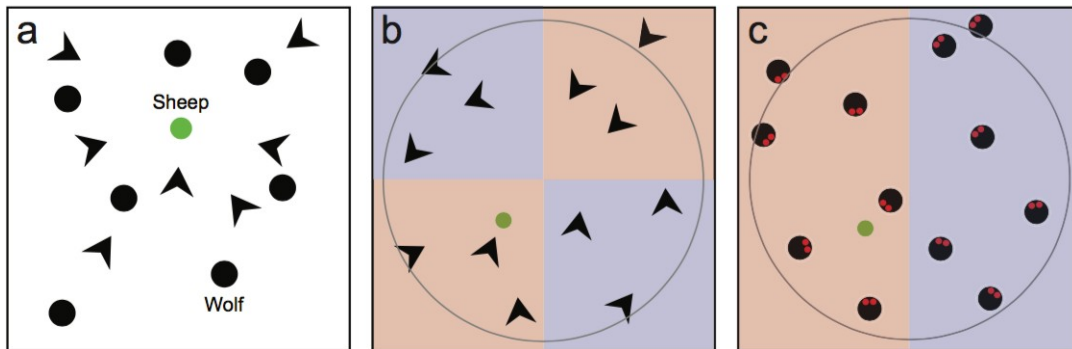
Figure 38. (a) Don't Get Caught Experiment in Wolfpack condition (b) Leave Me Alone (Darts) with two quadrants in Wolfpack condition and two Perpendicular (c) Leave Me Alone (Eyes) half the screen in Wolfpack condition and the other Perpendicular

A further experiment titled 'Leave Me Alone' reveals something important about the fast, perhaps reflexive nature of decision-making by subjects in these dynamic and interactive contexts. Twelve arrows they termed 'Darts' were distributed around the screen, three in each quadrant moving randomly but staying within their quadrant (Figure 38b). Subjects are asked to control the position of a green circle and tasked with avoiding the other figures moving randomly. Two of the four quadrants are set in Wolfpack condition, while the others are in Perpendicular condition. Subjects were found to spend more time evading the Darts in the Perpendicular quadrants.

"On the basis of the phenomenology of the displays, we suggest that the avoidance may have been due to the fact that observers felt that darts in the wolfpack quadrants were actively pursuing them, even though the darts were in fact moving randomly." 335 (Gao et al, 2010)

To determine if this effect was the result of merely the perceived "sharpness" of the figures, the researchers replaced the darts with circles featuring two dots that appeared to be eyes (Figure 38c). The experiment followed the same method. Either the eyes in a quadrant would orientate towards the subject in Wolfpack condition or they were turned away 90 degrees. Again, subjects spent less time in the Wolfpack quadrants where the eyes appeared to 'watch' their green circle, than in the quadrants where their gaze was averted.

What all of these results point to is the understanding that dynamic orientation is a powerful social cue. It generates compelling perceptions of animacy and can complement or conflict with other motion cues. The environment of these experiments features many moving figures compared to the earlier examples, making "comprehension" at any one time, of all of individual behaviours of the figures difficult. Subjects instead have to rely on instinctual, reflexive responses when overwhelmed by the variety and ambiguity of motion cues. This tight coupling between perception and action for the subject suggests interactive experiences turn to animate cues to make fast decisions. Orientation cues appear particularly important.

The Wolfpack Effect is a recently recognised (previously undocumented) perceptual cue still to be fully understood. As many researchers in the field point out, it is likely that there are more cues to discover that may not just be useful to perceptual research in this field, but also to designers. One can argue that designers and artists have already come upon these perceptual responses tapping into it for aesthetic potential. Random International and Chris O'Shea's *Audience* installation (Figure 39) from 2008 featured 64 servo driven mirrors tracking inhabitants. My own *Performative Ecologies* Installation also perhaps harnessed this cue, quite accidentally. Indeed, it is likely that artists in their own experimental practices are discovering and manipulating a variety of currently undocumented perceptual cues, which could be of benefit to scientific research.

Figure 39. Audience by Random International and Chris O'Shea (2008) [336]

Case Study of Behaviour Perception: Chasing

From a young age children play chase. Evolutionary and developmental psychologists have argued that there are clear fitness and survival benefits to such play. Variations include hide and seek or tag, and carry into aspects of adult sports. Interest in the dynamics of chasing spreads across disciplines from ethology, game theory, geometry and linear algebra, to the computational algorithms that drive autonomous robots and heat-seeking missiles. Chasing has its own body of research, namely 'Pursuit Theory', that is as important for understanding evasion as it is for understanding chasing.

"If you should encounter a mountain lion […] there are two things you must not do, according to the Mountain Lion Foundation: turn your back on the animal or run away. Either of these behaviors would trigger the lion's predatory chase behavior, transforming you from startled hiker into potential prey. It is possible to avoid becoming prey by denying the lion's perceptual system the cues that normally accompany being a mealtime animal." [337] *(Blythe et al, 1999)*

Not only are there evolutionary arguments for our playful desire to chase, but also our perceptual capabilities to quickly detect chasing. Like the Mountain Lion, Humans are very adept at making such behavioural judgments from simple motion patterns. These have been

extensively studied in developmental psychology. For a recent discussion on this body of literature, see Frankenhuis, et al *Infants' Perception of Chasing* [338]. One of the studies cited is Gao, McCarthy and Scholl[339], authors of the aforementioned Wolfpack Effect. Indeed, the effect had been discovered though the researchers' earlier studies of chasing using the same metaphor of the Wolf and Sheep. Using algorithmically driven computer displays the researchers were able to, in a systematic manner, manipulate subtle motion parameters to understand "the nature and limits of this percept" [340].
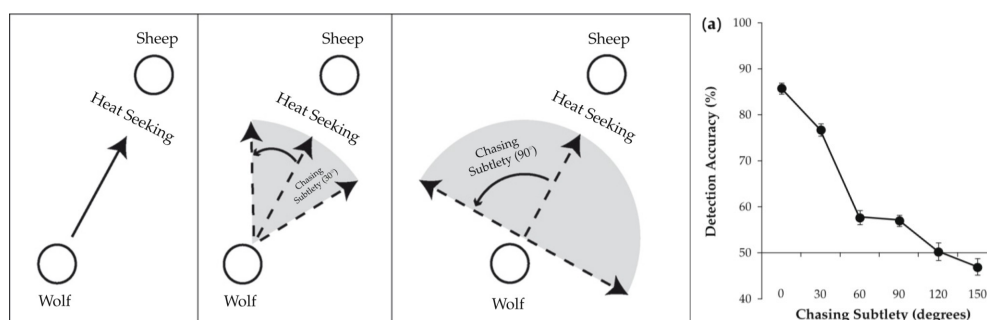
Figure 40.The psychophysics of chasing: (a) Graph showing chase was present, as a function of chasing subtlety

Unsurprisingly perhaps, chasing was most salient where the Wolf followed a direct path of pursuit - a heat-seeking behaviour. Levels of detection remained high even when there was some deviation of up to 30 degrees, until a sudden drop occurs indicating that the correlation between perception of chasing and angle of pursuit in not linear. As detection rates drop off towards 60 degrees an interesting phenomena appears where the Wolf is still making indirect progress towards the Sheep, getting closer and closer, yet undetected. The researchers describe this as a stalking behaviour, operating outside of the parameters of the perceptual cues for chasing.

These results point to is the subtlety with which parameter changes can alter observers' perception, and it is worth mentioning again that detection does not appear to be consciously reasoned about – in any sense of involving higher-order judgements – but rather appears to be instinctive. Again, we see animacy not as a perceptual "end product" but rather as having these downstream heuristic reflexes that require further study. As Scholl and Tremoulet point out in their conclusion to their summary article *Perceptual Causality and Animacy,* "rarely in experimental psychology or vision science has such a rich set of phenomena been so understudied"[341].

Heuristics

As we have seen in motion perception, the visual system selects salient cues of social significance fast, enabling immediate decision-making to take place even where there is insufficient information or time for higher-order reasoning processes to function. This is sometimes called a 'gut reaction' or 'gut feeling'[342], idioms which touch on the sense of bottom-up, rather than top-down, control - irresistible, reflexive, and heuristic in nature.

> *"A heuristic is a strategy that ignores part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods."* [343] *(Gigerenzer and Gaissmaier, 2011)*

Through the lens of evolutionary psychology, we can assert that nature, through selection, has shaped the heuristics that govern instant social perception. But what about when there is sufficient time and information available to make more considered decisions? Contrary to rational theories of social cognition, heuristics may continue to take a leading role, partly because of its primacy in response time, but more significantly because of the cognitive theory of 'accuracy-effort trade- off'[344] - the idea that we compromise on accuracy to save on effort, or put plainly, sometimes we simply just rely on our instincts.

There is an underlying assumption that putting more time and mental energy into gathering and processing information leads to more accurate judgements, but contemporary studies of heuristics are beginning to challenge this modern viewThe computational culture of the 20th and 21st centuries has strongly asserted its dominance in defining rational decision-making. Where information is known (and accurate), decision-making through statistical and logical methods can be very effective, especially within the fully defined, discrete spaces of digital environments.

However, in the context of human social relations, in a complex, and uncertain world, recent studies of heuristics have shown that the theory of trade-off between accuracy and effort are false. Gerd Gigerenzer and his colleagues at the *Center for Adaptive Behavior and Cognition* at the Max Planck Institute for Human Development suggest, "simple heuristics perform comparably to more complex algorithms, particularly when generalizing to new data – simplicity leads to robustness" [345]. We are all familiar with the argument that complex problems require complex solutions. This, they argue, is not always the case. Gigerenzer gives a critical example of a tendency towards computational concepts in contemporary

discussion of cognition, picking on a quote from Richard Dawkins.

> *"When a man throws a ball high in the air and catches it again, he behaves as if he had solved a set of differential equations in predicting the trajectory of the ball... At some subconscious level, something functionally equivalent to the mathematical calculation is going on."* [346] *(Dawkins, 2016)*

In an exercise in Occam's razor, Gigerenzer strips away the computation suggesting a simple "Gaze heuristic" [347] operating upon simple feedback control.

> *"Fix your gaze on the ball, start running, and adjust your running speed so that the angle of gaze remains constant. A player who relies on the gaze heuristic can ignore all causal variables necessary to compute the trajectory of the ball—the initial distance, velocity, angle, air resistance, speed and direction of wind, and spin, among others. By paying attention to only one variable, the player will end up where the ball comes down without computing the exact spot."* [348] *(Gigerenzer et al, 2011)*

What Gigerenzer is describing is the same heuristics understood to be used by various animal species in predatorial behaviour, from fish and birds, to cats and dogs. For example, in 2004, Shaffer, Krauchunas, Eddy, and McBeath studied the behaviour of dogs chasing and catching Frisbees, finding they hold a constant optical angle between themselves and their target. They then collated that the "dogs use the same viewer based navigational heuristics previously found with baseball players" [349].

It suggests that animal species sharing an evolutionary lineage of the visual processing system of the vertebrate eye, share heuristic strategies in their behaviours. One might have expected Dawkins, a proponent of evolutionary theory to offer an explanation in line with the hypothesis that perceptual heuristic processing has fitness advantages, over explanations of higher-order reasoning. However, Dawkins, first recognised for his work in computer simulations of evolutionary processes, draws upon computational thinking. Evidence, in itself, that even those firmly in the bottom-up camp, can still be seduced by top-down computational reasoning.

Gigerenzer suggests that ignoring information has often been mistaken as a form of irrational behaviour – the argument suggesting, the more you know, the more likely you are to make the rational decision. He argues that the real skill is knowing what one doesn't have to know. His research group's compendium *Simple Heuristics That Make Us Smart*, opens with the infamous Herbert Simon statement.

> *"Human beings viewed as behaving systems are quite simple. The apparent complexity of our behaviour over time is largely a reflection of the complexity of the environment in which we find ourselves."* [350]
> *(Simon, 1996)*

This bottom-up approach to heuristics, bound to its environment, in the immediate sense of embodiment, and shaped by adaptation over its evolutionary history is distinct from common notions of computational heuristics, such as 'expert systems' that are top-down. Gigerenzer and his group describe themselves as 'ecological rationalists' a name that echoes underlying principles of cybernetic thinking, recognising the combined roles of agent and environment in emerging behaviour. While computationalists focus on the internal organisation of rational behaviour, an ecological model emphasises cognition as a continuous exchange with an external environment. Rationality is context specific. To understand an ecological rationality, one must not only analyse the structure of the heuristics, but also what Ashby called the 'Environmental Half' - the role that the structure of the environment takes in the emerging of rational behaviour.

3.6 Agents

> *"A creature that can solve any problem given enough time - say a million years - is not in fact intelligent at all. We live in a time-pressured world and must be able to think quickly before we leap."* [351] *(Dennett, 1984)*

Parameterising Behaviour

Taking the ecological perspective of what shapes the heuristics of animacy perception, the question that emerges is what are the most important and distinct categories of social behaviour for survival and success? Two distinct fields of research, artificial life research and

perceptual psychology had approached this question from quite different directions, synthesising for the first time in Blythe, Miller and Todd's *Human Simulation of Adaptive Behavior Interactive Studies of Pursuit, Evasion, Courtship, Fighting and Play* [352].

Their ALife research focus on 'Simulation of Adaptive Behaviour' – primarily motion based – was, in their own words, too often reliant "on the creators' subjective impressions of whether a certain behavioural trajectory generated by a simulated agent was sufficiently lifelike or animate in a particular task" [353]. Seeking to overcome individual subjectivity, they devised an experiment where human subjects, controlled a 'bug' on a computer screen, simulating the motion trajectories of six behaviours they were asked to act out. The motion characteristics of these behaviours were then analysed, with the aim of revealing cues that are statistically correlated with categories of animate behaviour.

The behaviours selected by the authors were deduced from positive and negative 'fitness affordances' – attraction to food and mates on the one hand, and on the other repulsion to predators and sexual competitors. Five initial categories were pursuing, evading, fighting, courting and being courted. A sixth play was added as it was seen as a behaviour sometimes used by animals for learning the five others. As the experiments were based on social cues, subjects were paired so that, for example, two subjects with their two bugs on screen were asked to fight or one was asked to pursue and the other evade.
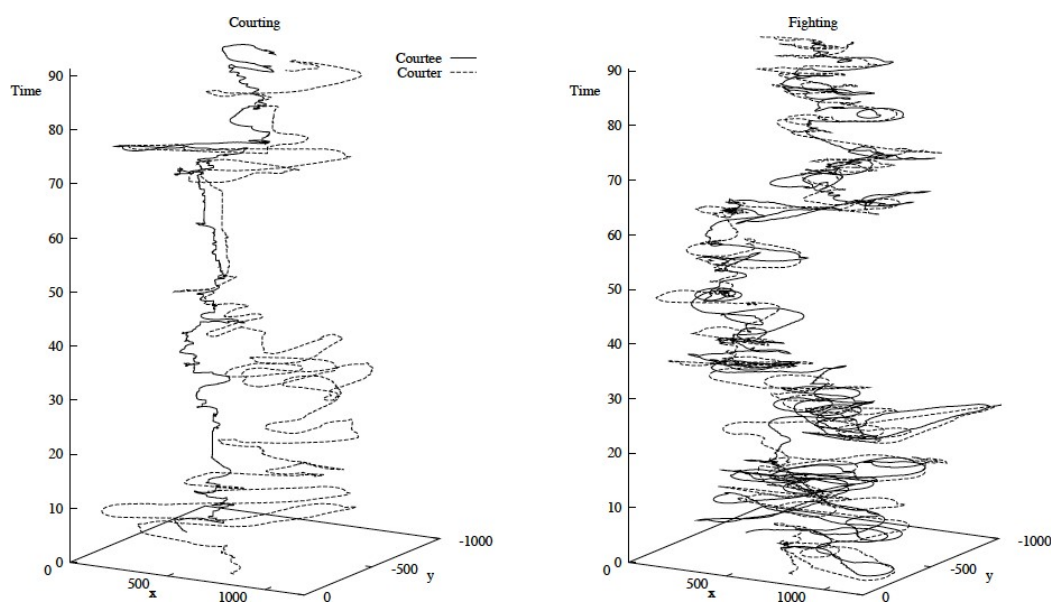

Figure 41. Samples of courting trajectories (left), and fighting trajectories (right) between two human operated "bugs" on a 2D Screen, with position represented on x and y axis.

Quantitative analysis of motion parameters over the 90 second trails was initially measured on average velocity, kinetic energy (sum of acceleration and deceleration), vorticity (the sum of direction change), and radial distance (distance between bugs averaged). They found, for example, that velocities were continuously high for pursuit and evasion maintained over a large distance, contrasted against courtship's slower and restricted movements. Courtship, however, involved high levels of kinetic energy, the result of rapid increases and decreases in speed. The courtee and courter were distinct by the Vorticity of the motion. The bug that was courting turned a lot, while the bug being courted turned much less. Playful behaviour inputted by the subjects appeared to combine features of the five other behaviours.

The recordings of the (human controlled) bug behaviour and the statistical analysis of motion cues provided the team with the data to invent a computer algorithm that could categorise animate motions [354]. In preparation for its development, a new group of human subjects unfamiliar with the earlier experiment, watched the recorded bug movements and, limited to a 'forced choice', were asked to pick between the six categories. Although Play was often confused with Pursuit, and Fighting was also confused at times with Pursuit and Evasion, participants often selected the correct categories, and certain behaviours were never confused, such as Pursuit and Courtship. The researchers, satisfied that the available cues in this minimal display were sufficient for categorisation, proceeded to explore a range of computational approaches. Essential to any recognition algorithm are its input parameters, which must be carefully considered. Positional information of an entity, for example, is irrelevant unless relative to the position of another entity, the same goes for orientation. Isolated motion cues discussed in Tremoulet and Feldman's research, namely speed and direction change, are also fundamentally important. Blythe and his team refined their data down to "seven simple, ecologically relevant cues" – individual and social: individual bug absolute velocity and vorticity, alongside relative velocity, vorticity, heading and angle (orientation). These were measured, and simply averaged, over the time of each recording.

The second step in designing a recognition algorithm is to develop a strategy for processing inputs. Their immediate choice was a parallel computing approach using a typical three-layer artificial neural network (ANN), trained using the researchers' 300 total bug motion recordings. Following this training exercise, the ANN categorised 90% of the recordings correctly. This is not entirely surprising as the training data and the testing data were identical, so the ANN was fed a new sample set and the results showed 67% accuracy. An impressive result considering the human subjects only scored 49% accuracy though, to be fair to them, they were not 'trained' on the data set before the experiment.

The researchers also explored linear computing approaches to the recognition algorithm. Three versions of heuristic 'if-else' logics were tested, however, none of them were as accurate at categorisation as the neural network. There is one caveat to that result. When particular input cues were omitted from the ANN, it was less effective than the heuristic approaches that were developed with the understanding that of the seven cues, not all are necessary to recognise certain behaviours. Absolute velocity was found to have provided the most accurate categorisation, followed by relative angle and then relative velocity. Their Categorization by Elimination heuristic algorithm checked the cues in a defined order, only using as many cues as (minimally) necessary making it "fast and frugal".

While it may not have been their primary intention to build a 'universal movement grammar', their ecologically rational approach offers a compelling method to identify a base set of animate behaviour categories. More complex examples involving three or more animate entities – such as the protective behaviours witnessed in Heider and Simmel early animation – are further interesting and unexplored building blocks. The Wolfpack effect also suggests categories that involve many animate entities, opening up a fertile research space, currently understudied. More recently Viksit Gaur and Brian Scassellati have presented a feature recognition approach for spline curves based on average coordinate points. This has enabled them to add an additional 'Straight Line' cue, the argument being that animate things do not typically move in perfectly straight lines[355].

As a final note on Blythe and his colleagues' work developing a "Motion Turing Test". Human subjects watched and identified behaviours of two bugs controlled by a computer, parametrically generating motion paths based on the six behaviour cues. For example, a bug performing pursuit behaviour would have high absolute velocity, with low relative velocity and low relative angle (as it is pointed at its prey). A bug evading pursuit would have the same high absolute velocity and low relative velocity, but differ in its high relative angle (as it is pointed away from its predator). The most noteworthy result from the study came when two computer- controlled bugs performed together, their behaviour was perceived as "mechanical and stereotyped", but when a human controlled one of the bugs, the behaviour of the computer-controlled robot became "very animate". One can only conclude that the animacy of the human controlled bug agent was reflected in the behaviour of the computer-controlled agent. The environment of the computer-controlled bug (namely the human bug agent) was responsible for giving it greater animacy than its own algorithms were solely capable of.

The Limits of Reactive Agents

The ability for agents to move around and navigate the features of their environments is a primary perceptual cue for determining animacy. Pathfinding algorithms are particularly common techniques for steering agent behaviour in environments that have developed out of AI research. Gaming systems typically use fast "grid-based pathfinding" approaches, such as the "A*" (pronounced A star) heuristic [356] technique, based originally on computer scientist Edsger W. Dijkstra's graph-based algorithm [357], developed in the late 1950s. The motivation behind the development of the A* algorithm by its primary author Nils Nilsson, was to accelerate path planning for the first major mobile robot in AI research, *Shakey* (1966-72). Named so, for its jerky motion, the robot was built upon "information processing" models of the mind, articulated as the physical symbol systems hypothesis of Newell and Simon [358]. Developed at the Artificial Intelligence Center of Stanford Research Institute, the robot had limited success as a mobile agent for reasons well documented in Rodney Brooks and Hubert Dreyfus' aforementioned criticisms of classical reductive AI systems in complex environments. The A* algorithm, however, would be widely adopted in computer gaming because it worked well in discrete, well-defined environments. When these algorithms are found to be ineffective, due to obstacles in these digital environments, game designers may often choose to modify the environment rather than solve the potentially more time consuming and complex challenge of modifying the algorithm. A luxury not so easily afforded to designers of mobile robotics for physical and complex environments.

In the field of computer game design, rule bases for behaviour have been crafted in innumerable forms to develop a wide variety of agents. With limited computational capacity in early computer gaming devices, developers needed to find simple rule sets to create compelling impressions of intelligent agent behaviour. An iconic example can be found in the programming of the four "Ghost" agents that gamers would excitedly try to evade in the classic arcade game *Pac- Man*. Developed by just three team members, it earned more than $1 billion in quarters within 15 months of its U.S. release [359], by creating an addictive tension, as the human controlled agent *Pac-Man* was chased by ghosts each with their own unpredictable autonomy. Their ghosts' names were *Blinky, Inky, Pinky* and *Clyde*. Their original Japanese names translated as *Chaser, Fickle, Ambusher* and *Stupid*, and gave away a bit more about the underlying rules that steered their behaviour. All the ghosts cycled between two states, called scatter and chase. In scatter mode, the ghosts would move toward their respective four corners of the screen (Figure 42).
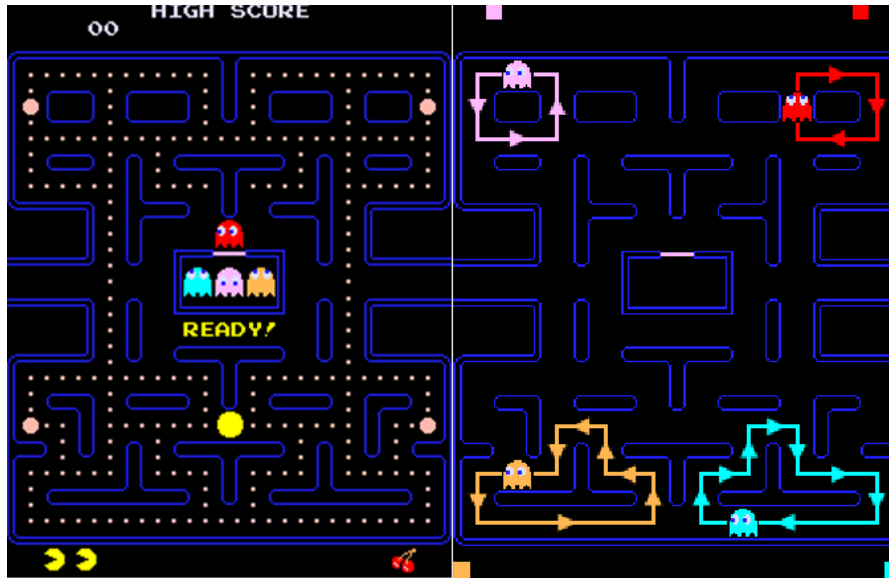
Figure 42. Left, Pac-Man environment at start of game. Right, behaviour in Scatter mode where Ghosts would go to predefined screen corners and follow paths.

In chase mode, each had more bespoke coding. *Blinky* was a simple 'chaser' agent with his target as *Pac-Man*, who he follows around. His speed increases as *Pac-Man* gets closer to achieving his goal of collecting all the yellow 'Pac-Dots' within the maze. *Pinky*'s strategy is more sophisticated always aiming for four spaces ahead of where *Pac-Man* is heading. *Clyde*'s behaviour can appear more unpredictable but does have an underlying logic with rules that change based on proximity. At more than eight square-distance, *Clyde* behaves like *Blinky,* chasing the target of *Pac-Man,* but when he reaches less than eight squares, he beings moving toward the bottom left corner of the maze. This gives *Clyde* the impression of being indecisive, at one moment, acting like a predator and then the next like prey. Finally, the most puzzling behaviour is *Inky's*. His chasing target is not only based on *Pac-Man*'s direction and position, but also on *Blinky*'s, drawing a line between the two and moving toward a position double the distance from *Blinky*.

The result of this is that *Inky* will show quite random movements at distance, but when *Blinky* closes in on *Pac-Man*, so will Inky. Skilled *Pac-Man* players can use all these simple rule sets against the ghosts – The *Pac-Man Dossier* by James Pittman catalogues these strategies [360] – but for the many millions of casual users of the game, the interaction of these simple rules creates a perfectly balanced and addictive game. A less inventive programmer may have simply made the ghosts chase *Pac-Man,* but chief designer Toru Iwatani was careful to craft a more multi- dimensional set of behaviours, by using a combination of state changes between scatter and chase, as well as individual behavioural traits in the agents,

that led to far greater of variety of game play.

From early arcade games to contemporary game design, much of the so called 'intelligence' of computational agents is driven by a variety of simple rule-based algorithms, combined with a measure of random functioning, leading to purposeful behaviour without being predictable. Fuzzy logic is also popular for employing probabilistic methods that lend degrees of uncertainty to purposeful behaviour, making computer-driven agents appear more animate.

These reactive approaches shortcut the need to develop adaptive forms of interactive behaviour, sufficiently convincing game-players, that they are encountering intelligent agents. Such a strategy could be called a form of 'Shallow AI', to use the term Persson, Laaksolahti and Lonnqvist [361] chose to describe simple heuristic strategies for designing "Socially Intelligent Agents". They acknowledge that these approaches to intelligent behaviour do not reflect cognitive models of human-like intelligence, yet they can create compellingly social and animate perceptions and interactions. The tense pace at which these games take place often demands fast heuristic decision-making by the gamer, and complete attention, leaving little time for them to question the calibre of their computer opponent's intelligence.

This has not deterred the industry, however, from claiming to have developed advanced AI to sell games. The development of genres of narrative gaming involving social interaction with computer driven agents, such as turn based adventure, borrowed from the decision tree logic of 'Choose Your Own Adventure' formats in book publishing. These relatively linear, 'progression-style' productions, with tightly defined sequences of events have led to criticism of repetitive behaviour in computer agents, and abnormal responses if human agents do things developers don't expect. The limitations of decision tree techniques, can lead consequentially to frustration and loss of immersion in gaming environments, as a direct result of the loss of belief in the 'life' of computer agents.

With the growth of gaming into an industry comparable in gross earnings to film, the complexity of these 'hand scripted' worlds has grown exponentially, as have the budgets to build more complex decision trees to overcome their limitations. These manually programmed hierarchical if-else logics are similar to those taken in classical AI approaches, such as the aforementioned CYC Project [362]. The practical limits of such approaches, and dissatisfaction with long-term interaction with primitive reactive agents, have led many gamers to go online and interact with other human players in networked multi-player games.

Simulated Adaptive Agents

In linear progression-style gaming environments, simple automatic and reactive agents can be ideal for performing pre-choreographed sets of behaviours at set locations. This is often an advantage for the game developer working in a similar fashion to a film director, crafting a scene with a very defined vision and scripted actors. For some game designers, giving agents adaptive behaviours makes them too unpredictable, with the potential to "throw a wrench in more traditional game production processes" [363]. However, interest from game developers and consumers alike, for non-linear open-ended games created a fertile space for innovation in emergent forms of behavioural design. Artificial life approaches found a natural affinity with the genre of 'God' games in the 1990s where the goal was explicitly to nurture the 'life' of virtual computational agents, whether simulations of micro-biology, bugs, human beings, cities or entire civilisations.

> *"I am just making insects and eventually I want to make mice and rabbits. There are millions of species on this planet and I see no reason to fear yet another species. Steve Grand interview for New Scientist."* [364]
> *(Graham-Rowe, 2000)*

Steve Grand's 1996 game *Creatures* was the first ambitious attempt to incorporate developments in genetic algorithms and neural network machine learning techniques, to give game players the chance to evolve and train their own agents. The pioneering aim of the game being to harness the creative parallel processing of many users to develop increasingly intelligent agents. Grand's design for his agents involved brains driven by use a neuronal processing system called 'State Value Rules' The brain made up of 10 lobes, each with specialist behaviour functions, and 900 neurons with thousands of dendrite connections, was linked to the creature's individual simulated biochemistry creating a complex interweaving of internal variables to determine behaviour through interaction with its environment.

By the second iteration of the game, its main character species featured 771 genes. Mutations in genetic material allowed for new features to emerge beyond the developer's expectations. Harnessing the community-building power of the internet, players could trade creatures and breed new offspring, creating the biggest web user community in the world [365]. The project has been credited with inspiring a new generation to explore the field of artificial

intelligence though has received criticism for the limitations of the design of the Creature's environment[366], populated with few pre-defined objects constraining the variety of adaptive behaviour.
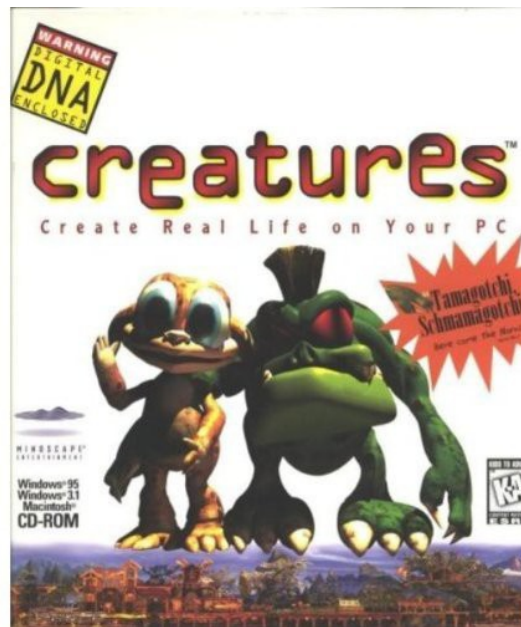
Figure 43. Packaging for Creatures the commercial artificial life game.

One defining difference between the scholarly exploration of computational ALife research in simulating life-like behaviour and the gaming industry is the focus on human interaction. Steve Grand explains his motivations for exploring life through playful gaming was to make people care for their creatures, rather than "passively watching hundreds of successive generations of norns blundering around the landscape, in the hope that one would finally evolve the ability not to bump into things" [367].

The motivation to create direct human connection between human life and artificial life has proven aesthetically potent, particularly where users nurture their computer agents. Emotional bonds sometimes referred to as the "Tamagotchi effect" drawing on a whole number of emotive human psychological tendencies that shape these experiences, and are discussed in the following chapter. A principle contribution of game development has been to bring the Promethean pursuit of artificial life to a far wider audience, exploring its application and ramifications to direct interaction with human life.

The gaming industry has also, as a bi-product of aims for commercial success in entertainment, financed the research and development of a far greater variety of agents than would otherwise occur in highly specialised AI research. Game developers have even opened their games to allow community contributors to develop agent intelligence. A notable

example is the *Quake* gaming franchise by id Software, who actively assimilates some of the most successful community made 'bot' agents into its game, with developers openly sharing their design strategies[368].
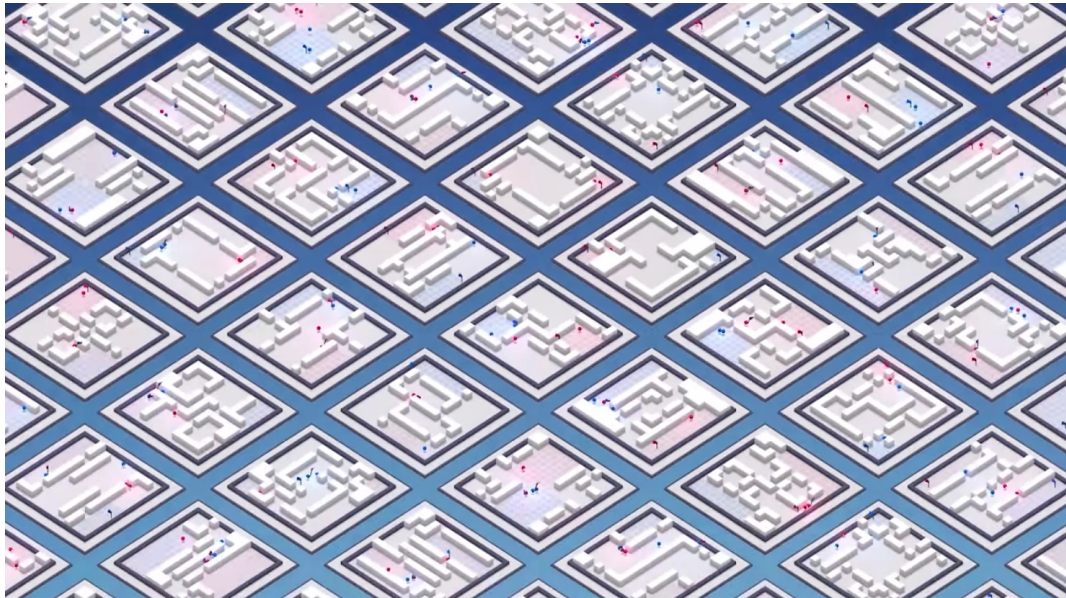
Figure 44. Google Deepmind. Agent training of Capture the Flag over hundreds of thousands of generations. Agents trained on changing environments so agents generalise for unvisited maps.

Recently, this has led to the relationship between gaming and AI research becoming closer. In 2018, Google's AI subsidiary DeepMind, modified a version of the *Quake III* game engine, to explore whether machine learning techniques could adaptively develop agents that could compete with human players in the canonical strategy game *Capture the Flag* (CTF) [369]. To make the challenge particularly difficult, each time the agents were trained, the procedurally generated environment of the game changed, so agents needed to generalise for unvisited maps. This prevented agents developing strategies that were specific to a particular map, but may otherwise be ineffective in other contexts. DeepMind's team used an increasingly popular method of reinforcement learning, where an agent learns how to behave in an environment it is placed into by performing actions and measuring the results. This behaviourist approach, where agents receive rewards for performing actions deemed positive against some goals defined by the designer, was used to train a population of agents to learn CTF, by playing alongside and against each other. The agents generate their own internal goals that begin to correlate with the reward signal they receive for their behaviour. In other words, they are not told anything about the game, but still learn the fundamental concepts of the game and develop an 'intuition' for how to win CTF.
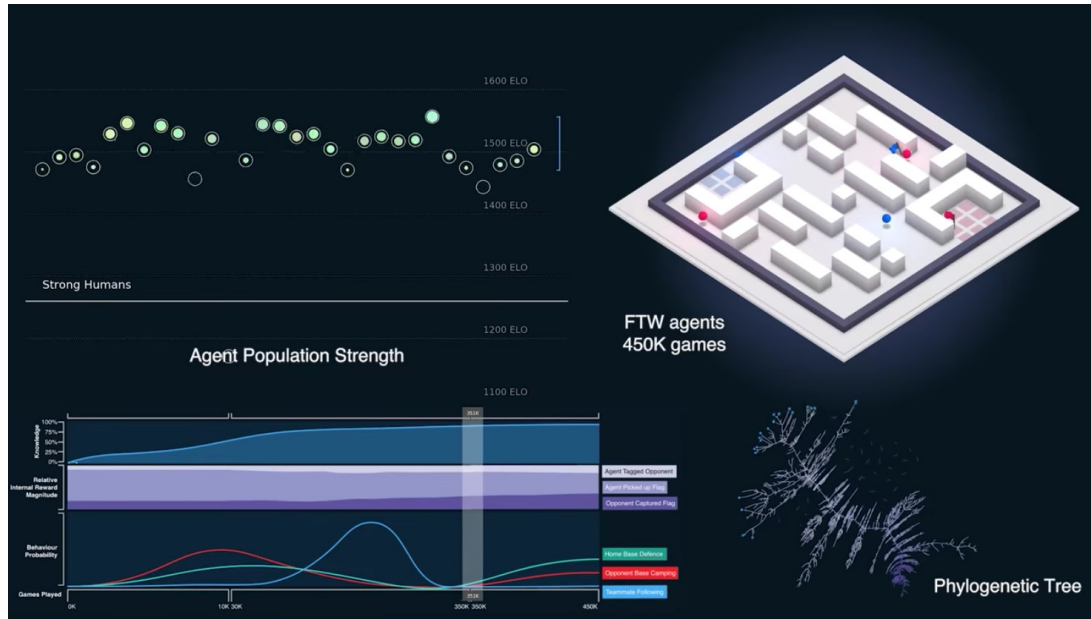
Figure 45. Google DeepMind, Phylogenetic Tree of agent species.

Analysis of the developed neural network showed that the importance of knowing whether an agent's teammate was holding the flag began 'early', after 45,000 games. This knowledge became represented by a single neuron after 200,000 games, which the team suggested was reminiscent of Rodrigo Quian Quiroga's theory of concept cells. A class of "Highly selective neurons that seem to represent the meaning of a given stimulus in a manner that is invariant to different representations of that stimulus" [370].

> *"DeepMind's agents not only learned the basic rules of capture the flag (grab your opponents' flag from their base and return it to your own before they do the same to you), but strategies like guarding your own flag, camping at your opponent's base, and following teammates around so you can gang up on the enemy." [371] (Verge, 2018)*

When they tested their agent's skills against human two-player teams they found them to be superior competitors at *Capture The Flag* - a complex game that requires strategic, tactical understanding of complex multi-agent environment, collaborative behaviour and navigational skills. This was all achieved without human supervision of the learning process, yet "agents in fact learn human-like behaviours, such as following teammates and camping in the opponent's base" [372]. John E. Laird and Michael van Lent suggest that "interactive computer games provide a rich environment for incremental research on human-level AI" [373].

Following Brooks' criticism that much of AI research involves highly specific research, too specialised to lead to general intelligence, they suggest that gaming may fill this essential gap, particularly as the complexity of these virtual environments increase. A testament to the intersecting research worlds of gaming and AI research was the adoption of blockbuster driving game *Grand Theft Auto V* by researchers [374] in autonomous vehicles. The high budget production's realistic graphics and physics engine made it an ideal platform to train car agents, interacting with other simulated car agents, pedestrians, weather and urban and rural contexts. At the University of Michigan Ford Center for Autonomous Vehicles (FCAV) [375], researchers screen-grabbed the near-photo-realistic imagery from the game to generate 'annotated data' that can then be used to train with. Comparing the effectiveness of their trained agent in a virtual world against an agent trained on photographic data (KITTI vehicle detection data set [376]) they were able to prove their synthetic data to perform better than current real-world data sets. Other ongoing projects include exploration of convolutional neural networks (at Princeton)[377], in order to learn safe following-distances to cars, while responding to lane markings, orientation of vehicles, and other essential variables for autonomous driving. Non-academic led initiatives include OpenAI and DeepDrives collaboration to develop an agent within *Grand Theft Auto V* that was shared publicly until issues of intellectual property [378] led the project to be ported to an open non-commercial engine [379].

In September 2017, Unity, a cross-platform game engine released its Machine Learning Agents (ML Agents [380]), an open-source beta initiative, to make its virtual gaming environments into training grounds for agents. The implication for gaming are more intelligent computational competitors to challenge game players, but the potentially larger implications are the harnessing of these agent behaviours out into the physical world, whether it is for autonomous vehicles, or ever-more sophisticated socially intelligent agents for human-centric interaction. Unity's AI and Machine Learning team now counts over 100 employees demonstrating the importance of these techniques in agent design. The next great challenge will be "porting" these gaming agents into the physical world.

Embodied Adaptive Agents

Embodied agents are subject to the laws of physics and behave as complex dynamical systems by virtue of both their morphological computation and electro- mechanical control systems, in interaction with the physical world. The shift in the past decade from classical focus on central processing in the "brain" towards a focus on adaptive and embodied interaction with the environment has seen a growing adoption of bottom-up strategies for

behaviour design. Grey Walter's tortoises were the first example of an embodied agent that was also given adaptive capabilities with the addition of CORA, an electrical learning circuit called a *Conditioned Reflex Analogue* that demonstrated simple Pavlovian learning. The new circuitry included some alterations to the sensors with a sound detector, light detector and a bump switch. Just as Pavlov's dogs were reported to salivating on hearing a bell, after training to associate the bell with food, Walter was able to train different behaviours by stimulating connections between the sensors and motors.

> *"Its education consisted very simply of trying to teach it that sound meant obstacle, which in turn meant trouble. The schooling was to blow a police whistle and kick it. After it had been whistled at and kicked about a dozen times, it learned that a whistle meant trouble. We then removed the specific stimulus—the stool. The whistle was blown, and it avoided the place as if there were a stool there."* [381] *(Walter, 1956)*

Grey Walter's pioneering work remains an important foundation to reinforcement learning for embodied agents, one that that Margaret Boden suggests may have all been forgotten if it hadn't been for "the end-of-century work in situated robotics and computational ethology" [382]. As we have found in examining developments in gaming agents in the previous section, connectionist computational architectures, such as deep neural networks, are now proving their superiority in making competitive and believable animate agents, versus classical reactive agents. The implication is that these approaches will solve the problems classical robotic agents face in physical environments, through embodied learning.

One facet of this emerging approach to embodied agents is the way it enables them to 'Self-Model', rather than rely on a manually constructed mathematical model, to determine strategies of locomotion. Roboticists Josh Bongard, Victor Zykov and Hod Lipson argue this makes robots more resilient to changes in their physical state caused by mechanical wear, or other unexpected damage caused through physical interaction with their environments - if they can continually restructure their internal self-models they can generate compensatory behaviour[383]. The teamed work with a four-legged shaped robot, driven by eight servomotors, that began with no self-model, only a large combinatorial range of possible models for a machine with eight motors. First, the robot makes an arbitrary motor movement and captures the sensory information of its resulting orientation (using tilt and motor angle sensors). A set of 15 'candidate self-models' are compared, to explain the detected sensory-

actuation causal relationship. It then generates new movements that are likely to gain further information for the self-modelling process. Through this adaptive process a model develops that eventually resembles well the physical configuration and leverage of the robot's motors and limbs. The standard configuration chosen for the robot was four legs each actuated by two motors. Once the robot has self-modelled this, it self- generates motor sequences that give it locomotion.
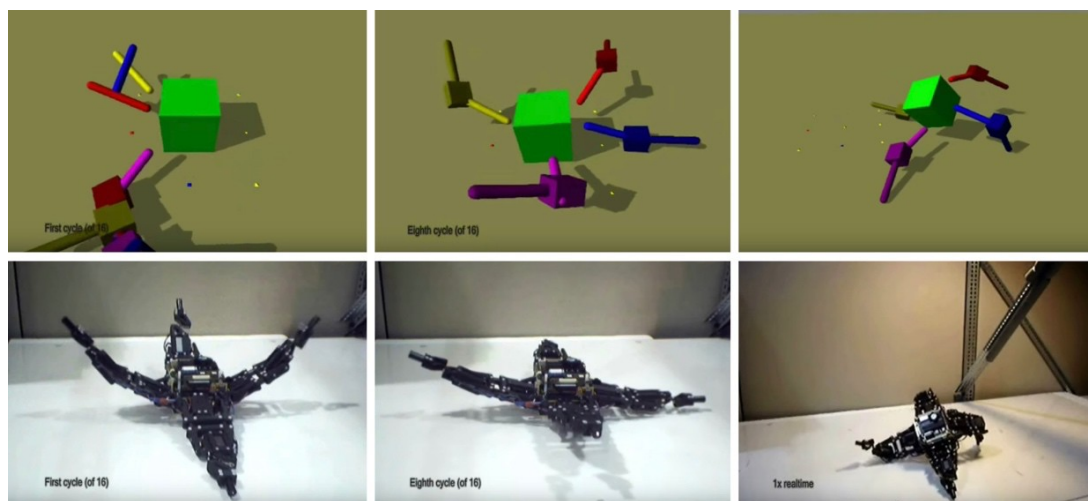
Figure 46. Robot self-models through cycles of action execution and self-modelling. It is later able to use its model to develop motion profiles to locomote.

The resulting gait in their experiments, were surprisingly life-like in quality. Footage shows the robot shifting is centre of gravity to propel itself forward rolling its limbs in a motion unlike any particular animal, yet familiar to invertebrates, such as snails, slugs, mussels, or octopuses. When a limb of the robot is intentionally damaged, its movements become even more remarkable. The researchers explain, "If the robot detects unexpected sensorimotor patterns or an external signal as a result of unanticipated morphological change, the robot reinitiates the alternating cycle of modelling and exploratory actions to produce new models reflecting the change"[384].

Compensatory behaviour is self-generated to recover functionality and the robot manages to maintain locomotion. Its compensatory motions appeared to use the broken leg like a crutch to press off against. This is a surprising strategy, perhaps not one that programmers might have considered themselves, yet the robot was able to adaptively find a solution itself, based on its new morphology. The behavioural possibilities of such self-generated motion strategies in robotics are a fascinating area of research, but there is also something more immediately engaging for audiences of the robot.

When I have shared the research footage in lectures, people often respond with empathy to the 'injured' robot, that cheerfully overcomes its limitation, with its somewhat tragic new gait. The limping motion is irresistible perceived as weakness. One might hypothesise that perhaps its motion triggers a percept rooted in our innate detection of prey and predators. The surprising behaviours that emerge out of an agent's embodied interaction with the world demonstrate the potential of these machines to both produce novel solutions beyond the imagination of the designers, and also compellingly animate perceptions from processes of learning.

Deep learning techniques for image and speech classification have made rapid progress in recent years. As I have discussed, learning techniques for decision- making in virtual environments, particularly games, are now making rapid progress too. Decision making by agents in physical environments, however, remains more challenging, because, for robots to act with intelligence they need to make decisions quickly about temporal relationships of cause and effect, and predict the results of their behaviour within far more complex physical environment than gaming agents face in virtual environments. All of this complexity increases further when robots must remain safe, robust and able to adapt to human behaviour and instruction.

This has not deterred researchers and recent developments in deep neural network algorithms are enabling robots to learn by trial and error. By coupling the recognition of physical objects with motor skills, within a single deep convolutional neural net, recent work at UC Berkeley [385] has examined whether "training the perception and control systems jointly end-to-end provide better performance than training each component separately". This is distinctly different to classical approaches, which would separate problems of visual perception from motor control. The team describes the approach as closer to how an infant develops coordination and problem solving through play. Using a two-armed robot and single camera, they trained the robot to insert Lego Blocks into each other, and a variety of other coordination tasks typical for early child development, such as placing a peg in a hole.

Roboticist Sergey Levine, co-investigating the robotics research at UC Berkeley with Pieter Abbeel, explained in a recent interview that, "The capabilities of this robot are still limited, but its skills are learned entirely automatically, and allow it to predict complex physical interactions with objects that it has never seen before by building on previously observed patterns of interaction" [386]. The fascinating result of this approach is the verisimilitude with which the robots behave like infants and so unlike classically programmed robots. The fledgling robots began to develop behaviour where they would try and land the peg

somewhere close the hole, so that it was in contact with the surface around the hole and then drag along that surface, sensing resistance until it disappears and then push the peg in. The motion is perceived as remarkably life-like, as the somewhat messy, self-correcting motion eventually achieves its goal.
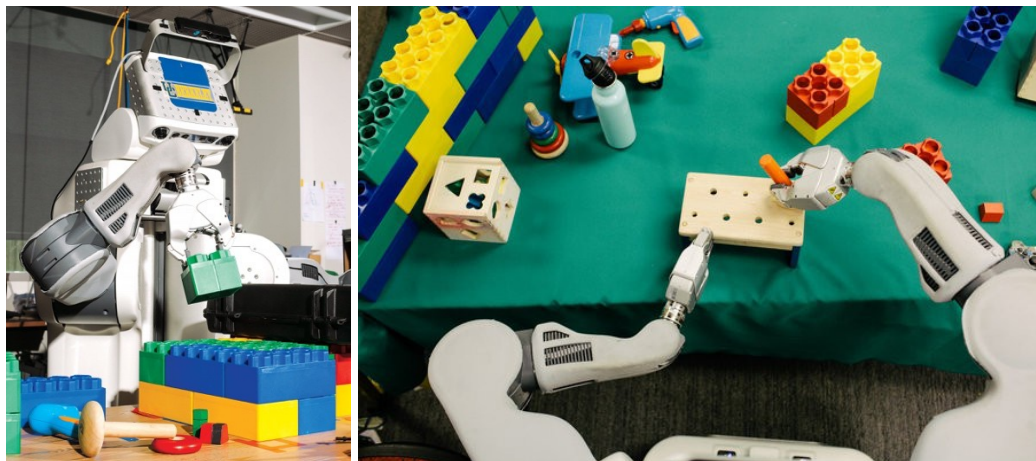
Figure 47. BRETT (the Berkeley Robot for the Elimination of Tedious Tasks) trained using deep learning techniques

In a classical approach to the problem of putting a peg through a hole, the challenge would typically be decomposed into separate tasks of vision and motor control. Two computer vision tasks would identify the location, orientation, shape and size of peg, and the location and size of the hole. Then two separate motor control tasks would try and solve problems of picking up the peg and then moving it to be aligned with the hole to go through. This requires high-resolution cameras, and high precision control, and even with the highest spec input and output hardware, these remain non-trivial problems. Nonetheless these processes can all be mathematically modelled and, with sufficient programming, a robot can follow a set of paths to achieve the task. However, as Gary Bradski, founder of the widely used computer-vision framework OpenCV explains, the power of these new algorithms is that, "It used to take hours on up to months of careful programming to give a robot the hand-eye coordination necessary to do a task…This new work enables robots to just learn the task by doing it" [387].

Not only does it offer a means to achieving effective visual-motor coordination for problem solving, the motion of the robot using this new approach moves with an entirely different quality. Whereas classically programmed robots can appear unsurprisingly robotic, by which I mean unnatural or mechanical, the behaviour of these bottom-up approaches leads to highly animate, natural motion paths, and distinctly different problem-solving strategies. An analogy of the two approaches can be made with two approaches Gerd Gigerenzer and

Richard Dawkins take to the problem of catching the ball. Gigerenzer proposes simple "Gaze heuristic" [388], while Dawkins turns to computing differential equations and trajectories.

The strategy that UC Berkeley's robots develop through trial and error, which appear highly animate, may also begin to reveal new understandings on the nature of the heuristics humans and animals take to interact with objects and environments. Through this embodied approach to animate behaviour, it may also have the impact of offering convincing evidence of the embodied nature of human and animal intelligence, and help to overcome the current Cartesian dogma that continues to shape much discourse in cognition and robotics.

The team at UC Berkeley are now looking to extend these skills into far wider range of manipulation problems, by structuring the learning around generalising to situations, giving machines the ability to learn what learning algorithms might work best in different contexts. An approach Pieter Abbeel, Director of the UC Berkeley Robot Learning Lab calls, meta-learning [389], aimed at shortening the time it takes for agents to find solutions to problems. Importantly, this meta-learning approach shifts machine learning from computer scientists and roboticists trying to find the optimal solutions to learning a task through their own ingenuity, to using the experience gathered by the embodied agent to discover algorithms. This is an exciting step that could finally bring robotics truly out of the lab and into the vast, varied and complex built environment. What this work indicates is that the quality of behaviour these robots will bring into our built environment will be highly animate, and unlike the aesthetics of behaviour that have characterised robots in the 20th century.

> *"A robot's perceived intelligence is significantly correlated with animacy."*[390]
> *(Bartneck et al, 2007)*

When Baron von Kemplen constructed his mechanical *Turk* in 1769 for Austrian- Hungarian empress Maria Theresa, he could not have anticipated the excitement his invention would attract. The extraordinary chess-playing automaton was, as we all know today, an elaborate trick perpetrated by von Kemplen and a diminutive human chess master hidden within a theatre of cogs and gears designed to convince observers of its mechanical veracity. So good were the small chess players that inhabited it over an 80 year tour of many cities of the world, that *Turk* often won, "It was even said to have inspired Jacquard to invent the automatic loom after it defeated him" [391]. Prof Noel Sharkey suggests that *Turk* followed in a tradition dating back to the ancients, where human mechanical ingenuity mixed with hidden

operators would perform deceptions to audiences, as acts of persuasion. The big change, however, with *Turk*, Sharkey argues, is that "von Kemplen's goal was to create a false belief in the technology rather than in the supernatural." He extends the argument to suggest that "Deception is an integral part of AI and robotics" and that "In some ways AI is the science of illusion" [392]. In reality, the state of AI and robotics has fallen far short of science fiction visions for machines engaged in meaningful social interaction with humanity.
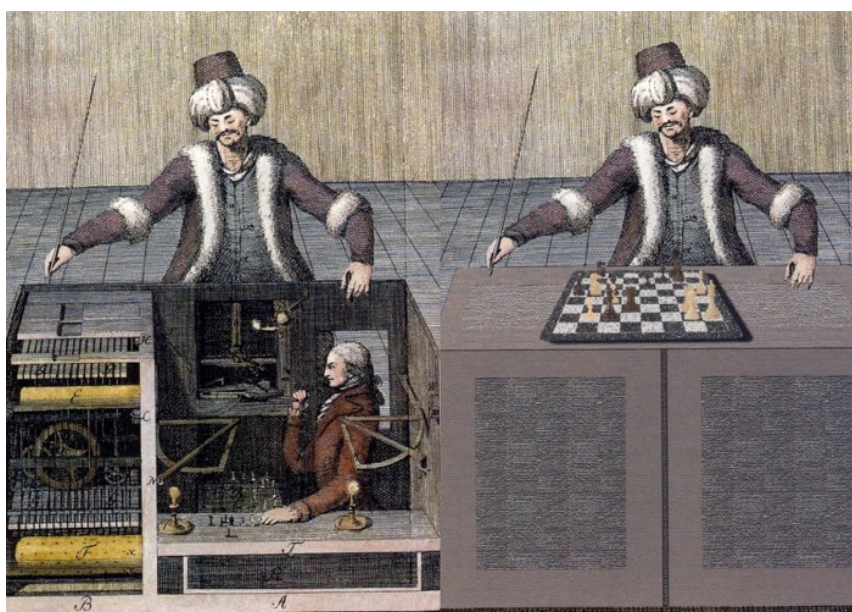
Figure 48. The Mechanical Turk of Johann Wolfgang von Kempelen

Public displays of humanoid robots are all too often a series of pre-coded motion routines or 'canned' responses to verbal instructions, little more cognitively advanced than Joseph Weizenbaum's text bot *Eliza*[393]*,* built in the mid-1960s.

Nonetheless, the excitement for human interaction with social robotics remains. The combination of the cultural myths of intelligent robotics combine with our cognitive tendencies to perceive life in animated objects, triggering "the active participation by the public in the suspension of disbelief" [394]. Though some of the slow progress can be put down to limits in computing power, I believe the larger obstacle to progress may be in the Cartesian cognitive cul-de-sac that characterises large parts of the field. Not only does it prevent progress in building more intelligent robotic behaviour, but it also prevents the field from fully appreciating human experience, particularly aesthetic experiences of Lively Artefacts.

The research field of Human–Robot Interaction (HRI) is a broad interdisciplinary community, including computer scientists, designers and engineers, cognitive scientists, linguists, and

psychologists, all interested in understanding, designing, and evaluating robotic systems, used by, or in the company of, human beings. The types of interaction are often quite one-dimensional, such as joystick control of a remote vehicle, or interfaces for control of manufacturing robots. However, with more social forms of interaction between people and robotic agents, we find a highly multi-dimensional spaces of communication. HRI has some of the difficulties that dogged classical AI approaches to robotics where problems of perception, decision-making and actuation are decomposed and distributed between different departments and universities only to be brought back together later. The risk with such approaches is as roboticist Rolf Pfeifer explains, is ending up with an unbalanced robot design, with a variety of systems patched together with no overall integration. Kerstin Dautenhahn suggests, "only a truly interdisciplinary perspective, encompassing a synthesis of robot-centred, human-centred and robot cognition-centred HRIs, is likely to fulfil the forecast that more and more robots will in the future inhabit our living environments" [395].

Methodologically, HCI and HRI are closely aligned, with HCI (the older more established field) having a significant influence of the formulation of HRI. This has shaped a tendency toward computationalist thinking with its Cartesian models of intelligence, and master-slave models of control. A continual discussion centres around the 'Llevels of Autonomy' (LOA) a robot is given. A commonly cited measure of this is Tom Sheridan and Bill Verplank's 10 level scale[396] of autonomy, developed to reflect on their research with unmanned underwater robots. At the low end of the scale, they describe how the "Computer offers no assistance; human must do it all". The robot is a direct tele-operated extension of human agency and makes no decisions itself. At the other end of the scale, "The computer decides everything and acts autonomously, ignoring the human". Most of the middle ground in the scale involves semi-autonomous machines that do actions based on commands reflecting HCI master-slave models. Note, Sheridan and Verplank's association between the computer and intelligence, with no mention of the physical intelligence of the robot itself.

Cartesian views of intelligence remain pervasive. Goodrich and Schultz's[397] survey of the field of HRI explains that "A common autonomy approach is sometimes referred to as the sense-plan-act model of decision-making". Though they acknowledge Brooks' [398] criticism of such top-down strategies they go on to defend classical techniques, suggesting the failures of early work may have been in the limited technical capabilities of these reasoning robots. This is a common defence of classical AI techniques in robotics, and Goodrich and Schultz use examples of autonomous robotics in aviation, aeronautics and missile control to demonstrate successful combinations of control theory and classical AI techniques. These, I

would argue, are quite specialised domains comparably simple to terrestrial or social environments. Another Cartesian methodology in wide use is John Anderson's ACT-R system[399] for modelling cognition. It has become a popular tool for symbolically modelling cognition in both human beings and robots[400], through a reductive and tightly rational lens. Other popular symbolic frameworks include Wooldridge's belief-desire-intention model, described in his book *Reasoning About Rational Agents*[401]. These frameworks build upon theories of mind, rooted in Fodor's 'representational theory of mind', where he argues that mental activity involves Turing-style computation of language.
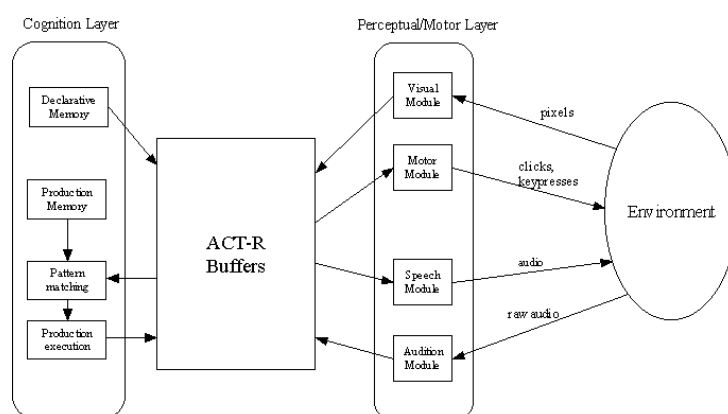
Figure 49. The updated formulation of Anderson's ACT-R model."[402]

This view of cognition complimented classical AI approaches, and was developed alongside one another. "The philosopher Daniel Dennett coined the phrase intentional system to refer to an entity that is best understood in terms of folk- psychology notions, such as beliefs, desires, and the like"[403]. Dennett's 'intentional stance' has become the de facto model of HRI, to explain how we rationally interpret agency in robotics.

Countering Cartesian explanations of experience, Matthew Ratcliffe suggests we interpret agency from the expressive gestures of others, through our own bodily responsiveness to these perceptions. Citing evidence of mirror neurons interconnecting our perceptual and proprioceptive cognition, his hypothesis explains our instant and unconscious awareness of agency, without resorting the theorising about minds. His theory extends to construct a plausible account of how we are able to coordinate in collaborative activities like dance. Ratcliffe argues that "computing each other's mental states on the basis of bodily movements in order to predict the next movements is clearly absurd" [404].

By exploring HRI literature, I have found explanations of human experience of robots, mirroring how robots are classically programmed to sense-think-act. The rationalising of all actors, human and machine, best expressed in the wide adoption of Theory of Mind (ToM) in robotics, is evidently as a useful short-cut in robotic research, but simply does not give us a

satisfactorily complete theory of these experiences, just as strictly rational approaches to aesthetic appreciation of art fail to recognise the embodied and layered complexity of cognitive processes.

In the 1990s and into the new millennium, examples of what roboticist Robin Murphy calls "hybrid deliberative/reactive" models [405] [406] [407] [408] tried to overcome limitations of classical approaches, by bringing together 'sense-think-act' type models on top of reactive behaviour-based substrates. The term hybrid is questionable with bottom-up and top-down systems operating virtually independently of one another [409]. The behaviour-based components are often for fast-reflex aspects of motion control, such as negotiating environments safely, while decision-making often remains tied to classical approaches. These approaches have had limited success in achieving the goals of HRI to bring robots out into complex physical and social environments. The very recent developments in deep neural networks, with end to end processing using a connectionist architecture incorporating sensing, problem solving and actuation may finally begin to shift approaches to programming robotics. This may also help to progress the ways in which not only robot cognition is conceived in HRI, but also how human experience is discussed.

Social Robotics

Social robotic research is a field of HRI's working towards 'peer-to-peer'[410] modes of interaction, rather than master-slave models of control. Researchers in the field develop machines that participate in social forms of behaviour, from primitive gestural exchanges through to imitating human-like capabilities. Robotics researcher Kerstin Dautenhahn offers a useful scale to place so called social robots along a cognitive spectrum from 'socially evocative' at the bottom – stimulating primitive perceptions of animacy – up to higher-level machines, where "we find socially interactive robots that possesses a variety of skills to interact and communicate"[411]. Machines at the higher end of Dautenhahn's scale are usually focused on human-centric user applications and satisfying user expectations in line with HCI methodologies.

By contrast, a niche field of 'Sociable Robotics'[412] explores robot-centric artificial life aims of emergent machine intelligence behaving like developmental infants, interacting in the interest of their own goals and cognitive progress. A prominent example of this bottom-up approach materialised out of Rodney Brooks' research group. As its chief designer Cynthia Breazeal explains, "if you really wanted to understand human intelligence, it was important to have a human-like body, to

have human-like interactions with the world...[and] that in order to learn from experience, you have to have something to get experience through, and that of course is this body situated in this environment" [413].

In 2013 Knox, Breazeal, and Stone[414] published a framework for learning through human feedback, claiming their embodied approach demonstrates promising training possibilities for developing multiple behaviours in robots from "free-form human-generated feedback", without algorithmic modifications. As the team at MIT are finding, this strategy of building human-level intelligence from the ground up, including verbal interaction skills, is extremely challenging and the project to develop human-like robotic intelligence remains some distance off the ambitions of its designers. Cynthia Breazeal is not modest about the aims of the field.

"For me, a sociable robot is able to communicate and interact with us, understand and even relate to us, in a personal way. It should be able to understand us and itself in social terms. We, in turn, should be able to understand it in the same social terms—to be able to relate to it and to empathize with it. Such a robot must be able to adapt and learn throughout its lifetime, incorporating shared experiences with other individuals into its understanding of self, of others, and of the relationships they share. In short, a sociable robot is socially intelligent in a human-like way, and interacting with it is like interacting with another person. At the pinnacle of achievement, they could befriend us, as we could them." [415]
(Breazeal, 2002)

Breazeal's group at MIT continues to develop towards these, announcing their first commercially available social robot *Jibo* in 2014, and shipping first orders in late 2017. Competitors have also recently come to market including a penguin-like robot called *Kuri*, astronaut-like robot called Kirobo, and ElliQ from Intuition Robotics. WIRED Magazine described 2017 as "the year of the robot assistant"[416]. Although Jibo raised nearly $73 million, and despite making it onto the Time Magazine list of the "25 best inventions of 2017", plagued by a series of delays and overpromises, the company closed in 2018. Its competitor Mayfield Robotics has also announced it is cancelling *Kuri* [417].

Figure 50. Jibo (left) and Kuri (right). Two recent high profile social robotics projects that failed to prove commercial successes regardless of experienced robotics groups behind them.

Ultimately, the problem was the rise of much cheaper and more feature-rich, though far less animate, home assistants like the *Amazon Echo* running on their Alexa AI, and *Google Home* running their Google's own AI, Google Assistant. As Evan Ackerman, senior writer for IEEE Spectrum's robotics blog explains, "Kuri, Jibo, and other social home robots have had to contend with embodied digital assistants that affordably duplicate a big chunk of their functionality. They've had trouble establishing compelling use cases and long-term value relative to their cost" [418]. With relatively simple voice command interactions, and libraries of canned responses, or spoken search results from the internet, social robots are yet to develop much more than rudimentary social behaviours, and are yet to find their unique selling point that justifies their price to a mass market.

Often the ambitions of researchers to explore complex interactions between robots and human beings are greater than the available technology or technical capabilities of their methods. A commonly used trick to overcome this problem is the Wizard-of-Oz (WoZ) technique [419] [420] [421] - a modern day *Turk*. This sees human subjects encounter robots that may appear autonomous but are tele-operated by a hidden human. Such techniques are considered methodologically sound, but as the illusion can only be maintained in the lab, there are limits to the value of research in intelligent behaviour if they cannot be replicated out in the world.

The ultimate challenge of social robots is whether they can maintain interesting enough behaviour to interact with over months or years? Most sustained interaction with current generations of social robots reveal limitations within minutes or hours of encountering them. Roboticists, just like game designers, have turned to computational short cuts to give the impression of greater intelligence in their creations. A common technique is to introduce a

random function into behaviour. The right balance of predictable with unpredictable behaviour can give the impression of intelligence, but this 'cheap trick' finds its limits quickly and, as roboticist Christoph Bartneck explains, "Given sufficient time the user will give up his/her hypothesized patterns of the robot's intelligent behavior and become bored with its limited random vocabulary of behaviors" [422].

Though such approaches are useful in designing virtual gaming agents, or primitive reactive toys, they will not bring HRI closer to finding solutions to longer- term interactions. Bartneck argues "Let's not waste any more effort on implementing methods from AI from which we know that they will not lead to intelligent robot behavior" [423]. He suggests that successful long-term perception of intelligence is fundamentally dependent on a robots competency and he proposes that robotics may hold an advantage over virtual agents, by virtue of their embodiment. Margaret Boden agrees, making the case that when the issue of embodiment is taken to be centrally important, "only robots of a very special kind (dynamically coupled with environment) would be philosophically plausible as bearers of psychological predicates" [424].

Instead, the current state of the art in commercially available social robotics overcome their cognitive limitations, with illusions of intelligence created foundationally by with socially evocative motion, and then higher-order verbal, and other auditory, behavioural cues, as well as formally evocative cue of living entities, such as eyes. Social robotics typically feature some abstraction of facial features. For example, where social robots communicate verbally, a visual display of the expression of mouthing words can assist in recognition [425]. The use of abstracted faces, closer to cartoon characters than human beings, can reduce our expectations of intelligence, and limit disappointment if its behaviours are unexpected.

In the context of animate motion, an emerging field of social signal processing [426] has developed over the past two decades to explore cues, particularly visual cues that reveal information hidden in social behaviour. A primary aim of the work in the field that encompasses fields of social sciences with computer science, is to provide "computers with similar abilities in human–computer interaction scenarios" [427]. This work focuses naturally on human social gestures, including blinks, smiles, crossed arms and laughter, rather than on the behaviour of abstract or non-anthropomorphic motion, leaving open an interesting area of performative inquiry around what can effectively make robots appear social, without simply imitating faces, or vocal expressions. Take, for example, mobile robots that share spaces with human beings that do tasks like cleaning and security monitoring. If the robot takes paths around people, rather than waiting for them to get out of the way, this implies a social

intelligence. A further parameter of consideration might be a person's orientation. If a person's back is turned to the robot, it should move slower and take a wider path around them. With the plethora of possible circumstances, soon such hierarchical logics may become unwieldy under classical approaches.

One of the most critical social cues to animate behaviour is gaze. Robots that appear to look around and lock attention on human beings, or events occurring in their environment, immediately appear to be alive. This is well understood in puppetry and animation, and is discussed in the next chapter. An added layer of social intelligence can happen if the robot switches gaze between multiple targets. For example, a robot may look at a person looking at an object and turn to face the object, before looking back at the person. The impression of turn taking, can also enhance an impression of social intelligence. Moments of stillness, followed by motion, enhance the sense of purposefulness, whether there is any meaningful purpose to those motions or not. These types of primitive socially evocative motion cues may have their limitations over long-term interactions, but for short periods of gestural exchange they can be quite compelling and exist as a base layer upon which more specialised forms of social communication can occur.

Relational Artefacts

> *"Its ability to inspire relationship is not based on its intelligence or consciousness, but on the capacity to push certain "Darwinian" buttons in people (making eye contact, for example) that cause people to respond as though they were in relationship. For me, relational artifacts are the new uncanny in our computer culture, as Freud (1960) put it, "the long familiar taking a form that is strangely unfamiliar."* [428] *(Turkle, 2006)*

Psychologist Sherry Turkle has defined technologies with social behaviour as "Relational Artifacts". She defines them as "artifacts that present themselves as having 'states of mind' for which an understanding of those states enriches human encounters with them"[429]. The term itself reflects the psychoanalytic tradition of Turkle's practice, which sees her examine the psychological effects of developing relations with machines, through understanding their inner "mental" states [430][431]. Her curiosity in these human-machine relationships came from encountering *ELIZA* a primitive 'chat bot' programme built between 1964 and 1966, that demonstrated how with clever use of linguistic 'pattern matching' and substitution techniques,

a superficial illusion of textual conversation between humans and machines could be created.

As Turkle explains, Joseph Weizenbaum, computer scientist and author of *ELIZA*, found "students, fully knowing that they were talking with a computer program, wanted to chat with it, indeed, wanted to be alone with it" [432]. He was disturbed by the willingness of the students to open up to the machine. Turkle, who co-taught classes at MIT with Weizenbaum, was less concerned, explaining the software acted like a Rorschach, mirroring textual inputs back at the users, allowing them to express themselves openly to a neutral agent. "They became involved with ELIZA, but the spirit was 'as if'. The gap between program and person was vast. People bridged it with attribution and desire. They thought: "I will talk to this program 'as if' it were a person; I will vent, I will rage, I will get things off my chest" [433]. Turkle later admitted that she underestimated the strength of the connection when she first encountered this behaviour and she has increasingly become a critic of the isolating impact of such technologies in her recent book *Reclaiming Conversation: The Power of Talk in a Digital Age*[434]. An early example of relational artifacts was the simple but phenomenally successful *Tamagotchi* toy. A handheld, LCD video game on a keychain that gave owners the responsibility of looking after virtual pets. The range of interaction on the 4bit microcontroller-driven, egg-shaped device was limited to a three-button input interface and a small range of responding, low-resolution animations. The small library of animations was predetermined by the sequence of events preceding it, namely the amount and type of care they gave their pets.

This was, systemically speaking, little different to a combination lock. Input the right information at the right time and unlock the predetermined behaviour. A simple state machine algorithm. Nonetheless, the limited gameplay had sufficient variety to hold the attention of its typically young audience, over short periods of gameplay, where they would care for their *Tamagotchi* by feeding, bathing and playing simple games with, the virtual animal. The phenomenal success of *Tamagotchi* has been attributed not to the appearance or movement of the agents, but rather to the emotional dynamic that it creates, as users see their creatures grow up as a result of their actions.

"I'll eventually feel we have succeeded if we ever get to the point where people feel bad about switching Cog X off." [435] *(Brooks 2006).*

The care-giving urge toward these machines is believed to occur because they trigger nurturing instincts within people. The Kindchenschema concept by ethologist Lorenz (1971), hypothesises that a deep-rooted baby schema, are triggered where the proportions and features, particularly facial, infer a juvenile animal. The 'cute' effect can be seen across humans, dogs and many other animals with common traits, such as smaller noses and larger eyes than adults.

In social robotics, this has been widely harnessed to make machines less intimidating, and encourage playful and careful interaction. How far are we willing to give ourselves to these robots emotionally, or are our emotional responses closer to imaginary play, than true emotional investment? Do we feel the same pleasure from seeing a robot smiling as we do another human being? Of course there are the ethical issues of aiming to create robots that draw people into bonds with machines that are programmed to care. These questions are being asked in robotics [436] [437], and will be shaped also by cultural aspects as well as by universal instinctual reflexes and individual preferences.

These matters are not solely related to children playing with virtual creatures. Surprising stories have emerged of adult companionship of battlefield robots with solders arriving at Baghdad's 'Droid Hospital', teary-eyed "carrying the blasted remains of their droid, and wanting to know if their little guy can be rebuilt"[438]. As relationships with social robotics become more convincing these emotional ties will only grow stronger, playing upon unconscious irresistible traits, which we might even call vulnerabilities.

Weizenbaum argues in his 1976 book *Computer Power and Human Reason* [439], that we must make a distinction between decisions and choices. He categorises deciding as a computational activity that can be reduced down to mathematical descriptions. Choices, however, require judgements of non-mathematical factors, such as emotions and context, rather than calculations, and it is this ability to choose that makes humans so very different to machines, and capable of sophisticated social intelligence. Designers of social robotics are limited under current paradigms to harnessing a variety of rather blunt tools for emotional sensing, and illusory techniques for imbuing emotional life into robotics.

3.7 Conclusions

Movement has primacy in visual perception, and animacy detection is a priority in our processing of visual information. This is because movement is a property of living things, and the perception of animate movement is the foundation of social interaction. Our visual perceptual systems are highly attuned to cues for social cognition that can uncover not only

the conscious but unconscious state of other animate agents in our environment. Specialised heuristic traits of the human cognitive model have a deep evolutionary history, that automatically, or we might say irresistibly, trigger perceptions before conscious reasoning occurs further down-stream. These fast heuristic traits operate in visual-cortical hierarchy with parallel asynchronous computation.

Study of these cognitive traits, in psychophysical and perceptual studies of the visual cortex, attempt to isolate motion stimuli for close examination. Experimentation characteristically involves the use of primitive geometry in motion, sometimes appearing to behave contingently on other geometry. Neuroaesthetic theory has pointed to the striking parallels that we find with abstraction in kinetic art, suggesting that there is an innate awareness in artists that the highly filtered stimulation of particular heuristic traits in human visual perception are aesthetically potent. I have also pointed to the practices of abstract experimental animation that seem to explore this aesthetic field, unknowing of the underlying mechanisms that shape our perceptions. These practices throughout the 20th century have operated independently of each other, and are only now finding connections through interdisciplinary research of the past decade.

Behavioural, non-cognitive interpretations of aesthetic experience provide a compelling alternative reading of artworks to conventional art criticism. Neuroaesthetic theories are in themselves a form of reductive rationalisations of complex heterogeneous phenomena, but as animate motion perception is one of the most primordial of visual percepts, neuroaesthetic theories are useful in drawing more attention to reflexive, and non-conscious, foundations that likely shape work like Calder's mobiles or Ihnatowicz's *Senster*.

This chapter has examined how motion is coupled to social perception. The ability to recognise agency through motion alone would be an evolutionary advantage, so much so that causal and animacy perception appear innate. The degree to this remains open to heated debate, but there is broader support for the idea that innate perceptual reflexes may provide a skeleton for structure learning to occur.

Innate percepts may create traits that determine particular concepts developing. Even with a lifetime of experience, understanding the differences between living and non-living entities, innate reflexes continue to interpret visual motion information and shape experience. As a result, robots, kinetic art, geometric animations, can all appear irresistibly animate without even the visual appearance of living entities.

There is a growing tool kit of statistical information on motion profiles that trigger perception of animacy and then a range of primary behavioural typologies, such as chasing, or evading. A few parameters are central to heuristic processing. Entities that accelerate and change direction the greatest amount, have the highest animacy ratings. When an entity appears aligned to its direction of motion, particularly if it changes direction, it produces higher animacy ratings than misaligned movement. Gravity also effects our perception of motion, which is likely a result of the gravitational environment in which this perceptual trait has evolved. Entities that move upward against gravitational force are considered more animate than those moving downward.

Animacy perception, in itself, is not the end state of perceptual visual processing, but rather only the beginning of downstream heuristic detection of a variety of behaviour typologies that remain under researched. Certain behaviours appear particularly animate, such as predatory motion to another agents, or the avoidance of obstacles in an environment. However, a richer set of phenomena that powerfully shape our experience and interaction exist, some of which, like only until recently discovered *Wolfpack Effect*, are still likely undocumented. Artists, in their own experimental practices, are discovering and manipulating a variety of currently undocumented perceptual cues, which could be of benefit to scientific research into the perception of animacy.

Spatial context can increase or suppress the impression of animacy, depended on how it perceived in relation to an entity's motion trajectory. However, the effect of context is still small when compared to acceleration, consistently is a dominant stimulus in perception. Absence of context, therefore, does not prevent perceptions of animacy occurring. In reviewing the literature of the field of social perception, I have concluded that the parametric analysis of animacy perception is a potentially useful resource for designing the behaviour of animate agents, whether virtual agents in games or robotics in physical environments.

Animacy perception appears to be a primary percept for stimulating human social behaviour, but could similar perceptual capabilities be built into robotic agents? Emerging bottom-up strategies for robotic agent behaviour might build upon motion variables, rather than classical approaches that typically employ image analysis, such as facial recognition, which has inherent problems with human orientation, and longer distance detection. As we have seen in a highlighted study, a broad variety of behaviour typologies can be defined parametrically, by gross movement of bodies, with a small range of parameters. These can be trained to an artificial neural network with a high degree of detection accuracy. This behavioural approach to recognition also supports a bottom-up attitude to the whole question

of how animacy and behaviour are cognitively processed. A variety of approaches have developed for making believably animate agents particularly in gaming. There is a strong appreciation in gaming of the balance between designing agents and their environments, which are both built upon the shared substrate of digital computation. This is quite unlike designing physical agents and their physical environment, which are materially heterogeneous. When these algorithms are found to be ineffective, due to obstacles in these digital environments, game designers may often choose to modify the environment rather than solve the potentially more time consuming and complex challenge of modifying the algorithm. This is a luxury not so easily afforded to designers of mobile robotics for physical and complex environments.

Early gaming pioneered the design of agents using simple rule-based logic to operate on limited computational power. These reactive agents were deterministic, so a degree of unpredictability needed to be resourcefully engineered to keep gamers guessing, and prevent a game becoming boring. A degree of indeterminate behaviour made agents appear more animate, giving gamers the impression the agents were impulsive and autonomous, rather than predictable and automated. Fortunately for the programmers, human players feed indeterminate behaviour into the environment with their behaviour. The complexity of the human gamers' behaviour can be mirrored in the agents, without it being too easily recognisable as we saw with *Pac-Man.*

State-machines can store sets of rules that are transitioned between offering a multi-dimensional set of behaviours. *Pac-Man's* 'ghost' agents have individual behavioural rule sets that further give the impression of autonomy. At the time, another 'cheap trick' for indeterminate behaviour was to use a random noise function, in conjunction with a simple determinate rule sets. Fuzzy logic was also popular for employing probabilistic methods that lend degrees of uncertainty to agent behaviour. These strategies are still used to today and, while a full account of these would be sizable, I have chosen to highlight a few strategies that characterise steps in gaming, that move us towards evermore animate intelligent agents.

Whereas gameplay in early arcades was based upon primitive typologies of behaviour, such as chasing or obstacle avoidance, the development of more powerful computing and artificial life techniques, for more advanced adaptive agents, opened up far more sophisticated worlds. In my own childhood, and occasionally adulthood, I have been particularly attracted to world-building games like *Civilization* and *Sim City*, that followed relatively primitive approaches compared to the first wholehearted attempt at an ALife Game - Steve Grand's *Creatures*. The game represented a shift from 'Shallow' approaches to AI, to conceptualising

agents as adaptive, and capable of novel behaviour.

The simulated evolution and cognitive development of agents opens up the potential for long-term experiences of animate agency with virtual agents, and even emotional attachment, where human behavioural tendency toward nurturing infantile creatures is manipulated. The gaming industry has developed into a fertile experimental space for training agents that may have application beyond entertainment, both in the development of general forms of artificial intelligence in virtual agents, and perhaps later into domains of social robotics. I believe the use of virtual car agents to develop behaviours of autonomous vehicles, is a step in that direction.

The behavioural possibilities of self-generated motion strategies in robotics are fascinating on functional level, for their ability to compensate for changing circumstances, whether that is mechanical damage or a change in environment. In my opinion, they are also fascinating on aesthetic grounds, for the qualities of behaviour that we find emerging out of their embodied interaction with the world. There is also something viscerally engaging about seeing a robot solving a visual- motor skill, with uncanny similarity to an infant. A deeper sense of an entity with its own life, making sense of the physical world, move by move.

When identical machines can learn in parallel to one another, the possibilities for rapid skill development, through collective trial and error, are tantalising. This does not make the project to bring robotics into the built environment immediately easier. For robots to act with intelligence, they need to make decisions about temporal relationships of cause and effect quickly, and predicting the results of their behaviour remains extremely complex - even more so when robots must act safely in the company of human beings. Nonetheless, the growing number of institutions and companies including Google, now taking bottom-up approaches like those discussed at UC Berkeley, demonstrate a neo-cybernetic shift towards cognition through embodied interaction, built upon connectionist computation. The aesthetics of this shift are far more animate than those that have characterised robots in the 20th century.

This shift in technical implementation may also begin to reinforce neo-cybernetic attitudes towards cognition, and help to overcome the current Cartesian dogma that continues to shape much discourse. This is not an easy conceptual turn- around to make. Richard Dawkins a proponent of evolutionary and emergent thinking, demonstrates that it is all too easy to fall back on computationalist higher- order thinking to explain behaviour, before accounting for lower-order reflexes. The great virtue of embodied machines in action is they can make explicit the relationship between the body and its intelligence.

4. Aesthetics

4.1 Introduction

As I have established, visual perception not only constructs the physical structure of the world, but also its social and causal nature. This is an under-appreciated and under-explored topic, particularly contrasted with the enthusiasm the visual arts have shown to the aesthetic potential of visual ambiguity in static paintings, sculptures and installations. The aim of this chapter is to draw a line between psychophysical understandings of animacy perception and their manipulation in arts, using insights from puppetry and robotic arts to focus on embodied experiences, whether in the context of the theatre, a gallery or the built environment.

I will develop the idea that experience begins automatically in the eye, irresistibly shaped by heuristic responses, and then draws the viewer into the participation of ambiguous visual information that triggers aesthetic experiences. Overlaps are found between discourses in arts and sciences on the notion of bistable experiences of animate motion. I examine how the essentialist pursuits of modern puppetry, and the related avant-garde conceptualisation of machine theatres, tended towards the animation of minimal abstract forms. This also resonates with the techniques employed by perceptual scientists in the later decades of the 20th century creating a surprising methodological link between these very different modes of investigating animate behaviour. The chapter concludes by examining the role the arts have played in probing the aesthetic field of robotics.
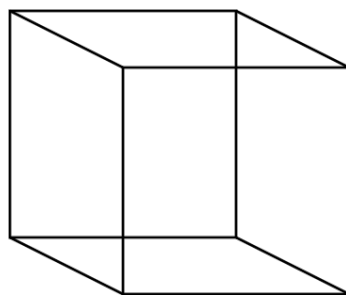
4.2 Ambiguity

Bistable Ambiguity

Figure 51. The wonder of illusions in the sciences, Necker cube published in 1832 by Swiss crystallographer Louis Albert Necker.[440]

Viewing the *Necker Cube* (Fig.48), we instantly perceive a 3D object. Extraordinarily, if one attempts to consciously flatten it into lines on a page, it resists. An irresistible sense of structure rises up. Even more fascinating - the perception is not entirely stable. If you continuously view the cube, its faces shift between two perceptual interpretations, occurring every couple of seconds. Interestingly, the *Necker Cube* can only be interpreted in one of the two states, at any one time [441].

"True ambiguity results when no single solution is more likely than other solutions, leaving the brain with the only option left, of treating them all as equally likely and giving each a place on the conscious stage, one at a time, so that we are only conscious of one of the interpretations at any given time. Thus a neurobiologically based definition of ambiguity is the opposite of the dictionary definition; it is not uncertainty, but certainty— the certainty of many, equally plausible interpretations, each one of which is sovereign when it occupies the conscious stage." [442] (Zeki, 2004)

The immediacy, and irresistible perceptual quality of the work, does not mean, however, that they are entirely automatic. There is evidence that the frequency of perceptual flips can be consciously affected [443]. Attention appears also to influence perceptual 'flipping', according to the focal-feature hypothesis [444] that shows that different focal points bias towards one percept or the other. Saccades and blinking are also integral. Leopold and Logothetis identify a tight coupling between saccades and perceptual switches, with both selective attention and bistable perception sharing underlying motor processes [445].

A bottom-up, connectionist account for these phenomena proposes that percept fatigue may be responsible. Neurons supporting a particular stable perception may, due to a sustained period of stimulation, exhibit short-term synaptic depression that causes a switch to the alternate more rested percept creating a continuous fluctuation between the two [446]. Such mechanisms are believed to be a fundamental form of negative feedback control throughout the brain. Contrary to this, the strongly top-down view is that ambiguous figures are not spontaneously flipped by subjects, but are preconditioned by suggestion to see the phenomena. This does not account for Necker himself first encountering the illusion of course but there is evidence to support part of these claims. The popular view is that bi-stability occurs in the interaction between bottom-up and top-down processes.

Animacy Ambiguity

Broaching ambiguity, as a form of cognitive illusion, Richard Gregory discusses these illusions as occurring between perceptual processing heuristics (what Gregory called perceptual knowledge) and higher reasoning from learnt (conceptual) knowledge.

> *"Perceptual knowledge is the assumptions that our brain takes, and can coexist with conceptual knowledge even when in contradiction, as in the case of several illusions."* [447] *(Ghedini, 2011)*

Building upon Zeki's theory that levels of ambiguity may exist in the brain, Fiammetta Ghedini [448] proposes four levels of ambiguity, between strongly perceptual bistable forms of ambiguity – the Necker Cube representing the most primitive level – and more complex varieties of ambiguity, occurring when intentional behaviour is perceived.
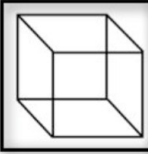
	1st level	2nd level	3rd level	4th level
	intracategorical figures	intercategorical figures	illusion of life	anthropomorphism
Possible interpretation:	X= cube, state 1 Y= cube, state 2	X= vase Y= faces	X= geometrical images Y= intentions	X= artificial creatures Y= animacy
Perceptual knowledge:	X or Y	X > Y, Y> X	X and Y	
Conceptual knowledge:	X = Y		X = false	
Subjects:	healthy subjects ≠ Schizophrenic + frontal-damaged patients		healthy subjects ≠ schizophrenics + amygdala-damaged	variability biased by: need of mastering the environment; social isolation

Figure 52. Fiammetta Ghedini's 4 levels of Ambiguity[449]

Animacy perception, Fiammetta Ghedini suggests, triggers a third level of ambiguity, where animate and inanimate perceptions coexist. The illusion creates a quale of life, regardless of the conceptual knowledge that geometric figures, or even anthropomorphic puppets and robots, are not alive. This illusion is powerful and has, in a number of studies, proven impossible to resist [450] [451].

Ambiguity in Visual Arts

As outlined, visual perception not only constructs the physical structure of the world, but its social and causal nature too. This is as under-appreciated and under- explored, particularly contrasted, with the enthusiasm the visual arts have shown to the aesthetic potential of visual ambiguity in such work as M. C. Escher's impossible objects and Bridget Riley's illusory patterns, or the chromatic interactions of Josef Albers' paintings and geometric engravings. The aesthetic impact on visual culture, of these artistic obsessions with perceptual illusions, is self-evident and, in some cases, has reciprocally stimulated scientific discourse. While Escher was famously fascinated by mathematical objects, such as the *Möbius Strip*, Roger Penrose published research on Impossible Objects [452].
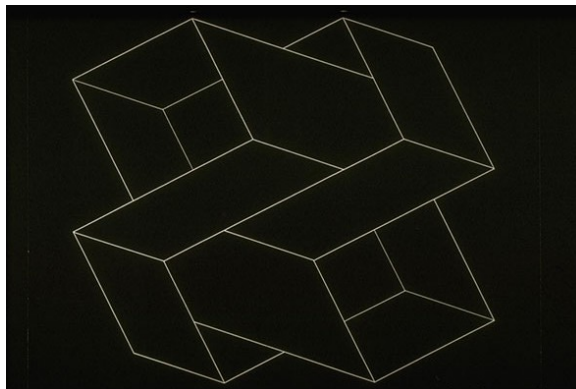
Figure 53. Josef Albers' Structural Constellation, Engraving [453]

"The function of art is an extension of the function of the brain, namely the acquisition of knowledge about the world, then it stands to reason to suppose that the mechanisms used to instil meaning into this world are the very ones used to instil meanings into works of art. It is those basic mechanisms that artists have used so successfully." [454](Zeki, 2004)

The potential of these intentionally ambiguous artworks to draw the participation of audiences, revealing the viewer's active role in the construction of experience and the unstable nature of visual phenomena, has been a characteristic theme of visual arts of the latter half of the 20th century. In optical art and minimal art forms, paintings, kinetic sculptures and installations, cryptically titled with letters and numerals, resisted linguistic narrative. The art experience was to be participated in, independent of, and unadulterated by, an intellectual encapsulation.

Meanwhile, the ancient art of puppetry, was having an aesthetic revolution of its own, as it begun to strip back its traditions of dolls, stages and costumes, to minimal objects, manipulating the ambiguous thresholds between perceptual and conceptual knowledge, unaware of parallel scientific inquiries that shared some uncannily similar aesthetic qualities.

Ambiguity in Puppetry

Puppeteer and aesthetician Steve Tillis characterises the effect of the puppet on its audiences as a paradoxical form of "double-vision"[455]. This contradiction of sensations chimes with Gregory and Ghedini's discussions on visual ambiguity. Independent of scientific studies, the field of puppetry has made its own attempts to explain the aesthetic experience of animate form. Its ambiguous nature appears to resist a common terminology, with leading author and theatre producer Jurkowski describing the "opalization effect"[456], while puppeteers T.A. Green and W.J. Pepicello discusses "oscillation"[457], both referring to the viewer's unstable sensation of animacy and inanimacy.

Within the constructed space of the performance, what Malkin[458] called the 'plausible impossible', the 'illusion of life' appears and disappears with dramatic and aesthetic affect. In one moment, the puppet is alive and then the next, the contrivance of the spectacle becomes salient, before again being drawn into the imaginary. Children are particularly able to create a stable imaginative world within the plausible impossible, but it is not strictly age dependent. The puppet embodies a collective memory of childhood and innocence. The essential bargain between performer and audience, is a willing embrace of a naïve vision.

The puppet exists as an invitation to participate in the creation of life, and as I will go on to explore, the most provocative of contemporary puppetry seeks to more than merely imitate life, but rather find freer, livelier, and surprising sensations of life. Though it may by now seem obvious in the context of my discussions on motion perception, it is worth recognising that, at the heart of puppetry, is the understanding that motion above all other stimuli is responsible for the illusion of life in objects. Motion is the beginning and end of every puppet's life.

> *"The puppets' motions convey a meaning of internal impulse corresponding to the impulse that produces the live beings' movements… and, by contiguity, this implied meaning reflects in the spectator's mind on the puppets themselves, thus tending to attribute to them life of their own."* [459] *(Veltrusky, 1983)*

With today's cultural production and consumption mediated by digital technologies, it is perhaps surprising to find that puppetry is seeing a revival, with international sell out shows, such as the National Theatre's acclaimed production of *War Horse* (Fig.49). In the streets, the historic home of the art, spectacular architectural scale puppetry by *La Machine* has brought city centres to a standstill, in astonished wonder. Some have asked why the art has survived and thrived even in the face of cinema, cell and stop animation and, most recently, in the remarkable advances in computer generated graphics.

Figure 54. War Horse (opened 2009) Life-size horse puppets by the Handspring Puppet Company.

Puppetry has a qualitatively unique aesthetic to other art forms - one that continues to beguile audiences with the special presence the puppet possesses. Oscillating between the world of the living and the dead, the puppet creates something quite uniquely captivating, sometimes comical, sometimes grotesque. An ancient art, with a rich, albeit poorly recorded history, puppetry holds a deep understanding of how the motion of an object can create irresistible and aesthetic perceptions of animacy. With some surprise, my review of scientific studies of visual motion perception found no mention of puppetry. Indeed, outside the literature of this somewhat mysterious art form, relatively few references are made to it, even when fields of research, such as robotics would seem likely to benefit from its insights.

"Westerners have an almost morbid fear of taking the power of their imagination as seriously as the power of their perception. They find the juxtaposition of perception and imagination, with the ensuing ontological paradox that threatens their understanding of "object" and "life", to be unnerving, and they therefore avoid the problem entirely by condescending to the practice of puppetry that raises it." [460] *(Jurkowski, 1988)*

Featuring in cultural traditions across the globe, puppetry has a unique ability to create, what puppeteer Nancy Staub called, a "theatre of possession"[461], a visceral performative role that has made it a function of animist rituals and storytelling practices for millennia. Victoria Nelson's *The Secret Life of Puppets*[462] suggests its place, once in the supernatural, has moved into the domain of psychology.

Puppets and automaton, now including robots and cyborgs, continue to delve into a human fascination with animating matter, or as Harold B. Segel described it in *Pinocchio's Progeny,* a "yearning to play god"[463], to build and breathe life into their own simulacra.

4.3 Puppetry

Making Distinctions

Puppetry, derives from the Latin 'pupa' for doll*,* the '–et' diminutive reflecting the historical role of the puppet playing miniaturised human or animal figures. As puppetry in the 20th century grew to find its own aesthetic, independent of actor theatre, practicing puppeteers and theoreticians made great efforts to relinquish themselves from this narrow and, some would feel, pejorative view. Puppetry scholar Penny Francis offers a contemporary definition that stresses the discipline's break from the constraints and traditions of anthropomorphic and zoomorphic figures.

> *'… the puppet is a representation and distillation of a character, the repository of a persona perceived by both creator and spectator within its outward form. It can be any thing, any object, if brought to imagined life through the agency of a human player who inspires it and controls it directly."* [464] *(Francis, 2012)*

Francis instead focuses on the notion of a shared participation of audience and puppeteer in the illusion. As a matter of technical definition, she insists on the directness of manipulation by the human controller, which immediately distinguishes it from automata, such as the aforementioned *Writer* by Pierre Jacquet-Droz and his son Henri-Louis. Francis' distinction between puppet and automaton, on the grounds of direct human manipulation, is one technical differentiation, but we can also make the distinction from the perspective of the observer. A puppet in the hands of a puppeteer is an extension of that manipulator's animacy -its potential for motion limited only to the dexterity and imagination of its puppeteer. This

dexterity reveals itself to the audience in the puppet's responsiveness to its environment, from its interaction with other animated puppets and, in some cases, its perceived awareness of an audience. Historical accounts of the relationship between puppets and automata in theatre [465] [466] [467] reveals that they often shared the stage. Machines played secondary roles as background characters, or moving scenery, while puppets were foregrounded and manipulated live. Jurkowski, in his account of the decline of automata, in favour of puppetry explains, "puppets, due to their complicity with the human performer, have always been more flexible and versatile than the best automata"[468].

Robotics, the descendants of automata, may be about to reverse this trend. Theatre director Blanca Li's use of Aldebaran Robotics' *Nao* android is one example of where pre-programmed robots present a compellingly animate performance, though the success relies heavily upon the human performers in direct contact with the advanced automaton performer.

Figure 55. Bianca Li's 2018 performance at the Barbican Theatre, in collaboration with Maywa Denki and Aldebaran Robotics

As I discuss earlier, robots can be built and programmed to run in both unresponsive (automatic) and responsive (reactive and interactive) modes of behaviour. Though early cybernetic machines, with primitive sensory-motor reflexes, have proven successful at creating compelling and sustained impressions of animate life, through their continuous interaction with their environment, typically robotics used in a performance context, are pre-choreographed, automatic systems.

Elizabeth Jochum's recent doctoral thesis examining the use of robotics in theatrical performances looks the way the mixing of automatic and responsive behaviours could

enhance the illusion of life, compared to purely pre- choreographed routines. She also identifies key distinguishing features between the design of puppets and robots, arguing that puppetry offers design strategies that could be very useful in robotics highlighting the mechanical simplicity, yet effectiveness, of the art form in creating compelling and engaging characters.

> *"Puppets and robots both use realism as their starting point, but unlike automata and robotics, puppets do not aim at precise mimicry or imitation. They are therefore capable of creating the illusion of life (or a different kind of life) in ways that pure mechanical replication cannot."* [469] *(Jochum, 2013)*

I too see a variety of benefits puppetry can offer robotics, not only in mechanical insights, but also in helping us reaching a deeper understanding of the psychological affect, and aesthetic potential, of animated machines. Within puppetry's avant-garde, throughout the 20th century to today, mimetic priorities have been replaced with kinetic exploration of abstract and non-figurative forms, with some remarkably similarities to the experimental work of perceptual psychologists. The staged performativity of puppetry, and the very physical presence of the puppet, give it a unique contribution alongside the aforementioned studies in visual-perceptual science. The deep aesthetic understanding within the art form, of its visceral impact that puppets have on audiences, and that robots to this date have failed to replicate or supersede, suggests it continues to offer insights of use to designers.

Illusionism and Primitivism

Harold Segel remarked that "no period or movement in the history of the European stage ever found such creative relevance in the puppet theatre as modernism and the avant-garde"[470]. As actor theatre relinquished itself of its Wagnerian traditions, to radical, dramatic forms of production and performance – laying itself bare to featureless stages and unclothed performers – puppetry's avant-garde stripped itself back in search of its own identity. In accordance with the modernist project, puppetry searched for the qualities both inherent and unique to define its 'puppetness'. Henryk Jurkowski's *Aspects of Puppet and Theatre* [471] describes the avant-garde's total rejection of pretence, with the figurative body replaced by abstracted or found objects. He also details the arrival of the puppeteer onto the stage, sharing his presence alongside the puppet and eradicating the illusion of mechanical separation. In the most extreme cases, the puppet is eradicated altogether, the puppeteer

instead conjuring characters from their own body parts. Jurkowski's described it as a period where all the elements of puppet theatre were atomised, even the term puppet rejected by some practitioners, to distance themselves from the cultural baggage of the traditions and perceived values of the art.
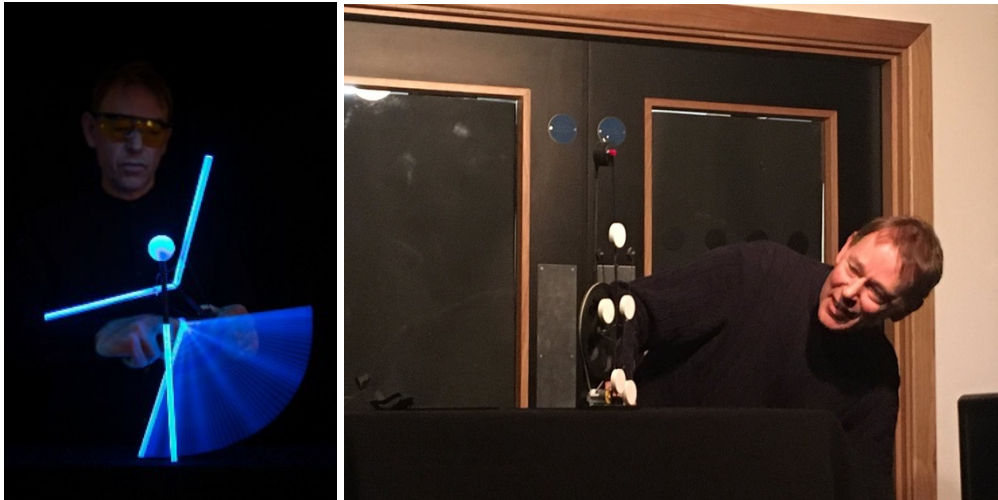
Figure 56. Left Puppeteer Stephen Mottram's "Paracute" performance exploring human visual perception of abstract form. Right: Invited lecture at the Bartlett Interactive Architecture Lab in 2017

Theatre director and puppeteer Roman Paska describes the division of the discipline between two groups, the 'Illusionists' focused 'on representation, treating their puppets as independent characters', and the primitivists.

"Primitivism differs from illusionism in consciously directing audience focus back and forth between the outward sign and the inner process of simulation. And the primitive puppet is flagrantly exhibitionist in exposing its own emptiness as a vehicle for expression in performance." [472]

(Paska, 1990)

Steve Tillis is less inclined than Paska to create two distinct 'illusory' and 'primitive' camps. Instead he distinguishes 'imitative' and 'conceptual' puppets (similar to Paska's terms), placing them again in polar opposition but suggesting that any puppet could be placed upon a continuum between them. Tillis, as a theoretician exploring the full spectrum of puppetry aesthetics, looks for the middle ground.

Paska is unapologetically a supporter of 'primitivism', seeing it as a form of purification - way to access the essential 'puppetness' of the art.

> *"While illusionists hope to produce an unbroken series of moments so that the puppet seems always alive, primitives aim always for a series in which the illusion of being is consciously fragmented by the intrusion of awareness into the structural mechanics of animation, the real nature of the objects employed and the real time of theatrical activity."* [473]
>
> *(Paska, 1990)*

Puppets that attempt to imitate human movements often create a superficial sense of realism. Once this novelty has worn off, the audience become aware of the puppets's inadequacy to replicate human action. Whereas the illusionist's intention is to produce a stabile continuous scene, contrarily, the primitivist's embraces a fragmentation and instability. Jurkowski talks about the essential difference for puppeteers in animating the representational puppets (of the illusionists) and the object puppets (of the primitivist).

> *"The puppet, which is only a pictorial representation of the character, passes through one stage of transformation only. It was dead and now it comes to life, but it remains the same thing. The puppet remains the puppet nothing more. On the other hand, the object passes through two stages of transformation. First it has to take on life, and second it must become a character, or vice versa. This is a double transformation… In contemporary theatre this is considered an advantage since the transformation has to be more sophisticated and more intense."* [474]
>
> *(Jurkowski, 2013)*

Intensity seems to appeal to the primitivists, as performing without the support of anthropomorphic form, costumes and other supplementary signs, demands more of the puppeteer and the audience. Free from the nostalgia of character representation of folk stories, object theatre comes as a shock to uninitiated audiences. The puppeteer's conviction for the life of an object needs to be total, but even in the hands of the most skilled of manipulators, it is difficult to sustain for long periods. Object theatre is most often used for short episodes or vignettes, which are comic or tragic [475].

Figure 57. Paul Zaloom workshop on object theatre at the AHRC Object Theatre Network.

The art of this primitivist puppetry is the confrontation of interaction between the object and visible puppeteer. The animacy of the object inexplicably bound to the animacy of the human performer, a tension exists in the struggle between the artistry of the puppeteer and the resistance of the primitive object. The audience's oscillation of perception of life exaggerated, the object itself becomes a self- reflective device about the nature of the objects and the theatre of the possession.

As Roman Paska describes, "The puppet seems to come alive without pretending to be alive, with an effect closer to magic than technology" [476]. The object puppet stripped of elaborate anthropomorphic mechanics, in its primitive form, reaches back to the ancient puppet of shamanic, and animist rituals.

Presence

"When movement fully dominates an object, we feel that the character is born and present on stage." [477] (Jurkowksi, 1988)

The sense of presence is a difficult notion to define, yet we know what presence is when we see it and, perhaps more viscerally, feel it. It is typically a quality of living things, a vital force, intangible but emanating from physical living bodies. On the stage in actor theatre, presence is exaggerated, its energy exudes a person's body to inhabit a site of performance. In Richard Schechner's book *Environmental Theater* he describes presence as "an actual, living relationship between the spaces of the body and the spaces the body moves through; that human living tissue does not abruptly stop at the skin"[478]. An actor who is said to have presence, is therefore not only physically present on stage, but also commands both the space of performance and their audience's attention.

"If puppets can be said to have "presence," it is a product of their gaze as well as their expressions and gestures; the degree to which they seem to reach out to a sympathetic viewer." [479] *(Zelevansky, 2006)*

The puppet's presence emerges from its perceived awareness of its environment and its responsiveness to it, from its orientation and purposeful motion, to its expressive interactions with what surrounds it. The puppeteer (often visible in contemporary theatre) commonly attempts to minimise their presence, focusing their attention solely on the puppet, showing little awareness of audience or surrounding environment. Through rod, string or other mechanical linkage, they transmit their animacy into the puppet. This alone, however, does not create the puppet's necessary presence. The puppet may be physically present and in movement, but it requires the additional participation of its audience.

"In a performance where the puppeteer is characteristically visible to some extent, we [the audience participant] are presented not only with the index of human agency, but with the reality itself... the result of this juxtaposition of sign and reality is an oscillation between the two that heightens the aesthetic perception of the performance by making the performance a collaborative effort between performer and audience." [480]
(Green and Pepicello, 1983)

Puppeteer Basil Jones describes how an audience immersed "into an empathetic relationship with the object" [481] can sustain the presence of a puppet for a period of time even when it is still, recalling these as some of the most dramatic moments. For puppet artists aligned with primitivist object theatre, their complete rejection of visual formal signs, in favour of energetic and short-lived vignettes, requires the most effort by both performers and audience. The "conspiracy"[482] to play together, in the conjuring of the puppet's presence is, intensified – the oscillation between life and death more frequent and more dramatic. The puppet's aesthetic presence in live theatre is quite distinct from its appearance in film animation, where separate cut sequences of footage dematerialise the puppet into mere simulation. An essential aesthetic appeal of the puppet is its continuous proximity to an audience. Even in an age of screen-based media and virtual life "there is a pleasure still to be found in the live performance of a tangible puppet-the direct confrontation between an

audience and a "living" object-that is distinct from the particular pleasures of media puppets"[483].

Embodied Behaviour

"Whenever the centre of gravity was moved in a straight line, the limbs described curves… The line was something mysterious, for it was no less than the path of the dancer's soul, and he doubted that it could be found except by the puppeteer transposing himself into the centre of gravity of the marionette… The movements of the fingers are related to the movements of the puppet rather as numbers are related to their logarithms, or the asymptote to the hyperbole." [484] (Von Kleist, H., Neumiller, 1972)

Perhaps most influential in the early staking out of an independent aesthetic for puppetry was Heinrich von Kleist, with his essay *On The Marionette Theatre*. A century ahead of its time, von Kleist drew attention to two unique characteristics of the puppet, its lack of self-consciousness as a performer, and its sublime movements formed by the rhythmic grace of its pendular mechanics. He writes, "where grace is concerned, it is impossible for man to come anywhere near a puppet. Only a god can equal inanimate matter in this respect. This is where the two ends of the circular world meet"[485]. The puppet's purity of motion, he argues, elevates its aesthetics above human motion, a perspective contrary to the aesthetics of the time. For the romantic poet, the exquisite craft of the puppeteer was in the natural manner in which the mechanics of the puppet's body reveal its performance. It would not be until the 20th century that his ideas were more fully appreciated.

Contemporary practitioners commonly discuss this notion of the puppet's intrinsic character, as a key force within the creative process of developing new productions. The idea that one puppet doesn't fit all, demands more of the designer-maker-performer, and has led to the emergence of an abundance of puppetry forms and techniques. Spieler provides some insight into the very material and physical processes of invention that so clearly distinguish it from actor theatre.

"Each show begins with some essential core of an idea. We almost never begin with a formal script… I call my co-workers together with sticks, cardboard, cloth, tape and odd assorted instruments to "brainstorm in action"… From the spin of the fabric, the click of the tongue, the odd gait of the box moved across the floor, I catch the poetic glimpses from which I plan the puppet design and draw a structured storyboard." [486]
(Spieler, 1999)

Figure 58. Puppetry Workshop held at Bartlett in 2011. Organised by Ruairi Glynn and led by Pif-Paf Theatre Company. The workshop focused on how to design and fabricate large scale puppets with bamboo structures.

Theatre reformer Edward Gordon Craig attributed puppetry a "noble artificiality"[487]. He too recognised behaviour latent within each individual puppet, seeing this as one of puppetry's most compelling attractions. "You don't move it, you let it move: that's the art"[488], stated Craig. Without the burden of a mind, its character was defined by its mechanics, it simply performed as itself. While human actors must pretend to play a character, Craig insisted the "Marionette does not play a number of parts, he plays only one … that is himself…The Marionette never pretends" [489]. Craig's infamous theory of the Über-marionette does not make direct reference to the writings of Kliest, but the similarities are evident. Craig's provocation to the theatrical arts was to abandon actors altogether, for his super-marionettes – mechanical performers free of the egotistical appetite of human actors.

For Vsevolod Meyerhold, a Russian theatre director and producer, the puppet embodied a performer resisting the role of imitating the human actor. In attempts to build more human-like puppets, he describes how adding mechanical improvements causes them to loose their own compelling aesthetic appeal.

"It was as though the puppet were resisting such barbarous improvements with all its being. The director came to his senses when he e realized that there is a limit beyond which there is no alternative but to replace the puppet with a man. But how could he part with the puppet which had created a world of enchantment with its incomparable movements, its expressive gestures achieved by some magic known to it alone, its angularity which reaches the heights of true plasticity?" [490] *(Braun, 2016)*

The puppet in Mayerhold's view "wishes not to copy but to create" [491]. As Henryk Jurkowski points out, Craig himself doubted a puppet would ever be able to replace a human for an entire play, and debate on whether his proposition was anything more than a metaphor remains without scholarly consensus [492]. Within the avant-garde the puppet represented the potential to transcend limitations of reality, by rejecting realism and searching for new forms of expressive life. After centuries of puppets playing the role of miniature versions of theatre, it began to find itself able to offer an original aesthetic contribution.

Mechanical Abstraction

Puppetry and robotics theorist Elizabeth Jochum encourages a reading of early 20th century avant-garde puppetry within the context of wider efforts to reconcile cultures of machine aesthetics with human performance aesthetics [493]. Oskar Schlemmer's essay *Man and Art Figure* captures the endeavour "to free man from his physical bondage and to heighten his freedom beyond his native potential resulted in substituting for the organism the mechanical human figure [Kunstfigur]: the automaton and the marionette"[494]. The non-human life of marionettes touched upon the human condition in an age of machines and mass culture. The marionette and the automaton featured heavily in the theatre at the time, though often performed by human actors. Karel Čapek's *R.U.R.* which premiered in Berlin in 1922, famously coined the term 'robot', where distinctions between man and animated objects dissolved as actors performed as automaton.

The semiotic and phenomenal attraction of puppetry to the avant-garde was embraced by Dadaists and Surrealists for its absurd and comic irrationality, while simultaneously for the Futurists, Constructivists and at the Bauhaus, it offered a contrasting mechanical dynamic rationality. Both interpretations had the capacity for eccentric abstraction. While directing the puppet Workshop at Tairov's Kamerny Theatre, Russian artist Vladimir Sokolov, in an essay published in *Das Puppentheater,* described this new mechanical abstraction as an "approach

of true movement", extolling "puppetry's virtue of creative movement and gesture over imitative, representational qualities." He goes as far as to suggest the "word *marionette* will disappear", instead "played through associated or abstracted forms, through planes, lines, or sets of fixed points, as well as through the changing of light and colour" [495].
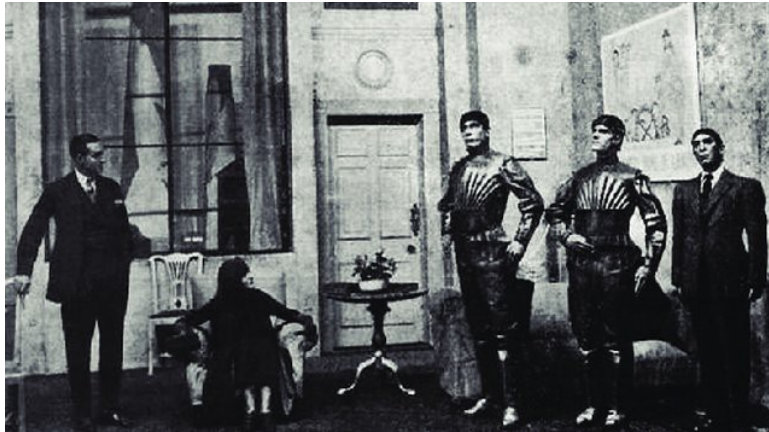

Figure 59. A scene from Karel Čapek's play Rossum's Universal Robots (1921)
Note: robots played by human actors.

Oscar Schlemmer, acknowledging the limitations of human performers to "laws of gravity, to which it is subject" [496] points to "the living geometry" of the Acrobat attempting to overcome this mortal obstacle. For theatre practitioners like Schlemmer, new technologies opened up the potential for artificial figures that would not replace the human, but rather represent in abstract form an "intensification of peculiar natures" [497]. Laszlo Moholy-Nagy's essay in The Theatre of the Bauhaus shares this vision calling for "die mechanische Exzentrik", a mechanised eccentric"[498]. The Theatre of the Bauhaus was rebellious to traditional notions of the theatre, including its roles as means a communication of events or indoctrination. Light, motion, sounds and form had been subservient to this purpose but were now invited to come to the foreground, narrative plot was diminished or eliminated entirely.

Limited by the technologies of their time, the marionette represented an immediate means to exploring the possibilities of autonomous and animate performance machines. Enrico Prampolini's 1915 manifesto *Futurista Scenografia,* grasping Filippo Marinetti's 1913 call for a theatre of "modern mechanics", and Craig's *New Stagecraft,* proposed performance machinery where the "abstract entity of the stage becomes one with the scenic action"[499]. Prampolini's theatre envisioned an architecture, not for performance, but as performer itself – an "abstract, autonomous, scenic event, uncontaminated by other artistic conventions and constructed from the elements of pure form, colour, light, and movement". Prampolini describes his *Magnetic Theatre* in mechanical terms, but hints at the animacy latent in its motion.

"To these plastic constructions, ascending, rotating, and shifting movement are given, in accordance with necessity. The scenic action of the chromatic light, an essential element of interaction in creating the scenic personality of the space, unfolds parallel to the scenic development of these moving constructions. Its function is to give spiritual life to the environment or setting, while measuring time in scenic space." [500]

(Kirby 1986)

Though award winning in its proposal, the *Teatro Magnetico* was never realised beyond miniature model, nor indeed were many futurist projects. However, the proposition, alongside Depero's "Teatro Magico" and Moholy-Nagy's "*Die mechanische Exzentrik*", marks the moment in theatre design where the kinetic stage is conceived of as a life force of its own. Without the presence of human performers, Elizabeth Jochum describes, "the appearance of a soul", caused by "the illusion of operating independently from any human impulse", suggesting Prampolini among others expected "the spectator adopt the same phenomenological stance towards the kinetic scenic space that they would when observing human actors or puppets onstage" [501].

Figure 60. Oskar Schlemmer's, Triadic Ballet Costumes Metropol-Theater in Berlin, 1926

At the Bauhaus, Schlemmer and his collaborators struggled to achieve entirely mechanical performers, instead building geometric costumes that transformed human dancers into machine-like performers. In their *Triadic Ballet* (1922) platonic forms abstract and exaggerate, rather than relinquish, figurative-human form (Figure 60), but were able to realise and further the aesthetics of abstract form in motion, in ways that futurist theatre's

naive mechanical models could not. This period of radical reconfiguration of the roles and relationships between the theatre, architecture, plastic arts, and human performers, was limited by the technologies of their time and the expertise of the artist, but the recognition of the aesthetic potential of abstracted animate form to create, what Prampolini called, "absolute synthesis" and Moholy-Nagy called a "theatre of totality was hugely influential".

> *"The goal of these machines was not to imitate human beings, but rather to open up new possibilities for expression and theatrical illusion. Unlike lifelike automatons, these artificial actors offered the possibility for wider geometric expression, a freedom from natural proportions, and lent themselves to inventive and fantastical theatrical illusions. Like puppets, these autonomous machines utilized the principles of abstraction and dynamic movement to create illusions of liveness."* [502] *(Jochum, 2013)*

At the core of this aesthetic exploration was an appreciation of the important contribution puppetry brought, with its deep knowledge of the primitive universal, cultural experience, to conjure life from the inanimate. The phenomenology of the puppet – its perceptual, aesthetic and metaphysical force – reflected an emerging aesthetics of purposeful, autonomous behaviour, in the age of machines. The limitations of the puppet to replicate human behaviour was not a disadvantage, but rather an opportunity that opened up "a complicated mix of practices encompassing old traditions, new aesthetics and technological innovations that have intertwined it deeply with other strands of contemporary culture"[503].

Concurrent to avant-garde theatre, new photographic and machine technologies of cinema opened up the emerging field of cellular animation to exploring the fabrication of life, albeit missing the unique presence that the puppet-object held.
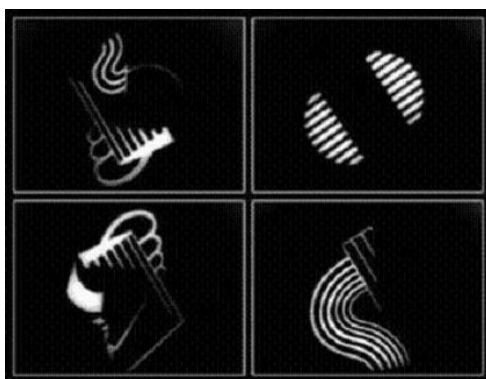

Figure 61. Cells from Victor Eggling's Diagonal Symphony

In animation's earliest decades of open exploration, the avant-garde examined abstract shifts in compositions of colour, form and line, with seminal works, such as Victor Eggling's *Diagonal Symphony* (1925), and the synesthetic experiments of Oskar Fischinger's *Composition in Blue* (1935).

> *"Non-objective animation is without doubt the purest and most difficult form of animation. Anyone can learn to 'Muybridge' the illusion of representational life, but inventing interesting forms, shapes and colours, creating new, imaginative and expressive motions – 'the absolute creation: the true creation' as Fischinger termed it – requires the highest mental and spiritual faculties, as well as the most sensitive talents of hand."* [504]
>
> *(Moritz, 1988)*

Even in the early work of Disney, Jeffrey Skoller suggests, "one could glimpse the promise of radical aesthetics within the context of the popular culture of the animated film. Such hopes for radical vernacular modernism were short lived" [505]. Regardless of the technical and aesthetic achievements of the avant-garde, audiences were to find them "difficult to relate to and even harder to understand" [506], turning instead to conventional narrative structures found within popular theatre and cinema.

This wasn't, however, to dissuade those animators who wished to explore territories outside of popular culture. For many working within animation's avant- garde, the freedom found in the medium allowed them to discover very personal conscious, and sometimes unconscious, forms of expression. Stan Brakhage, for example, explored the use of compound solutions and light to create fluidic dream like visions of hell, purgatory, and heaven in *The Dante Quartet* (1987). New Zealander Len Lye's use of batik directly onto film, allowed him to produce works inspired by primitive cultures.

Just as we find in puppetry's avant-garde, where the 'little doll' has been replaced by found objects, human limbs or other primitive forms of puppet, animators deconstructed and challenged the very foundations of their art form.

> *"The method of graphic expression which merely uses primal forms is concordant with the animator's atavistic intentions… a direct attempt to get in touch with different kinds of expression which precede Formalism."*[507]
> *(Wells, 1998)*

Sergei Eisenstein suggests that this 'heartless geometrizing' in opposition to his much-favoured Disney worlds, "gave rise to a kind of antithesis, an unexpected rebirth of universal animism" [508]. Like alchemical experiments, the pre-rational, pre- scientific state-of-the-art touched upon a sense of primordial forces. Resisting subjectivity, narrative and representation, animation was able to disintegrate into 'non-localised' movement. Along with Eisenstein, Lamarre talks about the spectator finding themselves in the "company of animism and vitalism"[509], a primitive mental space where "our brains must constantly fill in, correcting, enriching, and compensating for the poverty of actual stimuli"[510].

> *"Through poetic connections feeling is heightened and the spectator is made more active. He becomes a participant in the process of discovering life, unsupported by ready-made deductions from the plot or ineluctable pointers by the author. He has at his disposal only what helps to penetrate to the deeper meaning of the complex phenomena presented in front of him. Complexities of thought and poetic visions of the world do not have to be thrust into the framework of the patently obvious."* [511] *(Tarkovsky, 1986)*

Without perceivable figures or narrative, abstract animations do not necessarily dissolve into complete disorder. A unity of its own can be found in an animation, whether material, rhythmic, a chosen colour palette or symbolic in nature. For the audience, they offer sensual, rather than structured cues to intended meanings. To the animator they offer an experimental space to understand their communicative potential.

4.4 Animation

"The very idea, if you will, of the animated cartoon is like a direct embodiment of the method of animism"… if commentators speak of the animism and vitalism of animation in general, it is because a general experience of "movement-as-life" seems to underlie these specific forms."
[512] *(Buchan, 2013)*

Between Experimental Abstraction and Orthodox Mimesis

In the arts, animation is a relative latecomer to aesthetic exploration of animacy latent in motion. Puppetry and mechanical automaton hold histories of technical development that reach far back into animist and shamanic traditions. However, as a cultural phenomena of the past century, animation is better documented and accessible, than its historic counterparts. Few automata or technical literature have survived its golden age of the industrial revolution. Puppetry, by its very nature, is most affective when experienced 'in the flesh' - a real challenge with few dedicated theatres, and modest touring budgets for productions. By comparison, animation is pervasive through digital screen-based media and I believe is on the cusp of making an important contribution into the design of robotic agents that will increasingly inhabit our built environment. The sheer variety of forms of expression in animation makes it difficult to define a core theoretical or aesthetic concern to animation. Some who have attempted include Cholodenko[513], Pilling[514], Wells[515], Furniss[516], Leslie[517] and Buchan[518].

Animation and its mode of production today can be appreciated as a synthesis of the latest techniques in computational modelling and artificial life, meeting animist traditions of puppetry and theatre. Such animated mechanical wonders as Vaucanson's *Digesting Duck* and the Droz Brothers' *Writer* android*,* were the performative precursors to the optical machinery of Joseph Plateau's *Phenakistiscope* and Simon Ritter von Stampfer's *Stroboscope,* that first manipulated retinal persistence of vision to bring image to life.

Figure 62. Cells from Oskar Fischinger's Allegretto animation (1936)

In Oskar Fischinger's 1936 animation short *Allegretto* [519], 2D abstract forms, composed of lines and primitive geometry, move around the screen (Figure 62) to the music of composer Ralph Rainger. Darts move across the screen with striking similarities to the aforementioned experiments in perceptual psychology conducted decades later. At one moment in Fischinger's two minute film, a field of darts burst across the screen with the appearance of a shoal of fish, or Craig Reynold's flock of *Boids*. For the avant-garde of cell animation, experiments with audio and visual composition were always latent with moments of life, though contrary to popular conceptions of the art form, these animators were not universally interested in creating impressions of animacy.
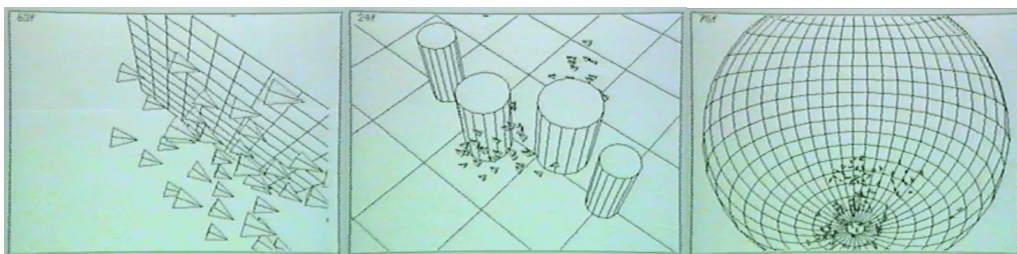
Figure 63. Craig Reynold's Boids software demo film (1986)

Alongside Oskar Fischinger, pioneers, such as Victor Eggling, Fernand Léger, Harry Smith, Stefan and Franciska Themerson were among a wide-ranging field of artists who pursued experimental practices of moving collages of image, colour and form. Jeff Malpas asserts that, "it is movement, rather than life that is at the heart of animation" [520], citing, as one of many alternative practices, Norman McLaren's *Synchromy* (1971) in which sound produced through mark making directly onto film is both projected visually and played back acoustically. McClaren himself described the essential defining characteristic of the art as its construction of time, or as George Griffen called it an art "devoted to creating realms of synthetic time"[521], distinguishing it from cinema's photographic recording and playback of live action.

Unbound to physical laws, experimental animation has a metamorphic freedom to explore the potential for what Eisenstein called 'plasmatics'[522] - an infinite experimental world of alchemical transubstantiations in form, and colour. Contemporary versions of this field can now be found in digital motion graphics and various synesthetic audio-visual art forms. Theorist Pall Wells in *Notes Towards a Theory of Animation: Styles and Approaches* [523], proposes that all animation be placed on a continuum between practices of abstraction, that include non-figurative, rhythmic, non-linear, and "Interpretative Form", all under a broad title of 'Experimental Animation', in contrast to what he calls 'Orthodox Animation', encompassing the character-based mimetics of the commercial animation industry. While 'Experimental Animation' is a complex field of heterogeneous practices, 'Orthodox Animation' has a distilled doctrine of techniques.

Theoretical discourse in the field has coalesced around the field of animation studies, as a melting pot for media and cultural studies, sociology, film theory and history, and feminist studies[524]. Attempts to theorise animation from the outside i.e. not by practicing animators, has led to some fierce debate over the value of "imported" criticism. Andrew Darley's article *Bones of Contention: Thoughts on the Study of Animation* [525] executes an incendiary attack against the state of theoretical discourse, arguing that literary approaches to animation have too often relied on "metaphorical, associative and speculative routines, which are divorced from real phenomena and practices", going on to argue this fails to provide a "rational understanding but rather forms of rhetorical extemporization: a kind of poetical riffing with theoretical concepts and ideas that bear very little relation to the real-world practices into which they are being "shoe-horned"[526]. Darley's critique gives direct reference to the widely cited collection of essays *The Illusion of Life,* edited by Alan Cholodenko[527], slamming it for heavy handed application of philosophy and "highly tendentious argumentation… and endless (futile) searches for ontological/metaphysical legitimation"[528]. Cholodenko's response *Animation (Theory) as the Poematic: A Reply to the Cognitivist* [529] is just as combative, and certainly lives up to some of the "riffing" Darley refers to.

It is likely both feel they won the argument, and I mention this dichotomy here to say that I share Darley's critique. There is an evident disconnect between the technical practice of animation and theoretical discourse. Cholodenko's writing is of importance and is discussed later on the important subject of the uncanny, but in the context of discussing the practice of animating objects and images, animation studies often remains at arm's length. This review of animation therefore limits itself to two 'hands on' aspects of the field. First, the principles of

animation behind orthodox practices and, secondly, an emerging theoretical discourse on embodied cognitive perspectives of animation that relate to the aforementioned fields of perceptual psychology and discourse of embodied cognition. Together, they explain the pervasive experiences of animate media in the technologies we encounter on a daily basis.

Principles of Animation

The colloquial use of the term animation immediately inspires associations with childhood and the giants of industry, including Disney, Warner Bros and Pixar. The cultural hegemony of these companies and their dominant models of production have met with considerable criticism[530][531], for creating an orthodox style that has overshadowed the art's early history of radical experimentalism and the multiplicity of contemporary independent animators. The industrialisation of animation in the 1920s, subsumed individual authorship demanding conventions for collective practice be established. Specific materials, techniques and aesthetics became standardised - all constraints that Thomas Lamarre suggests were productive in contributing "to making movement-as-life a central concern or problematic of animation, and maybe the central concern" [532].

Literature on orthodox animation is consequently where practical attention is given to defining types of motion that lead to perceptions of animacy, whereas experimental and abstract forms of the art remain too heterogenous for universal rules. While orthodox animation seeks to sustain the life of moving characters, the appearance of lively artefacts in experimental work is, more often than not, unstable, fleeting and strange.

The principle author of orthodox animation is unarguably Disney. Its core team of animators – who Walt Disney himself called the Nine Old Men – established widely adopted techniques for (figurative and non-figurative) character animation. What is striking is how their techniques, refined over many decades and published by veteran Disney animators Ollie Johnston and Frank Thomas (two of the Nine Old Men), in their 1981 book *The Illusion of Life* [533]*, remain doctrine to this day, regardless of the digital revolution that has occurred in production methods. This is evident in the ground-breaking computer generated short *Luxo Jr. (*1986), directed by John Lasseter, whose paper[534] presented at Siggraph conference in 1987, pays homage to the *12 Principles of Animation* distilled in Johnston and Thomas' book.

1: Squash and Stretch	2: Anticipation	3: Staging
4: Straight ahead action and pose to pose	5: Follow through and overlapping action	6: Arcs
7: Slow in and slow out	8: Secondary Action	9: Timing
10: Exaggeration	11: Solid Drawing	12: Appeal

Luxo Jr. is a useful case study, as a short film that uses the full range of Disney's 12 Principles with animated characters made up of rigid bodies similar in this respect to the mechanics of machines I have built and attempted to 'bring to life'. As the first CGI film nominated for an Academy Award, it is also a masterclass in narrative story telling from a series of discrete behaviours. Perhaps the simplest and most immediately useful principle I have adopted in my own work is Arcs, which explains that curved motions appear more natural than straight line motion. We find this evident in the photography of Etienne Jules Marey, where human and animal bodies in motion are rarely linear but rather a choreography of curved motion profiles. This understanding of pendular motion is also later discussed in theoretical foundations of puppetry, where it has been long understood that natural motion is rhythmic [535].

Figure 64. Luxo Jr. (1986) by Pixar, directed by John Lasseter

A quality of motion common in animation practice, but untouched in visual perception is, 'Squash and Stretch'. A principle John Lasseter regarded as the most important. "Movement emphasizes the rigidity in the object… Anything composed of living flesh… will show considerable movement in its shape during action" [536]. Though Luxo Jr. is a rigidly mechanical character Lasseter explains how the principle of 'Squash and Stretch' is still used. "An object need not deform in order to squash and stretch… a hinged object like Luxo Jr. squashes by folding over on itself, and stretches by extending out fully" [537]. We see Squash and Stretch behaviour, therefore, in Ihnatowicz's *Senster,* as its armature retracts and extends demonstrating an animate quality of softness through motion independent of its material and structural properties. *Senster* also demonstrates, in its smooth motion profiles, the related principle of 'Slow In and Slow Out'. The seventh principle, which in traditional cell animation is meticulously produced frame by frame, with speed of motion between 'keyframes' determined by the number of frames in- between, and their spacing. Equal spacing will appear as a constant velocity.

Acceleration or deceleration is produced by increasing or decreasing differences in spacing between frames. Subtle changes in these motion profiles can dramatically change the impression of a movement or gesture and requires constant attention by the animator. With the development of spline interpolation in computer generated graphics the parametric adjustment of 'Slow In and Slow Out' allows for quicker testing of the expressive range of these motion profiles.

These techniques are now being deployed not only in character animation, but also often in graphical user interface design. For example, in Google's *Material Guidelines*, we find beside colour, font, shadow and other visual style specifications, the required speed and acceleration profiles for moving elements. As Google invests into the physical animated world of robotics one might wonder whether we will see a unified material specification for virtual and physical motion profiles.

John Lasseter explains that the character movements of Luxo Jr. are constructed in three parts, the movements that prepare for an action, the action itself and then the terminating actions. The principle of 'Anticipation' explains the important influence that, often small, preparatory movements have, before larger movements follow. A character may use a moment to align itself to another character or its environment before executing a significant motion. These small alignment motions indicate to an audience where to focus their attention in anticipation. Lasseter's reflective writing on his use of the 12 principles of animation illustrates how thoughtful and deliberate ever motion is that appears on screen.

The principles of animation evidently borrow from theatrical techniques, when steering audience's attention, are well understood. Lasseter discusses the 'Staging' principle, where speed of motion tells us which character to follow at which time. "As soon as Jr. hops on-screen, he is moving faster than Dad, therefore the audience's eye immediately goes to him and stays there" [538]. The more animate, the more we irresistibly attend to a character, and when attention is secured, the animator makes use of the further principle of 'Exaggeration', to make explicit the narrative content of motion. "If a character is sad, make him sadder, if he is bright, make him shine, worried, make him fret, wild, make him frantic… The movement [of Luxo Jr.] had a sense of natural physics, yet almost every motion and action was exaggerated to accentuate it" [539]. Used carefully and sparingly exaggeration enhances all of the other principles of animation. Such ideas have found their way out of the screen into the use of animatronics at entertainment resorts. Psychologist and scholar of human-robot relationships Sherry Turkle tells an anecdote about speaking to a research scientist at the Walt Disney Company, who was not surprised to find these exaggeration techniques change our expectations of animate behaviour.

"When Animal Kingdom opened in Orlando, populated by "real," that is, biological animals, its first visitors complained that these animals were not as "realistic" as the animatronic creatures in Disneyworld, just across the road. The robotic crocodiles slapped their tails, rolled their eyes, in sum, displayed "essence of crocodile" behavior. The biological crocodiles, like the Galapagos turtle, pretty much kept to themselves." [540] (Turkle, 2006)

Back in the world of cell animation, typically based on 24 frames per second, orthodox animation's continuous smooth action is sometimes referred to as 'Full Animation'. Productions of this kind are expensive and time consuming demanding industrial processes of production that few studios can resource. More economical technical and aesthetic traditions have developed internationally, such as in European animation houses where lower frame rates and simplified, choppier motion are still effective in creating the 'Illusion of Life'.

In contrast to Full Animation, and at the other end of the spectrum, is Japanese Anime, which relies on dialog primarily to maintain narrative supported by minimal motion. Regardless of where work sits on this spectrum between full animation' and minimal Anime techniques, some motion must be maintained, as without it as Maureen Furniss explains,

"when an image within an animated production becomes still, its lifelessness is readily apparent" [541]. In Anime a scene may be still but for including blinking eyes and moving lips, or panning shots across still characters and backgrounds, yet still delicately holds a sense of life. In Anime, perhaps more so than anywhere else in the field, we find that animation need not be always about movement so much as about the composition of movement and stillness.

For the purposes of this discussion on 'Life in Motion', I have focused on the full animation techniques of American production houses, as they most closely relate to the continuous live experience people have when they encounter my own animated machines. Though in the later context of a discussion on aesthetics, I touch on the haunting aspects of minimal forms of animation and their potency.

Embodiment and Animation

Interestingly, the technical exchange of expertise between animation, computer graphics, gaming and emerging new media art forms, has created new spaces of discourse that are more technically grounded. In the past decade animators have begun to draw direct connections between practice and interdisciplinary theories of cognition with recent articles by Patrick Power [542], Jeff Malpas [543] and Dan Torre

[544]. It seems that this synthesis has taken a very long time to happen considering psychologists have been using animation techniques since the 1940s, to study motion perception. One explanation is certainly the disciplinary make up of animation studies comes largely from the humanities. Another issue might be the perceived naivety of the subject that makes serious academics across arts and sciences nervous. Editor of Animation Journal Suzanne Buchan argues that the naive delight of animation is a strength rather than regressive feature of the art worthy of scholarly study [545].

> *"From this perspective, animation is a complex and sensational phenomenon. This means that it is composed of very different dimensions of reality. Once could also call these dimensions discourses. Then animation would be an inter-discursive phenomenon. In its prismatic existence philosophy, theology, media theory, engineering, natural sciences, the history of technology, aesthetics and ethics meet and overlap."* [546] *(Buchan, 2013)*

To date, the most substantial effort to bring together contemporary theories of embodied cognition to the experience of observing animation in digital media is by interaction design theorist Kenny Chow. Discussing how digital screen-based artefacts exhibit various types of phenomenal "technological liveliness", such as motion, reactivity, adaption and transformation, he argues that we feel our bodies are in touch with these digital objects. "We sense that we can move them or stop them; in other words, interact with them. We are embodied in the digital environment through the sensorimotor experience of touching or moving objects"[547]. Chow makes the case that our experience of animated phenomena is not passive, but actively constructed, grounded in our own sensorimotor experience of animate behaviour, both our own and that which we interact with. He gives examples of how, "A bird flies away when someone approaches. The crowd disperses to make way for someone trying to cut through" [548], suggesting that when similar behaviours occur on screen-based media, our body relates these to a lifetime of bodily-spatial experiences.

Though much of our digital media interaction with animated artefacts occurs on small mobile screens, or sat in front of TVs and computers, new domains of responsive media facades and digital projected art installations are becoming more common, following in the pioneering work of Myron Krueger. Sensing of bodily motion can range in resolution from basic proximity, to sophisticated computer vision techniques of gestural recognition. A common interface input is hand motion, which offers individual and collective forms of public interaction with on- screen graphics. 'Hand waving installations' are often very effective at engaging people in intuitive interactions. This is, I believe, because it sets up an immediate social framework for interaction. We wave towards the digital artefact and if we recognise a response, a social connection has been made. We may perceive life in these responsive behaviours and enter into extended gestural exchanges to explore these novel relationships.

The repertoires of actions we employ reveal habituated motor habits for social interaction that function quickly and naturally. Bodily motion, Merleau-Ponty explains, reveals our consciousness as "not a matter of "I think that" but "I can'" move toward something"[549]. For example, our habituation allows us to reserve cognitive capacity for higher-order processing of language. Meanwhile, bodily cognition of animate interactions occurs unconsciously, in chorus with the emotional experience that phenomenologists, such as Roberta De Monticelli [550], argue is deeply tied to our motor action.

Primary and Secondary Liveliness

Avoiding the term animation, Kenny Chow suggests the use of the term "liveliness". He argues it circumvents loaded connotations of particular fields of practice and academic study. For Chow, liveliness, as a term, focuses on perceptual and experiential qualities, without association to particular materials, media, contexts and purposes. 'Technological liveliness' focuses on how these contemporary experiences of digital media often involve dynamic responsive experiences with animated phenomena, enabled by computing and other related technologies. Despite the pervasiveness of animated digital objects in media technologies, Chow explains that these qualities are "commonly dismissed as peripheral concerns" in interaction design, game development and digital art, and argues that they "should be at the core of the study and creation of digital media artefacts, because they actually manifest the primal and persistent urge among humans to animate the inanimate that spans periods and cultures" [551].

Chow proposes two types of liveliness. A primary liveliness of artefacts that have clear goal-directed behaviours, such as chasing and avoiding, and a secondary liveliness which involved complex and ambiguous behaviours over fields of behaviour, such as dancing and flocking. Secondary liveliness, he suggests, can extend to other complex phenomena that are not goal-directed, such as weather formations. He makes a point of not giving prominence to either, even though his labels might suggest this. In his words, "They represent the two 'sides' of the same coin" [552]. After all, the agency of a single boid may exhibit primary liveliness, and the flock of boids exhibits secondary liveliness. "If character animation is considered to display primary liveliness, motion graphics are definitely representative of secondary liveliness" [553]. One concentrates the observer's attention on a centre of action, the other on a complex transforming whole. Primary liveliness, he suggests, has drawn more attention because of its ease of simulation and clarity of observation, however, advances in computer graphics will increasingly afford opportunities to explore the second.

4.5 The Uncanny

"The origin of the uncanny is the natural tendency of man to infer, in a kind of naive analogy with his own animate state, that things in the external world are also animate or, perhaps more correctly, are animate in the same way. It is all the more impossible to resist this psychical urge, the more primitive the individual's level of intellectual development is." [554] *(Jentsch, 1906)*

For modernity at the dawn of the 20th century, animist tendencies to perceive life in objects represented the irrational and primitive mind. Animism was a problem, a childish and degenerate pathology that became the interest of Ernst Jentsch, with his 1906 article *On the Psychology of the Uncanny* taken up and developed further by Sigmund Freud in his 1919 *Das Unheimliche*. Both Jentsch and Freud draw up on E.T.A Hoffman's 19th century tragic tale *Der Sandmann – The Sandman*[555], where a mechanical automaton of female appearance gains the amorous attention of a poet named Nathanael.

Fantasising himself as Pygmalion, Nathanael ironically casts aside his fiancée Clara (who embodies rationality) as a "damned, lifeless automaton!" Nathanael's Pygmalionesque delusions allows him to believe the mechanical doll named Olimpia has come to life, until the automaton's creators Spalanzani and Coppola dismember it to reveal its mechanically lifelessness, which, in turn, leads to Nathanael's death. Olimpia, representing a liminal figure, between the living and the non-living, embodies both the familiar, rational and intimate 'heimlich' and simultaneously strange, irrational and repressed 'unheimlich'. For Freud the tension between these irreconcilable perceptions – particularly triggered by figures of dolls, and mechanical automata – was the principle cause of the compelling phenomena of the uncanny.

"An uncanny effect is often easily produced when the distinction between imagination and reality is effaced, as when something that we have hitherto regarded as imaginary appears before us in reality… It is this factor which contributes not a little to the uncanny effect attaching to magical practices." [556] *(Freud, 1919)*

Both authors understood the ontological paradox between the living and non-living as the primary source of the uncanny and examined its visceral emotional effects, Jentsch describing it as a "dark feeling of uncertainty" [557], while for Freud, the uncanny was more menacing, belonging "to the realm of the frightening, of what evokes fear and dread" [558]. Freud's Uncanny was associated with "harmful forces and the return of the dead" [559], an irrational dark mysticism, "the old animistic view of the universe" [560]. In an age of Modernity, animist tendencies, once familiar, but now repressed, re- emerged through the animating power of technology. Hoffman's *The Sandman,* and the writings of Jentsch and Freud, should be seen within the context of the rise of industrial automation, and the emerging anxieties about the potential autonomy of machines. It is no wonder then, that the avant-garde emboldened by machine culture, embraced the aesthetics of the uncanny, both in their use of primitive icons from animist cultures, and in the abstract shamanism of their kinetic explorations of primitive form.

Over the past century, the visceral aesthetics of the uncanny have been popularly discussed in puppetry and animation theory. More recently in robotics, research into the effect of the uncanny has received considerable attention, typically with the aim of reducing its presence rather than harnessing it.

Puppetry

"There is something in the puppet that ties its dramatic life more to the shapes of dreams and fantasy, the poetry of the unconscious, than to any realistic drama of human life. That is part of its uncanniness, that its motions and shapes have the look of things we often turn away from or put off or bury. It picks out our madness, or what we fear is our madness. It creates an audience tied together by childlike if not childish things." [561]
(Gross, 2011)

Puppeteer Kenneth Gross describes puppetry as the art inextricably linked to "the dead, with the realm of the uncanny, the threshold realm of things unknown" [562]. Often barely human in form, a foetus, a mistake of nature, a monster or a corpse, puppets instil a magical thinking, part wondrous, part terrifying. They elicit a visceral effect, a primitive but flickering fear of the dead brought back to life.

Roman Paska describes his practice as a kind of necromancy [563], every puppetry

performance containing the underlying story of the puppet struggling for life, what puppeteer Basil Jones call the puppet's "Ur-narrative" [564]. Seen through Tillis' "double vision" [565] or what Jurkowski calls "opalization" [566], the viewer can share in sensations of fear or creepiness and, in the same moment, the contradicting triviality of the spectacle. The uncanny of the puppet is a source of a strange pleasure, both frightening and at the same time compelling in its playfulness. Fear is overcome in the participation of 'le jue' of the puppet performance, in the embrace of the spectacle and its artificiality. In this way, the puppet can invoke gasps of anxiety and, moments later, turn us to laughter, or even the sublime.

"The audience or observer was said to derive pleasure from being (temporarily or potentially) overwhelmed by an object or entity that seemed infinite or vast, powerful or terrible, exceeding the capacities of the human to imaginatively grasp or understand it. Breaking with conscious control and individual personality or preferences, the pleasure- in-pain that was integral to the sublime seemed to take man temporarily beyond the human; but the pleasure was generated by an object – not by a god or by the divine – and opened a kind of split within the subject before consciousness and reason re-establish control." [567] *(Battersby, 2007)*

Puppetry in the context of modernising rationalism has pulled against the grain, holding onto a deep history of beliefs and traditions. In the face of unrelenting modernisation and reductive tendencies to resist the instinctual and emotional basis of aesthetic experience, puppetry reveals the visceral, primordial nature of the material world and its agency. In contemporary puppetry the atomisation of puppet theatre, reforming into primitivist experimental practices, continues the resistance against the imposed rationality of modernity. It reminds us and celebrates, like no other art form can, the un-modern nature of ourselves, of our deepest and most primal of social instincts.

Animation

With a similar bistable ambiguity found in puppetry, the theorist Alan Cholodenko affirms that, "Animation always has something of the inanimate about it… a certain inanimateness that both allows and disallows animation" [568]. He too points to the phenomena of uncanny as "never not with us"[569]. Animator Paul Wells goes further by claiming that the uncanny is "central to the whole art of animation" [570].

Not all animation media has the same potential for the uncanny. Maureen Furniss suggests stop-motion, object animation elicits the uncanny "to a greater extent than drawn, painted or most digital 3D animation" [571]. She suggests that stop- motion objects 'real life' status makes a tangible difference. Susanne Buchan elaborates on the important distinction and the perceptual differences for the spectator.

> *"Studies of object animation need different approaches that those of 2D 'orthodox' animation, because it presents physical space and materials that occupy this space instead of a mimetic, drawn rendering of the same. Objects and the materials from which they are constructed are tangible and have an intrinsic set of references to our lived experience which is not the case in the fully graphic fantasy of 3D animation." [572] (Buchan, 2006)*

The work of object and puppet stop-motion can often be where the most 'uncanny' moments and experimental practices in animation can be found. Films by the Brothers Quay, for example, are unsettling, enigmatic and sometimes frightening, utilising a clapping monkey, rotating screws, hollow-headed dolls, amongst a range of other sinister artefacts. Without a clear narrative to follow, they create a dark visual poetry that can be uneasy to watch particularly to the unfamiliar.

> *"This lack of understanding adds to the uneasiness one feels as he or she watches the eerie figures, confirming our darkest fears that, deep in the shadows, inanimate objects do in fact live." [573] (Furniss, 1998)*

Animation as Robyn Ferrell points out, is not in a permanent state of the uncanny but rather is in a permanent state of potential for the uncanny.

> *"The sly turn of a doll's head, the imperceptible flicker of a statue's stone eyelids, the animal whose expression is for a moment almost human, these can be uncanny. The uncanny must be fleeting, peripheral, threatened. It is a type of moment rather than a class of object; an affect of a process of perceiving rather than of an image perceived." [574] (Ferrell, 1991)*

Whether examining the production of Émile Cohl's hand drawings of the 1900s or John Lasseter's computer-generated worlds a century later, the constant we discover across generations is the animator's obsessive, repetitive and meticulous nature - the painstaking production of imagery, carefully timed and displayed in rapid succession. What has changed, are the modes of production, shifting from meticulous hand drawing and model making, towards equally meticulous digital methods. The 'Digital Turn' in animation has been the source of a great deal of contemporary discussion, enthused by Manovich's polemic, assigning cinema as a subset of (digital) animation[575]. With ever increasing resolution, computer generated imagery has provided the live action film industry with a means to create synthetic worlds for actors to inhabit, at a fraction of the cost of built environments. The virtual elephant in the room is the question of when, one day, actors, like their sets, will be replaced by human simulacra?

Animation productions, such as *Final Fantasy: The Spirits Within* (Hironobu Sakaguchi, 2001), made much of their technical innovations in photorealism, but found their audiences critical, and ended in box office failure. Lamarre comments that it was not only the quality of the photorealism that came under scrutiny but the "the verisimilitude of their movements" [576]. Regardless of the large budget – one fifth of which was spent on rendering the 60,000 hairs on a single character's head – what emerged, Lamarre describes, was "the lifelessness of mechanical reproduction"[577].

Research in cognitive neuroscience has found correlating results. Building upon aforementioned Gunnar Johansson's point light walker experiments (1973), neuroscientists Chaminade, Hodgins and Kawato[578] examined how varying degrees of anthropomorphic realism in animated bodies would affect perception of movement as either 'biological' or 'artificial'. They found an inverse correlation between anthropomorphic realism and viewers' perceptions of natural motion. The animated bodies that performed a simple running motion, it would appear, became more closely scrutinised by the added physiological detail that the anthropomorphic models provided. In contemporary animation, regardless of the impressive semblance of realism available with computer graphics, many artists are rejecting the technological imperative for higher-resolution and realism, returning to their core principles of life appearing in motion.

Robotics

"Our machines are disturbingly lively, and we ourselves frighteningly inert."
[579] *(Haraway, 1985)*

Discourse of the uncanny in robotics invariably begins with Masahiro Mori's 1970 hypothesis of *Bukimi No Tani*, often translated as *The Uncanny Valley* (first by Jasia Reichardt's 1978 book *Robots: Fact, Fiction, and Prediction*). It has also been more accurately translated was the *Valley of Eeriness,* and later literature has amalgamated these into the *The Uncanny Valley of Eeriness*. Mori observed that, as robots become more humanlike in appearance, observers' emotional responses increase positively, until reaching a point where there is a sudden drop replaced by intense repulsion. Only when appearance and movement is improved close to indistinguishable from human appearance could emotional responses become positive again. The sudden drop in the otherwise steadily increasing graph FIGX is the uncanny valley. Motion, Mori argues amplifies the peaks and valleys creating the most visceral of effects.

"Imagine a craftsman being awakened suddenly in the dead of night. He searches downstairs for something among a crowd of mannequins in his workshop. If the mannequins started to move, it would be like a horror story." [580] *(Mori, 1970)*

Mori's observation is so commonly cited in discussion of robotics, it has reached a remarkable degree of public awareness, considering it was published in the rather obscure Energy journal [581]. On a number of occasions, when discussing my research with people quite far removed from robotics, they have brought up *The Uncanny Valley*. Its ubiquity is perhaps a result of its unusual and memorable name, and the endless somewhat repetitive publicity that these creepy machines attract. Arguably its popularity has led to a doctrine emerging over the decades that says robotic interaction is improved between humans and humanoid machines, when anthropomorphic realism is pursued [582].
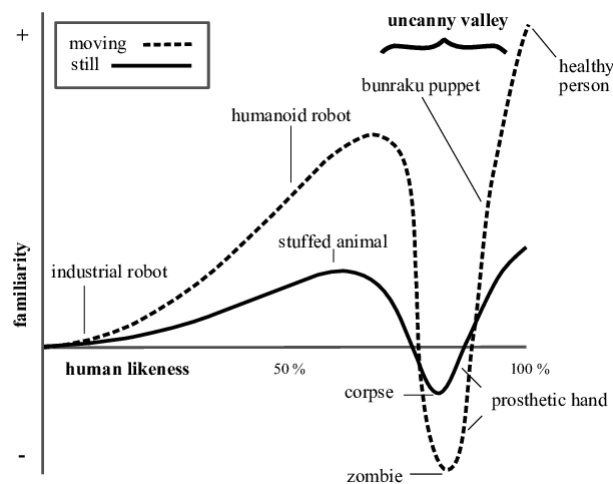
Figure 65. The Uncanny Valley hypothesis by robotics professor Masahiro Mori

However, an often over looked paragraph in Mori's paper discusses the appeal of Japanese 'Bunraku' puppetry. He acknowledges that they fall far short of the humanlike appearance, yet he places them high on the scale arguing that their small stature, presented on stage is put aside by the "tendency [of] an audience to become absorbed in this form of art" [583]. Instead, he suggests, it is the motion of these primitive mechanical performers that leads to "a high level of affinity for the puppet" [584].

Mori's insights on Bunraku are less discussed in favour of issues of figurative semblance. However, humanoid robots, such as *Sophia* by Hong Kong-based Hanson Robotics, and the long running *Geminoid* project of Hiroshi Ishiguro Laboratories, Osaka University, have often obscured a more nuanced discussion of the uncanny found in the arts, leading instead to the uncanny being almost universally seen as a negative effect - a problem to be engineered out of design, rather than a powerful aesthetic property to be harnessed. The technical challenges of building, and choreographing the behaviour of such machines are tremendous. Many passionate attempts to cross the uncanny valley have failed, particularly once robots are put into motion.

A number of contemporary robotics researchers, including Ken Goldberg argue that some artifice is better than complete realism. Roboticist Christoph Bartneck has questioned whether *The Uncanny Valley* should in fact be called The Uncanny Cliff[585]. His lab's research concluded that there is little added value in attempting to build highly human-like androids, over cartoon or toy-like figures if the aim is to increase likability. The future may be less like *Blade Runner* and more like a world of Pixar-animated robots, suggests Ayse Saygin, director of UCSD Cognitive Science and Neuropsychology Lab. "Wall-E is so simple yet so expressive and we feel for the emotion that the robot feels. The design can be very simple yet still press our buttons"[586].

Though a study of cultural effects on people's feelings towards robots is beyond the scope of this discussion, it is worth noting that cultural influences do affect perceptions. With the notable exceptions of science fiction heroes, such as Star Wars C-3P0 and R2-D2, Hollywood's typically menacing dramatisation of robots (Skynet, HAL, Cylons) contrasts with Japanese cultural icons, such as Astroboy, a robot that saves society from its human flaws. Underlying these modern icons, however, is a deeper religious complex. Mary Shelley's story of Frankenstein reflects Western monotheistic fears of a God, exacting punishment on the arrogance of man, daring to usurp their creator. Contrarily, Japan's religious roots in Shinto animism, explaining all objects, animals, and people as sharing a common spiritual harmony, has no hierarchical structures and, consequently, embraces new technologies as complementary companions. The roots of this can also be traces back to Japanese traditions of not discarding or recycling puppets after use, rather burying them in cemeteries instead. Media art and robotics scholar Machiko Kusahara explains "once spirit has encountered a material form, the latter cannot return to mere matter set apart. A dilapidated puppet - a head, arms, perhaps a costume, rattles, flutes, masks - will never again be merely a sum of parts. Today, they are put in museums or glass cases a practice that worries many older puppeteers".

4.6 Robotic Arts

Resisting Anthropomorphism

"The cybernetic automaton's mirroring of the human body was not established on the basis of conventional mimicry, as in the case of androids and their internal parts, so much as on a common understanding of the similarities that existed between the control mechanisms and communicational organizations of machine systems and living organisms."

[587] *(Tomas, 1995)*

Human-robotic interaction research typically utilises our tendencies toward certain formal anthropomorphic cues (i.e. Kindchenschema) to trigger emotional responses in human spectators. For example, the social robot *Kismet* by Cynthia Breazeal and her team at MIT, was "explicitly designed to tug on your emotional heartstrings" [588], with infant-like features and exaggerated emotional expression that were designed to elicit impressions of emotion coming from the machine. A similar zoomorphic example is the Paro robotic seal[589],

designed as a therapeutic aid for elderly care.

In 2017, *Sophia*, Hanson Robotics' humanoid social robot by was handed citizenship of Saudi Arabia - the first robot to be recognised as having legal personhood. This seemed to mark success in Hanson's mission, "upending the uncanny valley"[590], but the robot itself, covered in a sophisticated skin suit, was more publicity stunt than paradigmatic exposition of humanoid robotics. Yann LeCun, Chief AI scientist at Facebook, criticised it, calling it as a "Puppet"[591], intended to deliberately deceive people into believing the machine was far more intelligent than it was. Such use of highly realistic anthropomorphic forms to elevate the status of machines raises serious ethical issues of intentional deception by the technology industry – being a form of deception that distinguishes them from the arts, where audiences are invited into a willing suspension of belief. In the animatronic arts, there are many examples of humanoid and zoomorphic figures, some of which that have developed into HRI research platforms. The *RoboThespian* by British company Engineered Arts is an example of a humanoid robot designed to interact with the public, in such places as museums and visitor centres, taking on roles as exhibition guide. It has also been used as a stage performer in theatre shows[592]. In these types of contexts, robots take roles that may otherwise be performed by human actors, and are typically limited to pre- scripted dialogue. What all these works have in common, to varying degrees, is a reliance on formal qualities of their machines to encourage audiences into emotional responses.

Figure 66. Bill Vorn, robotic installation titled Red Light (2005)

By contrast, robotic arts have often resisted anthropomorphic works, exploring unconventional mechanics, morphologies and materials. A fundamental question in artist Bill Vorn's work is is it "possible to create an impression of life simply through human-machine reactive behaviors of abstract robotic structures?" [593] He characterises his work as exploring perception from human and machine perspectives - how audiences experience the behaviour of his artworks on one side, and on the other, the robot's perception of its environment, including human observers.

Emphasising life-like behaviour over life-like form, Vorn draws upon artificial life algorithms, including cellular automata, genetic and reinforcement learning, to imbue his machines with animate qualities, stating "as long as they manifest autonomous behaviors in the interaction process, agents could bear any abstract visual form" [594]. Elizabeth Jochum supports this perspective when she discusses the emerging relationship between puppetry and robotics practices, advocating the benefits of incorporating performance theory into robotics design. Her central argument borrows American theatre historian and scholar Joseph Roach's phrase, "kinesis is the new mimesis". Roach, writing in the context of contemporary dance, asserts that "expressive movement is becoming a lingua franca, the basis of a newly experienced affective cognition and corporal empathy"[595].

In the context of neurological explanations of corporal cognition, Freedberg and Gallese argue that "A crucial element of esthetic response consists of the activation of embodied mechanisms encompassing the simulation of actions, emotions and corporeal sensation, and that these mechanisms are universal" [596]. Mirror Neurons provide an interface for our motor-experience of our own animate motion in space, to make sense of the animate motion of other bodies. These it appears, are largely automatic and unconscious processes, streamlining social interaction by giving us fast access to interpretations of the agency of others and the social codes of human gestures.

> *"Engines… are really mysterious… They have their moods, unexpected bugs. It seems that they have personality, soul, will. It is necessary to stroke them and to behave with respect to them…"* [597]
> *(Schmidt-Bergmann, 1993)*

As I have discussed, in relation to my work and the work that surrounds me within the Interactive Architecture Lab, that it is striking that moving bodies, which are not at all

anthropomorphic, can still illicit visceral perceptions of life and emotional character. With the "intention of producing an aesthetic medium out of machines", Vorn explains how his "work is defined by an aesthetics of empathy and anthropomorphism from human reactions engendered by animating abstract mechanical structures"[598]. There appears to be something aesthetic in the process of making sense of other animate motion, whether the body is human, or somewhat anthropomorphic, or abstract, and this fascinating phenomena is acknowledged by many artists in the field.

Figure 67. Bill Vorn's Mega Hysterical Machine (2010), non-anthropomorphic robotic installation

Pioneer of robotic art, Louis Philippe Demers suggests that, "the role of the designer is to endow both structures and movements of the machine performer with some level of shared mutual bodily understanding with the audience" [599]. Demers suggest wheels elicit a different response to legs, for example. Remarkably, linkages of limbs in many morphological configurations can be evaluated and quickly interpreted into body mappings, even when they are quite unlike the human body. Gunnar Johansson's point light walkers [600] demonstrate how attuned we are to identify correspondences between moving parts that infer a body, even when the body is unlike our own.

"The Senster elicits from people the kind of reactions that one might expect when someone is trying to communicate with another human being or an animal. It comes close to the sort of robot which we could imagine must have feelings because it behaves like creatures that have them." [601]

(Reichardt, 1978)

Staging Lively Artefacts

Louis Philippe Demers maintains that the staging of his robotic artworks is important in how the machines are perceived as agents - the staging of his mechanical performers enhancing their presence as actors. In more abstract mechanisms like his *Tiller Girls*, he believes theatrical staging particularly benefits the machines as it "creates a tighter coupling of the animation process to the given morphology of the robot" [602].

Figure 68. Louis Philippe Demers, Tiller Girls (2009), 32 small autonomous robots.
Staged as a performance, its title inspired by the famous early 20th century dance troupe

Tiller Girls' swinging pendulum motions, which come from their shifting centre of gravity, are at times graceful, in much the way Heinrich von Kleist talks of Marionettes. Their behaviour is true to their morphology, harnessing the latent behaviour in their construction.

"In embodied AI, the notion of environment is limited to the physiological level. It excludes theatricality as a variable because fiction is not considered a scientific method. By taking an AI robot away from its lab and using it in a different context, I illustrated that a broader definition of embodiment enables a richer palette of perceived behaviours." [603]

(Demers, 2016)

The practice of artists, such as Demers and Vorn, to harness morphological behaviour reflects practices in some respects closer to puppetry than robotics. This leads to radical experimentation with material systems outside of the lab. Take, for example, the work of physicist-turned-artist, Theo Jansen. His *Strandbeest* (Figure 69), assembled from PVC conduit tubes and little else - his practice over the past two decades has been to metaphorically evolve his own lifeforms. He has taken on he role of artist as evolutionary

engine, mutating and testing out new species of beach dwelling creatures, that grow with sophistication over the years. Jansen's practice seems to resist conceptual processes, manifesting itself instead in the materiality and latent theatricality of mechanical spectacles.

Early machines were passive mechanisms driven by human and wind power, but later generations developed primitive sensory apparatus to detect when they got near to water, and change direction of motion accordingly. The first signs of autonomous purposeful behaviour. They also now have the ability to capture and store energy with pressurised air in plastic bottles. His latest creations feature primitive logic gates powered by the air, which built into networks could begin to store information and programme behaviour. One day, he declares, his *Strandbeest* might be able to pass on information to new generations.

Jansen's work embodies, in perhaps the purest sense, a bottom-up approach to the design of 'Lively Artefacts'. His PVC tubes are the 'protein molecule's, for creatures akin to Braitenberg's early Vehicles. Anthropomorphic design has been disregarded in order for life, both systemically and materially, to emerge from direct relationships between agent and environment. In doing so, Jansen and other artists exploring these proto-life explorations, merge aesthetic, philosophical and scientific questions about the ontology of machines, their perception, and potential sentience.
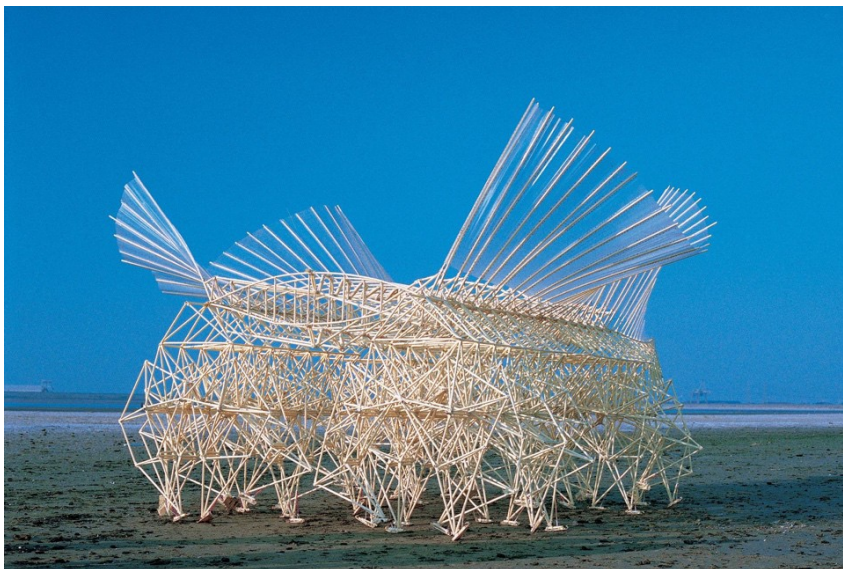

Figure 69. Theo Jansen's Animaris Currens Ventosa, Oostvoorne, Netherlands (1993).

In Scientific American 15th anniversary issue Simon Penny asks the question, *"Why do we want our machines to seem alive?"* [604] Two "persistent motivations", he suggests, are mimesis and anthropomorphism. Though these concerns are typically associated with the arts, he contends that they are at the heart of technological developments, such as artificial life and artificial intelligence.

Mimesis is central also to interactive arts, but Penny rightly points out that much of the field has a kind of "Pavlovian press-the-button-get-prize quality to it", based on tightly predefined interaction models. Artificial life offers a wholly different form of interactivity, where systems might respond in entirely unexpected ways, "These works exhibit a new order of mimesis in which 'nature' as a generative system, not an appearance, is being represented" [605]. Another example of embodied arts practice intersecting with artificial life is Penny's autonomous robotic artwork, *Petit Mal* - a two wheeled naturally balanced mobile reactive robot that explores gallery spaces responding to people and objects it encounters.

> *"The goal of Petit Mal is to produce a robotic artwork which is truly autonomous; which is nimble and has "charm"; that senses and explores architectural space and that pursues and reacts to people; that gives the impression of intelligence and has behavior which is neither anthropomorphic nor zoomorphic, but which is unique to its physical and electronic nature." [606] (Penny, 2000)*

Penny explains how the "focus was on the bodily experience of the 'user' in the context of behaving installations, and on the construction of a fluid relation between bodily dynamics and technological effects" [607]. The robot's ability to navigate its environment, and negotiate space with human occupants, sets up a dance of agency, to borrow a term from Andrew Pickering. Careful thought was given to the scale of mobile robot which was waist height for an adult or roughly child height.

Figure 70. Simon Penny: 'Petit Mal', (1989-2005)

Penny acknowledges, "Were Petit Mal twice or half the size, different emotions would come into play" [608]. Its behaviours were hesitant, to avoid intimidating its audiences and create an uneasy but seemingly safe and playful scene, so people would feel confident to interact with it. The childlike, or pet sized, scale also sets up certain modes of interaction, with Penny noting people having a caring affectionate relationship with the diminutive robot agent. Penny notes that this affectionate interaction occurs very quickly, indicating certain instinctive relationships constructed when first encountering the agent. Penny emphasises behaviour in making these impressions irresistible, explaining, "although physical instantiation is fundamental to the inducing of empathy, the specific qualities of that embodiment, as expressed in physical form and dynamics, ensure it" [609].

> *"Uncertainty also plays an important role in the behavioral relation with the viewer. Animated metal parts in a robot or dots on a computer screen can be seen as being alive if they move and react in a non-repetitive and unforseeable way, giving a strong impression of self-decision and autonomy."* [610] *(Vorn, 2000)*

Many robotic artists, like the designers of computer game agents, use unpredictability as a technique for enhancing the impression of intelligence in the agent. Whether it is hesitant, or misguided, movements, these subtle features powerfully shape our empathic perception of these machines. Penny's *Petit Mal* named after an epileptic condition that causes lapses of consciousness, explores behaviour that is not perfectly engineered for optimal interaction, but rather has lapses of directed motion that create suspense. Moments of stillness create anticipation of the next move, like a creature taking a moment to consider its options before progressing forward. As we find in cell animation techniques, stillness and movement need one another, and so too animate motion needs inanimate stillness for maximum dramatic effect.

4.7 Conclusions

Kinesis is the new mimesis. Embodied cognitive theories of agency perception, hypothesise a direct empathic corporal interface between our own bodily agency and that of other human beings, as well as animals, animated characters, puppets, and robots. Moving bodies, that are not anthropomorphic, can still illicit visceral perceptions of life and emotional character. We feel emotionally the behaviour of others, not solely through rational reasoning, but

through deep unconscious processes of perception, both innate, and learnt heuristics. Only by investigating these complex, heterogeneous phenomena from a variety of disciplinary perspectives, do we come to a deeper understanding of what shapes the aesthetics of animate art forms.

Through a lifetime of embodied interactions with our environment, we develop stable perceptual constructs for meaningful interaction with the world around us. Instability, or uncertainty, is reduced through the acquisition of knowledge that refines and reinforces these interfaces. As a result, by adulthood, much of world we encounter in the everyday has robust models for interaction. Gordon Pask suggests that encountering novel situations, with uncertain objects, spaces and agents that contradict the models we have constructed of our world, draw us into interactions to restablise our models. He suggests that there is something aesthetic about this pursuit and, indeed, the delight of uncertainty, namely in the form of ambiguity[611], has become a defining feature of the experience of modern art.

The human mind is remarkably flexible in the way it negotiates judgments of uncertain stimuli, be they visual, spatial or social. When two interpretations share equal validity, we find our mind oscillating between competing perceptions, only ever holding one consciously, at any one time. From puppetry scholar Steve Tillis' description of "double-vision", to animator Paul Wells assertion of the centrality of the uncanny, and roboticist Bill Vorn's tension in the uncertainty of behavioural relations, we find ambiguity at the heart of all animated art forms. The convergence of our instinctive and naive perceptual reflexes, meet contradictory rational

understandings of the world. A visceral aesthetics emerges within the conflict between fast heuristics and slower, higher-order cognition. Ambiguity drives participation, encouraging observers to seek to resolve the uncertainty through their own action. This helps animated art forms set up social behavioural relations between artwork and observers that draw people into becoming performers themselves.

Although visual ambiguity in the perception of form and colour has been extensively studied leading to various syntheses of artistic and scientific studies – visual ambiguity in the perception of animacy remains understudied, without synthesis, because social perception remains commonly considered a higher-order cognitive process, rather than powerfully shaped by irresistible reflexes. Robotics arts is well placed as a transdisciplinary field, I believe for examining this with its versatility for incorporating artistic and scientific methodologies.

For neurologists like Semir Zeki, ambiguity "gives us some insights into how activity at different stations of the brain can result in a micro-consciousness for an attribute". He goes on to acknowledge that the neurological study of ambiguity may provide insights into the mechanisms that "artists have tapped to create the ambiguity that is commonly a hallmark of great works of art" [612]. In many ways, the arts have pioneered the exploration of this essential human trait of animacy perception, that all social behaviour is built upon.

Today, the venerable art form of puppetry finds new purpose in filling a theoretical vacuum surrounding the aesthetics of robotics. Largely a subject examined by engineers and social scientists, robotics fundamentally misunderstands aesthetics as only a matter of appearance. Aesthetics in robotics often leads to discussion of the idea of the uncanny valley and the aversion to it. The uncanny is treated often as a problem to engineer out of a design.

Puppetry, by comparison, understand the uncanny as a source of a strange pleasure, both frightening and at the same time compelling in its playfulness. It understands that fearfulness is overcome in the imaginative participation of the puppet performance, in the embrace of the spectacle and its artificiality. In this way, the puppet can invoke gasps of anxiety and moments later turn us to laughter, or even the sublime. Contemporary puppetry seeks more than to merely imitate life, but rather to find freer, livelier, and surprising sensations of intelligence behaviour. It is my strong belief that the field of robotics would benefit greatly from examining this ancient art form to better understand its own potential.

By comparison to puppetry, animation in an age of digital techniques, allows for the translation of simulated character motion sequences into physical motor control. Computable vectors create an easier interface for dialog between robotics engineers and animators, than the dynamics of theatrical arts. We have recently seen elements of the *12 Principles of Animation* employed in research projects [613] and commercially available social robots like Jibo [614]. Formal lessons from character animation have also encouraged robotics designers to appeal to our innate responses to childlike appearances.

Perhaps less immediately obvious to roboticists, is the knowledge latent in the work of more experimental abstract animation. While orthodox animation seeks to sustain the life of moving characters, the appearance of lively artefacts in experimental work is more often unstable, fleeting and strange. Artists, architects and designers working with robotics may find the work of experimental animation offer a richer palate of inspiration for non-figurative, rhythmic, and non-linear behaviour. Equally, I believe that cognitive research could benefit from drawing on experimental animation to discover stimuli that widen and deepening our understanding of what motion characteristics shape social perception.

In abstraction, the worlds of psychophysical, perceptual and cognitive science meet puppetry, animation, theatre and robotic arts. As Lamarre discusses in the context of aesthetic experience, abstraction opens up a space for our minds to participated creatively, faced with poverty of stimuli. In that space of what Sergei Eisenstein called "heartless geometrizing", a primitive and universal animist experience emerges. Within the avant-garde, animation and puppetry represented a potential to transcend limitations of reality, by rejecting realism and searching for new forms of expressive life.

Elaborate anthropomorphic mechanics were stripped back to explore primitive forms reflecting puppetry's pre-history in shamanic, and animist rituals. These primitive aesthetics, primordial in nature, represent a resistance to imposed rationality of modern aesthetics, and search into deeper visceral aspects of human experience. Animated art forms, whether spectated or actively interacted, shirk conceptualisation for immediate viscerality - the essential bargain between performer and audience being a willing embrace of a naïve vision, an act unadulterated by intellectual rationalisation.

Across the animated arts we find the common continuum between formal anthropomorphism and abstraction. In puppetry, on one hand we have illusionist and on the other, primitivist camps. The illusionists' intention is to produce a stabile continuous life, and the primitivists' who embrace fragmentation and instability, seek short episodes or vignettes. The animate abstract, non-figurative objects requires greater energy and commitment from the puppeteer and greater leaps of imagination in the audience. The result, puppeteers have argued, is more sophisticated and more intense. The audience's oscillation of perception of life exaggerated, the object itself becomes a self-reflective device for questions about the vitalist nature of the objects and the theatre of the possession.

The rejection of anthropomorphic realism in experimental puppetry and animation, connects itself to the early 20th century avant-garde's adoption of primitivistic iconography and rejection of rationalist modern aesthetics. The embrace of machine culture, the fears and excitement of automation, and possibilities of machines as performative agents, brought puppetry practice and scenography together to imagine a stage of animate performers and architecture in interaction. A living geometric spectacle that, at the time, was beyond the technology of the time, and the technical capabilities of the artists. As the cost of robotics, and ease of use improves, we may yet see the visions of Prampolini, Depero, and Moholy-Nagy realised.

5. Lively Artefacts

5.1 Introduction

Bringing robotics into a performing arts context opens up a freedom of experimentation not necessarily afforded by robotics labs. Theatres and galleries that exhibit performance work, create controlled spaces for a different type of lab environment, with public audiences and performers as the subjects. Performance spaces are also in essence, spaces of narrative exploration and speculation. The adoption of methodologies from human acting, and dance choreography challenge the kinetic affordances of these machines, and new tactics for behavioural design. Performing arts also offer analytical tools on human behaviour, that can be applied to robot behaviour, and indeed to human-robot interactions and robot-robot interaction, as they do to human-human interaction.

This chapter describes a series of experiments synthesising ideas drawn out of artificial life, perceptual psychology, animation, robotics and puppetry. A particular focus has been made on examining how puppetry can offer alternative approaches to robotics design, both mechanically and behaviourally. These works demonstrate the practical value of a deeper understanding of the perceptual stimuli that determine the qualities of animacy, and aesthetic approaches that harness these stimuli for aesthetic potency.

5.2 Experiments between Robotics and Puppetry

Most types of puppets in use today, fall into four broad categories: hand puppets, rod puppets, marionettes and shadow puppets [615]. The art of puppetry holds a wide assortment of techniques that, in order to understand how to animate inanimate objects, I have investigated through conversation and collaboration with puppeteers at the Central School of Speech and Drama, The Little Angel theatre and the London School of Puppetry - organising and participating in workshops and performances, and harnessing their expertise in the design of my installations.

An important distinction between puppetry and robotics is that puppeteers directly bring objects to life, by transferring their own animate motion (through a multitude of physical interfaces) into their manipulated objects. Even modern-day

animatronics work on similar systems, using hydraulic or cable systems to transfer smooth muscle driven motion [616]. While, all too often, robotic behaviour begins its development in digital simulation, puppeteers begin with appreciation of the latent embodied behaviour in their puppet's physical organisation. They hold a tacit understanding of the influence of physical forces gained from an often-obsessive focus on the subtlest of gestures. There is an aesthetic quality to well-manipulated puppets that I do not believe can be replicated by robotics, and this makes them fascinating in their own right. As Kliest points out, marionettes also have qualities of motion that are beyond the dexterity of the human body.

"My reply was that, no matter how cleverly he might present his paradoxes, he would never make me believe a mechanical puppet can be more graceful than a living human body. He countered this by saying that, where grace is concerned, it is impossible for man to come anywhere near a puppet. Only a god can equal inanimate matter in this respect." [617] *(Von Kleist, 1810)*

Marionettes

From an engineering perspective, the marionette is a wire- (or string-) driven multi- limbed, under-actuated mechanism, under the influence of gravity [618] that exhibits rich kinematic and dynamic behaviours. This rather reduces the sublime description of von Kleist gives, but it inspired me to reconcile these very different ways of looking at this extraordinary approach to puppetry. I began by spending time looking at the plethora of mechanisms and control techniques from Asian and Indonesian traditions, through to the rod and airplane techniques of European theatre.

Figure 71. A selection of European Marionette Control Systems.

In my early technical investigations, I attempted to bring together the traditions of marionette puppetry with robotic control, developing a cable driven rig to manipulate objects. A marionette-like system was appealing because it offered a means to separate the clunky, sometimes noisy and heavy, mechanical nature of robotics, from a performing object. The simplest of training marionettes I found were based on three-string systems.
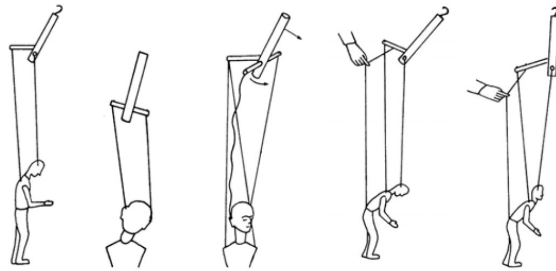

Figure 72. Examples of beginner training Marionettes

While there are many versions of the same principle, all of these enabled the controller to manipulate an object with considerable variety. Three strings, for example, attached to a head - one on the forehead and one on either ear - allow control of vertical lift and fall, pitch and yaw. Wishing to avoid figurative cues, a three-string manipulated object naturally suggested a triangle. Cut from a sheet of plywood and spray-painted black, a triangle, in homage to Heider and Simmel's *An Experimental Study of Apparent Behavior,* acted as an initial primitive puppet.

A small number of research projects had been conducted looking at robotic systems for imitating traditional marionette systems [619][620][621]. Three features that common to these were:

1. The marionettes and their control systems dealt with the animation of humanoid marionettes.

2. The primary actuation systems were digital servos (affectionately called hobby servos).

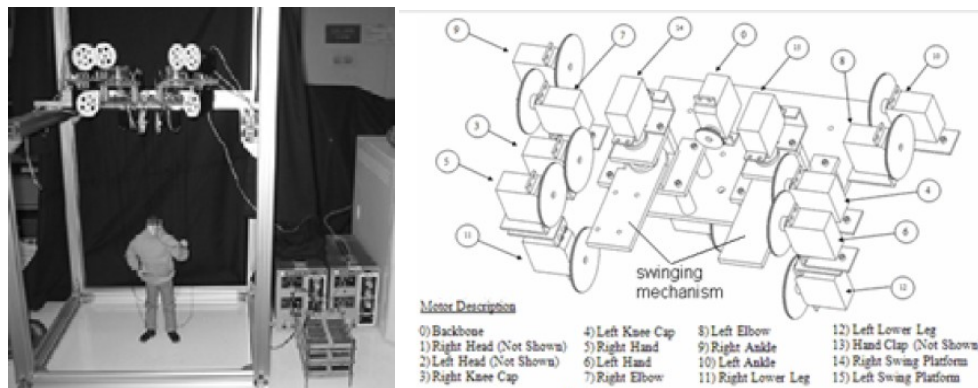3. The rigs developed were small, animating doll-sized marionettes.

Figure 73. Complex Servo rigging system to actuate a humanoid marionette doll. I-Ming Chen et al. (2005) School of Mechanical and Production Engineering, Nanyang Technological University.

These projects were fascinating for a number of reasons. However, they were not able to offer any directly applicable approaches to building my own rig system for the following reasons:

1. The animation of humanoid figures was extremely complex and unnecessary for the purposes of animating a primitive triangle.

2. Based universally on 'hobby servo' systems, none of the case studies are able to perform smoothing in acceleration and deceleration, with the level of resolution that I saw as essential, following my study of biomechanical systems and the behaviour of *Senster* in particular.

3. The size of the rigs and their marionettes did not offer human or architectural scale interactions to be considered. The servo technology was not directly scalable.

The existing literature was primarily useful in understanding some of the engineering challenges associated with harnessing the motion of suspended objects. Murphey and Egerstedt [622] describe marionettes as sophisticated and challenging mechanical systems, and therefore represent good test-beds for many current issues in robotics, such as systematic modelling of relatively high degree of freedom systems, as well as high-level motion planning and control. Even by simplifying down to a triangle there would still be highly non-linear constrained dynamics and degenerate Lagrangians, due to strings having nearly no mass [623]. Under-actuated mechanisms, under gravity-influence [624] exhibit rich kinematic and dynamic behaviours.

A few key choices were made in the rig's development. Industrial stepper motors (typically used for CNC Milling Systems) were used for their resolution and relative ease of control. The final rig could lift to an accuracy of 0.3mm. This was essential for me to test digital approaches to smoothing control. Four motors were used, one for each suspension string and a further one for orientation. The use of steppers meant that scalability was possible by changing motors without the need to develop completely new control systems. A steel extendable frame enabled triangles of varying sizes to be suspended. Made from waterjet cut 2mm steel it was robust enough for transportation. The entire rig was held by a single vertical bar, around which it rotated, allowing it complete multiple 360˚ turns, although not infinitely, due to power and data being delivered by coiled cables from the ceiling. On the rig, an Arduino MEGA microcontoller acted as the master computational system, to slave Motion Control MSD542 stepper controllers, mounted beside each high torque motor. Dedicated controllers allowed high-resolution micro- stepping.

Figure 74. Prototype three string marionette control rig

Robotic Manipulator with Software Smoothing

With a high degree of resolution in the stepper motors, it was possible to explore methods for simulating the digital/analogue predictor circuit used by Edward Ihnatowicz in his *Senster* robot. As discussed earlier, Ihnatowicz's use of a sophisticated arrangement of op-amps operated as a second-order, low-pass filter, which today is often simulated digitally in signal processing. With the support of Ihnatowicz' researcher Alex Zivanovic, a basic second-order, low-pass filter was developed in Processing. For a full description of the code see Zivanovic's paper *Elegant Motion: The Senster and Other Cybernetic Sculptures*[625].

In my implementation of this approach there was, however, a problem with using this simple algorithm in a robotic system – a stepper can only move one step per time unit. Zivanovic's algorithm curve does not account for this as it is not based on a particular drive technology. The unit of time is based on the minimal amount of time a stepper can make a move to its

next step, while keeping sufficient torque to lift its payload. The algorithm moving between two points, e.g. 0 – 100, must never move toward its target with a velocity of greater than one step, otherwise the stepper will not be able to keep up with the path generated by the algorithm. With some experimentation on the filter parameter, determined by the number of steps, an effective solution was found.
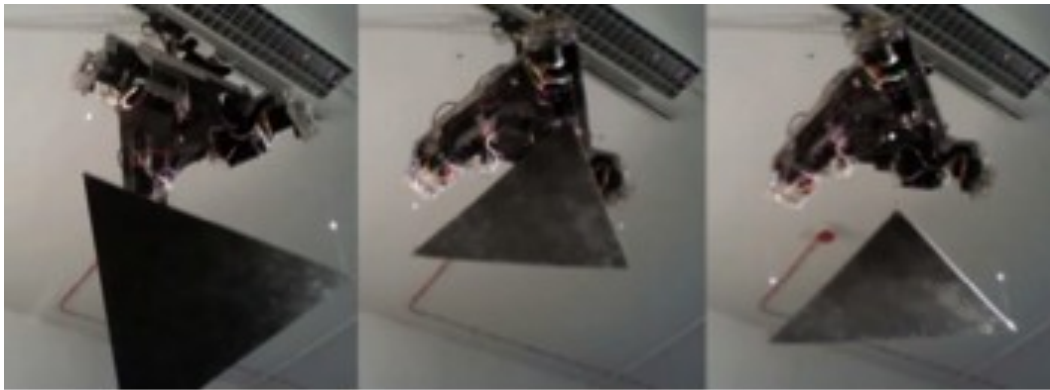

Figure 75. Suspension of triangle as a proto-marionette performer.

The primary conclusion from the testing of the first marionette-inspired robotic manipulator, was that the highly nonlinear dynamics of the suspended triangle would require feedback and sophisticated active dampening measures, to ever move close to the control human manipulators can achieve. Without measures, once any oscillation begins, it becomes very difficult to eliminate. Another key observation was that the use of a flat triangle was not suitable in a performance context as it would become almost invisible at particular angles of view. Future experiments would adopt a tetrahedron form instead.

Rod Puppets

The 'under-actuated' problems of driving marionettes have some similarities to those found in aerial robotics and legged locomotion. They require state of the art feedback control systems that made this approach less attractive to pursue.

Instead, I began to examine other forms of puppetry that could work with rigid-body kinematic models. Rod puppets directly transmit their manipulator's gestures into the puppet, without having to negotiate the complexities of string-suspended motion. Typically, a rod puppet is manipulated from below, or its surroundings, as we find in Japanese Bunraku theatre. There is also a lesser-known rod marionette (ancestor of the string marionette), that is typically made up of a main central supporting rod and then finer rods for manipulating a puppet's limbs.

Bunraku puppets interested me because of their larger than typical scale, measuring between 4 and 5 feet tall. They are manipulated by puppeteers in full view of an audience controlled by short rods. Principle puppets on stage are controlled by three puppeteers who perform with exquisite synchronisation.

Bunraku are also the type of puppet referred to by roboticist Masahiro Mori in his seminal paper on the uncanny valley, where Mori positions Bunraku rising out of the valley towards higher affinity and human likeness. As a matter of chance, while exploring approaches to three-rod puppetry, I came across a type of robotic manipulator, also made of three-rod like arms working in unison. The so-called 'delta robot' invented by Reymond Clavel in early 1980s at EPFL Switzerland, is a fast, light payload manipulator, which immediately made it an ideal approach for puppetry. When the patent for the delta robot design expired at the end of 2007, it opened up the opportunity for experimentation beyond its typical industrial applications.

Motive Colloquies, Centre Pompidou 2011

Commissioned by the Centre Pompidou, Paris, *Motive Colloquies* was a collaboration between the Bartlett School of Architecture and the Royal Central School of Speech and Drama, combining expertise in puppetry, performance, robotics and interaction design. The result is was responsive installation and performance held within the Pompidou's Pablo Picasso Gallery in May 2011.

Figure 76. Motive Colloquies, Centre Pompidou, Paris (2011)

Unlike *Performative Ecologies*, the work needed to be free standing and placed in a brightly lit room. Embracing the idea of 'full-view' manipulation that is found in Bunraku theatre, a custom robotic was designing to manipulate a primitive tetrahedral form, and made from folded aluminium sheet. Built from aluminium box and tube sections, an inverted 2m tall delta robot was developed, giving the appearance of three legs. The 'legs' met at an elevated end-effector, which became the platform from which to suspend a second, smaller and lighter, delta robot, whose end-effector held a folded aluminium sheet 'head'.

In Bunraku the puppeteer is often dressed in black, and distinctly different to the puppet. The robot manipulator and the tetrahedron head, however, were both aluminium so, rather than appearing as independent puppeteer and puppet, the two parts were read as one. The design was based on parallel robot principles. These are used extensively in the manufacturing industry, but not in a performance context before this work. The final strategy involved a novel kinetic structure combining two delta robot mechanisms. The structure of the manipulator read like a three-legged spider's 'body', and the single moving tetrahedron, with its purposeful searching behaviours, was read as a 'head'.

Three Kinect depth sensors were hidden beneath the edges of the triangular plinth, on which the robot continually scanned the surrounding gallery for the movement of visitors. When people came into range they triggered a reactive 'mirroring' behaviour. This primitive reactive algorithm is in contrast to *Performative Ecologies'* more complex, evolving behaviour. The only complexity of behaviour in *Motive Colloquies* was a direct reflection of the complexity of the environment it was sensing. If people crept towards it, the robot would turn and creep towards them. As people became more animated, the robot would become more animated. Due to the difference in the kinematics of its motion, compared to the human bodily motion it was copying, the simplicity of the mirroring behaviour was not immediately perceptible. As the robot was approachable from any side, and would always turn towards people who came closest, the dynamics of people changing proximity as they moved around it created a sufficiently rich indeterminate behaviour to maintain the sense of the robot's autonomy when, in fact, its behaviours were extremely primitive and entirely driven by human motion.

5.3 Fearful Symmetry, Tate Modern 2012

Ambition

Following the success of the exhibition at the Centre Pompidou, I was invited to participate in the Tate Modern's inaugural arts programme, launching its new gallery space, Tate Tanks. This was the first dedicated 'live art' space in a UK Gallery, and opened as part of the nationwide cultural events that marked London's Olympics, over the summer of 2012. *Fearful Symmetry* was the first interactive installation to be exhibited in a programme that largely consisted of performances, including the work of Tania Bruguera and Teresa De Keersmaeker.

The cavernous concrete chamber of the south tank, 32m in diameter, 7m tall, adjacent to the Tate Modern's Turbine Hall, had previously lain dormant for decades cloaked in darkness. In discussion with curator Mark Miller, the idea of a 'living luminaire' was agreed upon. The luminaire moved within the darkened gallery space, it would reveal its dramatic location, and interact with the visiting public.
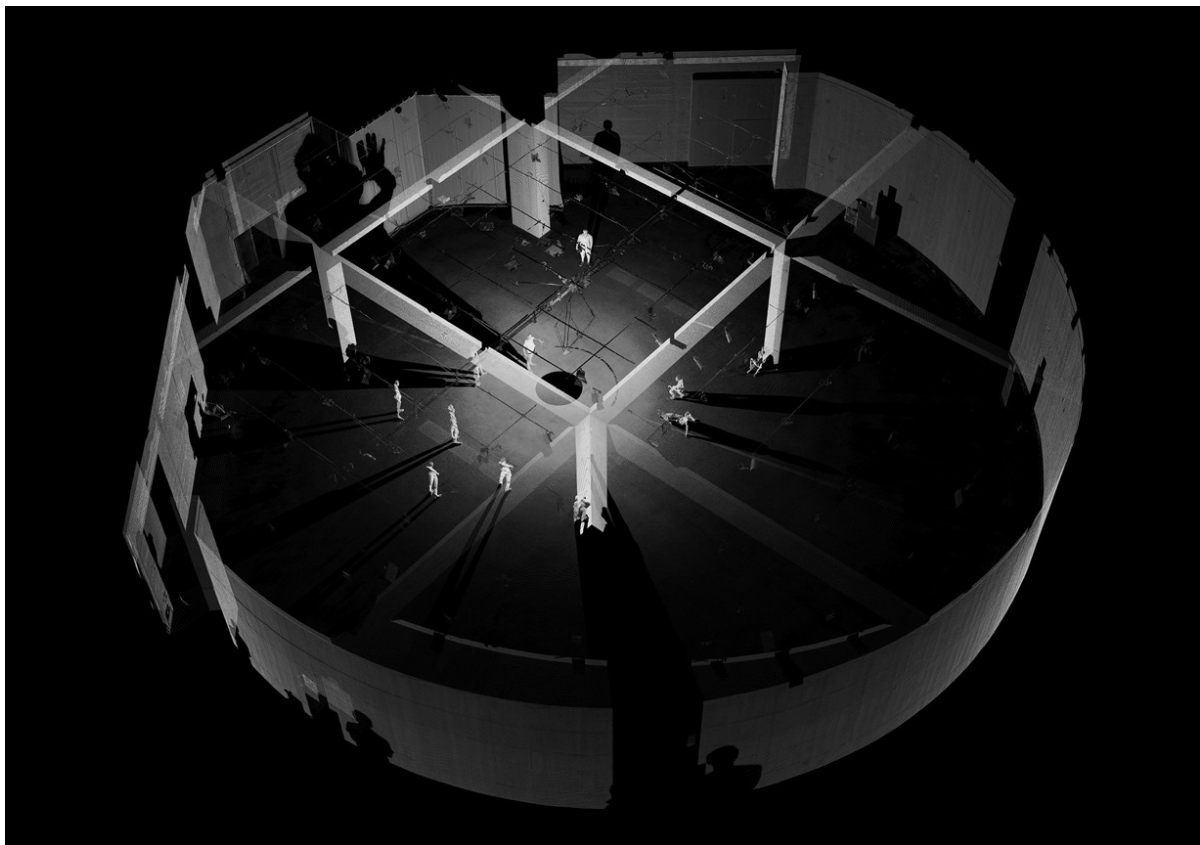
Figure 77. Lidar Scan by ScanLab Projects of The Tanks at Tate Modern (2012). Scan gives a sense of scale of the space. At the center is Fearful Symmetry and the team involved in the project standing around it.

Early in the design process, I was looking for some hints as to the character of the machine I was to build. William Blake's famous poem *The Tyger*, touched the mood of the experience I wanted to create, and also touched on ideas of creating life. The short poem asks questions about the creation of life that, like a work of art, must in some ways reflect its creator. What would the existence of a terrifying Tyger tell us about the nature of its creator, God? What does something equally beautiful and horrific tell us about our creator? This is its fearful symmetry.

The poem also talks about the 'forging' of the life, with an anvil and furnace - a dark alchemic craftsmanship, with a sense of intense physical production that resonated with my personal experiences of making the work, and my aims for the mood I wanted to create. The opening lines of the poem describe the vision of the Tyger "burning bright" in a dark forest, creating an immediate visceral image.

Thinking about the moment people would enter into the gallery for the first time, I wanted to create this sensation for the public, as they encountered the intimidating dark chamber and the strange 'life form' that inhabited it.
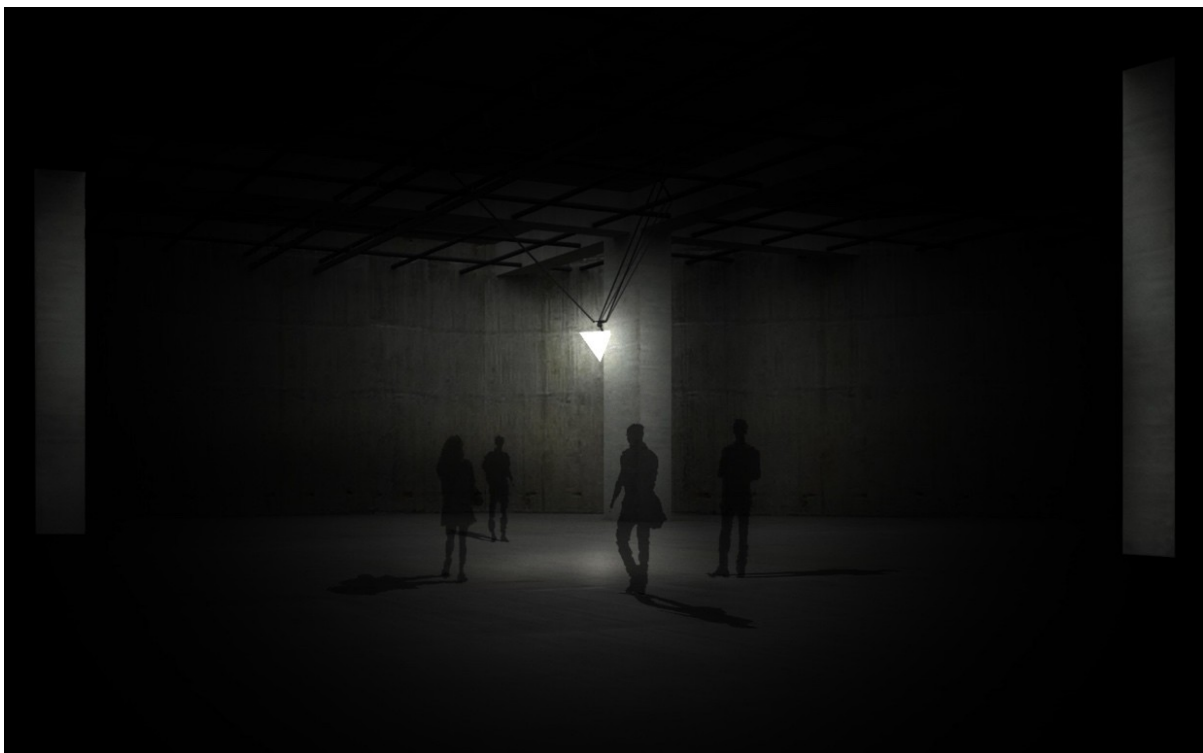
Figure 78. Render of proposal for installation used to agree intention for the exhibition

As in earlier work, I chose to use a tetrahedron form to avoid figuratively inferring life. The geometry was wrapped in a cold white electroluminescent sheet material to illuminate itself with a perfectly flat white light. Hidden up above in the darkness, like a long rod marionette puppeteer, a 5m tall autonomous delta robot, custom built to manipulate the motion of the luminaire beneath it, moved back and forth through the space on a 21m motorised rail. An array of Kinect sensors mounted on the travelling robot built a real-time 3D point cloud of its local environment, detecting the public and reading their individual movements using gesture recognition algorithms and responding with a variety of behaviours drawn out of the research discussed in this thesis.

Encouraging the public to suspend their disbelief and play with the living luminaire, the more people enthusiastically gestured to the work, the more enthusiastic its responses would be. If visitors were stationary it would hover over them, slowly turning mechanically and abstractly, almost mocking their inanimateness. With the subtlest change from mechanical to smooth fluid motion, the work transformed from a lifeless platonic solid, to a living performer. While at first intimidating to the Tanks visitors', many of the public became increasingly comfortable and confident in performing with their luminous companion, as their exchanges developed.

Figure 79. Final tests in The Tanks shortly before turning off lights and opening to public. The fine carbon fibre body of the delta robot rig visible holding the illuminated tetrahedron.

A detailed technological breakdown of the installation is provided in the introductory chapter. Here I will focus on interrogating the works aesthetics in relation to the multiple disciplinary perspectives examined in the previous chapters. I will at times shift forwards and backwards between system descriptions, and how the installation was perceived, between what Valentino Braitenberg called the "law of uphill analysis and downhill invention".

Motion Cues

Fearful Symmetry's use of a moving geometric figure, through an otherwise featureless environment (the darkness cloaking much of the context of the gallery), shares the characteristic, uniform environment typically found in perceptual research experiments. Tremoulet and Feldman's *Perception of Animacy From the Motion of a Single Object* [626], discussed in the chapter three, is the most similar work I have referenced, and it can, in part, be seen spatially manifested in the installation. The circular arrangement of their experimental 2D environment is, in some senses, reflected in the circular plan of the Tanks.

Fearful Symmetry hovered beneath the dark ceiling of the Tanks, rising up and descending down, remaining just out of reach of the visitors beneath. When it ascended, these moments of elevation, of defying gravity, violating "Newtonian laws of motion", as Stewart might describe it [627]. Spontaneous accelerated and decelerated motion implied internal energy reserves that encouraged an immediate sense of the tetrahedron's autonomy and vitality

Figure 80. Mirroring behaviour: Fearful Symmetry hovers almost motionless
above child stood motionless beneath it.

Sometimes the robot would appear motionless or very slow moving. At other times it would traverse the gallery quickly with dramatic changes of speed and direction. These energetic moments of behaviour were the most perceptibly animate, though they benefitted from moments of stillness. When there were changes in speed and direction occurring simultaneously, they appeared controlled, and purposeful.

The mounting of a pan and tilt servomotor mechanism, on the end effector of the delta robot, gave the tetrahedron the ability to orientate itself towards its direction of travel, as it moved around the gallery. This gave the impression of it 'looking where it was going'. Even if there was no visible target in the darkened environment to explain its movement, the correlation between orientation and motion direction created strong impressions of purpose in the tetrahedron's movement. These observations support Tremoulet and Feldman's findings that orientation plays an essential role, alongside the speed of motion and degrees of directional change, in perceptual judgments of animacy.

There are, however, contradictory instances where lack of motion, or directional motion misaligned with orientation, to create equally compelling impressions of animacy, suggesting other stimuli could be as important in shaping the observers' experiences. One particularly strong factor was the quality of movement that occurred when the tetrahedron would turn away from the direction of motion and towards a member of the public, seeming to hold its gaze upon them. Again, a strong impression of purposeful behaviour is at the centre of this effect, but it is amplified by the sensation that *Fearful Symmetry* is responsive to human presence. This creates a whole set of psychological effects beyond the scope of visual social perception studied, that I will address later. The closest phenomenal effect that we can draw from perceptual science could arguably be related the Wolfpack Effect [628], though, in this case, there is only a single robotic agent. It could be argued that the Wolfpack Effect, was perceived in the attention behaviour of the many visitors to the gallery, observing individuals or small groups interacting with the machine.

Figure 81. Wolfpack behaviour: Audience surrounding the single illuminated agent

Efforts were made to make the gallery as dark as possible. These including the use of a 'light trap' tunnel at the entrance to the Tanks. Though this darkness helped to cloak the spatial context of the luminous figure, the light it emitted locally began to reveal the features of the Tank, as intended. As discussed in the chapter three, animacy attributions can be elevated or suppressed by context [629]. The gallery environment amounted to a curved perimeter wall with four central columns - a relatively simple space. Due to the mechanical limitations of the rail and delta robot, *Fearful Symmetry'*s range was limited to between the columns. The motorised rail was placed centrally and perpendicular to the entrance to give the strongest immediate impression of movement to visitors entering into the space, and hide any impression that the robot had a limited range of travel.

Tremoulet and Feldman had observed that acceleration has more influence in readings of animacy than contextual cues, suggesting fundamental motion percept's have considerable influence on overall perceptions of animacy. They qualify this conclusion by recognising that their environments may have not had much effect due to their limited features, but in the context of *Fearful Symmetry* this is relevant. In the event of limited stimuli, to make judgements on the status of objects in our environment, we rely on reflexive responses to these primary cues, and they are most powerful in these conditions.

By darkening the Tanks, I had attempted to focus perception of the work on the quality of the motion, however, the role of visitors willing to participate in the performative interactions of the piece were essential to the work, and created a more complex environmental context than we find studied in the controlled environments of psychophysical and perceptual sciences.

A couple of other clear differences can be drawn between the installation of *Fearful Symmetry* and the environments that characterise visual motion perception experiments. From Fritz Heider and Marianne Simmel's 1944 landmark study [630] with simple geometric stop frame animations, to today's parametric software animations, screen based 2D environments remain common experimental spaces, regardless of developments in 3D graphics that arguably reflect more the context in which the human eye, and our social perceptions, have evolved. By contrast, installation work is essentially spatial and agency occurs within a shared space.

While contemporary perceptual research examines short animations, with modifications to discrete events, physical installation experiences are continuous for viewers. The events that occur before, set the context, and upon entering the gallery, an observer's understanding of the animacy of the work is constructed through a succession of observed movements, leading more complex interpretations of animate behaviour to narratively unfold.

Agency

Practical aspects of the exhibition shaped the strategy for developing *Fearful Symmetry*'s behaviour. The Tate Modern had a busy rolling schedule of artworks on display within the Tanks over the Cultural Olympiad that accompanied the 2012 London Olympic Games. The entire 21m motorised rail, Delta Robot, sensing system, sound and control systems had to be installed within 24 hours and open to the public the following morning. There would be no time to develop code in situ, so it would have to be crafted offsite.

Finding alternative spaces that offered the volume of hanging space proved challenging. Behaviours were prototyped first in animations produced in Autodesk 3ds Max, and then simulated in the opensource Java framework, Processing. A sufficiently lengthy warehouse in Tottenham allowed for the install of the 21m long rail, at 3m off the ground. Though this was 4m short of the rail's planned height in the Tanks, it was tall enough to hang the delta robot and the tetrahedron head just above the ground, however, not to walk underneath the work, or allow for interactions to be easily prototyped. Therefore, I was able to test all the hardware, but not to test the entire system until installation at the Tate itself.

My strategy for dealing with this was to stick to simple rule-based logics that generated three main behavioural typologies: pursuit, evasion and play. These were three of the five behaviours that Blythe, Miller and Todd [631] examined and developed into distinct parametric features, and that I discussed in chapter three of this thesis. These behaviours were easily simulated in Processing code sketches, but making sure that this translated into sensing of a physical environment and motor control was only completed onsite, with minutes to go before the opening.

The short nature of the two-day exhibition precluded exploring the aesthetic possibilities of adaptive algorithms as there would be too little run time to see behaviour develop. It also would have added an extra layer of complexity to code when I would have limited time on site to make adjustments. Complexity in behaviour would be drawn from the complexity of the environment, namely the visitors that populated the sensing space within the gallery, where the robotic rig travelled with an array of Kinect sensors. This strategy of using an array of Kinects to 'feed' life into the installation was similar in some respects to *Motive Colloquies*, but the types of responsive behaviour were entirely different.

Figure 82. Search behaviour: Fearful Symmetry travels though gallery till it locates visitors and then closes in.

Fearful Symmetry's 21m motorised rail offered the possibility to really explore pursuit and evasion behaviours. It would have been difficult to elicit such behavioural perceptions in earlier work, as they were fixed to the ground or ceiling. The possibilities for playful actions were also far greater with this extended range of interactions. The range of this mobility was unlike typical kinetic installations, and amplified the sense of the robot's autonomous freedom. This correlated with the idea that when agents move around and navigate the features of their environments, this acts as a primary perceptual cue for determining animacy.

The aim of the behavioural design was to make explicit changes between three primary modes, and trigger fast heuristic perceptions that, though abstract, are coherent. The architecture of behavioural control was a state machine. Putting to one side the states used for start-up, debugging and manual control, there were in total four states. These were Search, Play, Chase (pursuit) and Escape (evasion).

Figure 83. Behaviour Chasing: Fearful Symmetry circles in on visitors' movements

Search

Condition: If no human sensed in over ~30 seconds the robot switches to Search mode.

Behaviour: Chooses a random location along the motorised rail and travel to it. On arrival search for human presence making ~4 random movements with Delta Robot (not Rail), orientating head towards direction of travel.

Play

Condition: If in Search, Chase or Escape mode and person detected.

Behaviour: Mirror back the behaviours of people in sensing area. If they move enthusiastically, the tetrahedron responds back energetically. If people stand still below the work, the piece hovers above them motionless.

Chase

Condition: If in Play mode and person moves off the edge of the sensing area

Escape

Condition: If in Play mode and >2 people sensed

Behaviour: Chooses a random location along the motorised rail and travel to it.

The use of a random speed function in most moves – sometimes a bit faster, sometimes a bit slower – and a random function on search and escape targets, added degrees of indeterminacy that contibuted significantly to a sense of animacy rather than repetitive robotic control. The constantly changing environment also feeds variety into the system, so that the performance remains continually surprising, yet the simple rules also add a degree of predictability, and it is this careful balance between chaos and order that gives the impression of intelligence.

Such a strategy may eventually prove to become boring but only after long periods of observing exchanges with the public. While I would agree with roboticist Christoph Bartneck's statement that "Given sufficient time the user will give up his/her hypothesized patterns of the robot's intelligent behavior and become bored with its limited random vocabulary of behaviors" [632,] such a strategy works very well in gallery contexts. It would have limited value, however, in longer-term contexts, such as social robotic interaction. It may also be limited in robotic work installed in wider built environment, where interactions may occur over weeks, months or even years. However, the counter argument may be that carefully crafted rules, in concert with human behaviour can create enough variety to continue to generate novel interactions.

As I have discussed in chapter three, the gaming industry, particularly in its early years, was arguably defined by clever use of minimal computing power to create compelling but 'Shallow AI' [633]. Multi-dimensional sets of behaviours using a combination of state changes in agents led to far greater variety of game play.

Though I did not explore adaptive behavioural approaches in this installation, there are clearly some exciting possibilities to extend this work to learn and change over time that I may explore in the future.

Figure 84. Behaviour Play: the energetic movement of the children is mirrored back in the movement of the tetrahedron.

A feature of the behavioural system I have skipped over was a manual control mode that would allow me to treat the installation as a mechanical *Turk*, what is sometimes called Wizard-of-Oz (WoZ) technique [634]. This was used on a couple of occasions, where the lights were put on and I was able to demonstrate the work piece by piece to the press, and at the opening private view. For health and safety reasons, my team always had a person in front of a keyboard and mouse controller with CCTV footage of the gallery. Though this was only a precautionary measure, on more than one occasion, I found team members in our technical room beside the gallery, manipulating the robot to prove play with the public.

In our technical room we also had our sound team made up of Sam Conran and my brother Emmett Glynn, who live-mixed and manipulated audio signals from contact microphones on the robot motors, to create an atmosphere and amplify the motion of the robot. The sound system could have been automated given sufficient time onsite to develop software, but for practical reasons we kept this element of the performance safely in human hands.

Ambiguity

The cold and perfectly flat white light that wrapped *Fearful Symmetry*'s tetrahedron had an unexpected visual effect when viewed from across the gallery. Depth on its surfaces was imperceptible because of the consistent luminosity of the electroluminescent sheet material, and at only 0.3mm thickness, the triangular faces of the geometry butted up tightly preventing gaps at its edges. As it rotated it became difficult to determine its form, as edges and depth disappeared. The ambiguous form, was at one moment like a flat triangle, the next like a kite, trapezium or other varieties of quadrilaterals. As we find in illusory optical arts, where unstable visual phenomena are leveraged to draw participation, the ambiguity of the form brought people closer, encouraging participation. Only by getting close would visitors start to make out the faintest of lines at its edges which helped with perceiving its orientation.
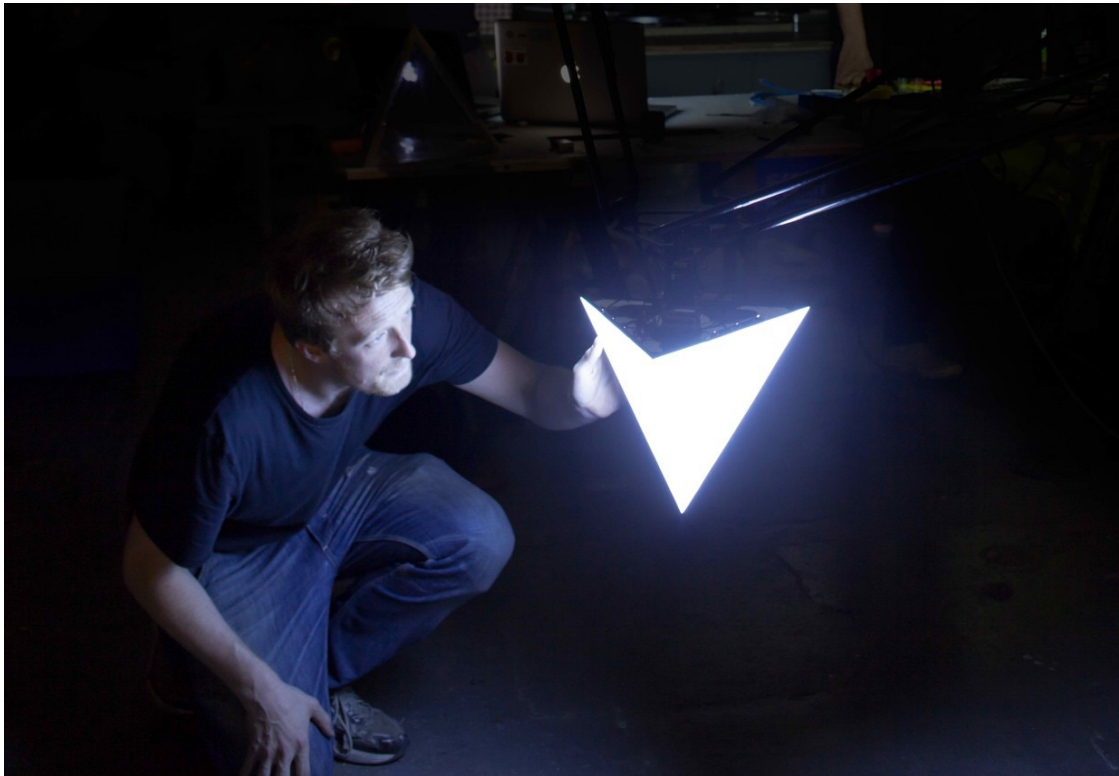
Figure 85. Electroluminescent sheet faces of the tetrahedron

Considered in the context of animation aesthetics, and drawing upon Furniss[635] and Wells' [636] proposed continuums of animation, *Fearful Symmetry* sits firmly towards the abstract, rather than mimetic/orthodox bounds of animation. In visual terms it resists figurative interpretation in the same way as animators Victor Eggling's *Diagonal Symphony* (1925), or Oskar Fischinger's *Composition in Blue* (1935), have done. The glowing tetrahedron, in its "heartless geometrizing", to use Eisenstein's earlier cited phrase, is in opposition to any orthodox objectivity of animation and "rebirth of universal animism" [637].

The tetrahedron's luminous geometry is not without semiotic hints of animist, alchemical and esoteric vocabularies. The title of the work, borrowing from freemason William Blake, also suggests parallel connotations. This semblance of the archaic and vitalist is purposeful, yet as Tarkovsky suggests [638], left ambiguous enough to encourage the audience to actively engage and would, I believe, answer Moritz's demands that abstract animation "have an intriguing spirit and integrity of its own... suggest[ing] more meanings, various, almost contradictory depths and speculations beyond the surface value" [639].

Roman Paska's distinction of illusory and primitive, or Steve Tillis' distinction of imitative and conceptual puppets, share similarities with the continuums of animation theory, drawing the distinction between figurative imitation and abstract aesthetic practices. As I discuss in the

previous chapter, the imitative, or illusionist intention is to produce stabile continuous scene, while the primitivist, in opposition, embraces a fragmentation and instability. *Fearful Symmetry*'s aesthetics follow the later approach, distancing itself from the baggage of the traditions of figurative puppetry and humanoid automaton. Similarly, we could also draw on Kerstin Dautenhahn's continuum for social robotics [640] and position *Fearful Symmetry* firmly at the socially evocative end of that spectrum, as it does not attempt to create the illusion of human-like behaviour, such as speaking or being voice responsive. Nor does it attempt to replicate human gestures. The strategy of the work, by the nature of its primitive geometry, probes the primitive gestural exchanges that underpin all social behaviour.

As the most skilled puppeteers have acknowledged about work at this primitive end of the continuum, 'life' is difficult to sustain for long periods. Its fleeting, fluctuating nature intensifies the drama of what Pepicello called 'oscillation', Steve Tillis called 'double-vision', and Jurkowski described as the 'opalization effect' [641]. The primitive nature of *Fearful Symmetry*'s appearance requires intense acts to animate, as the robot must first appear alive with motion – its first transformation – and then take a further step to have character through the enacting of the rules of its behaviour – its second transformation. This demands more of the audience as well, which in contemporary theatre is considered an advantage as the transformation has to be more sophisticated and more intense. The tetrahedron becomes a self-reflective device about the nature of animated objects and the theatre of the possession.

The essential bargain between *Fearful Symmetry* and the audience relies our willing embrace of a naïve vision. Children at the Tate quickly and easily threw themselves into expressive exchanges with the floating tetrahedron. Adults were often more cautious but would gradually become more playful. The robotic puppet offered a way for audiences to access their childish side - their playfulness and innocence. At the same time, the dark space, the natural home of the uncanny, would have triggered naïve fears of the dark. This contrast is common to puppetry creating an aesthetics of ambiguous emotion, where fear and a playful wonder exist simultaneously.

Staging

Approaching the gallery, visitors arriving at the Tate Modern in daylight (the exhibition taking place at midsummer) would walkin through a long dark corridor built to accommodate people's eyes adjusting to low light, much like entering a theatre. As their vision adapted, they could hear the strange filtered sounds of the machine amplified within the chamber, as their first sense of what was to come. Finally, and often with some trepidation, they entered into the Tanks, where their first sight was the luminaire (anywhere between 5 and 25m away

from them) moving above the heads of other visitors. This confrontation demanded the viewer come to terms with the intimidating darkness, the resonating chamber and the strange glow of the electroluminescent lighting - flat, featureless and uniform in appearance upon the tetrahedral geometry.

In its staging, my ambition was to create an immediate visceral effect and, I hoped that, before any interaction took place, the very coldness and hostility of the initial encounter would create a contrast to which the animation and perceivable personality of the performing machine could then bring a warmth and playfulness. As the only light source in the gallery, the position of tetrahedron and the light radiating off it became the focal point of the space, wherever it was positioned. Visitors who found themselves immediately under the light were most brightly illuminated. This in effect created a stage for a human-robotic performance, while other visitor hung back in the darkness as an audience surrounding the dance.

There was a tangible sense of presence from *Fearful Symmetry* that went beyond its proximity, physicality or luminosity. The installation commanded presence, much like an actor on stage - the intensity and purpose of its motion, giving the impression of life and emotional character.
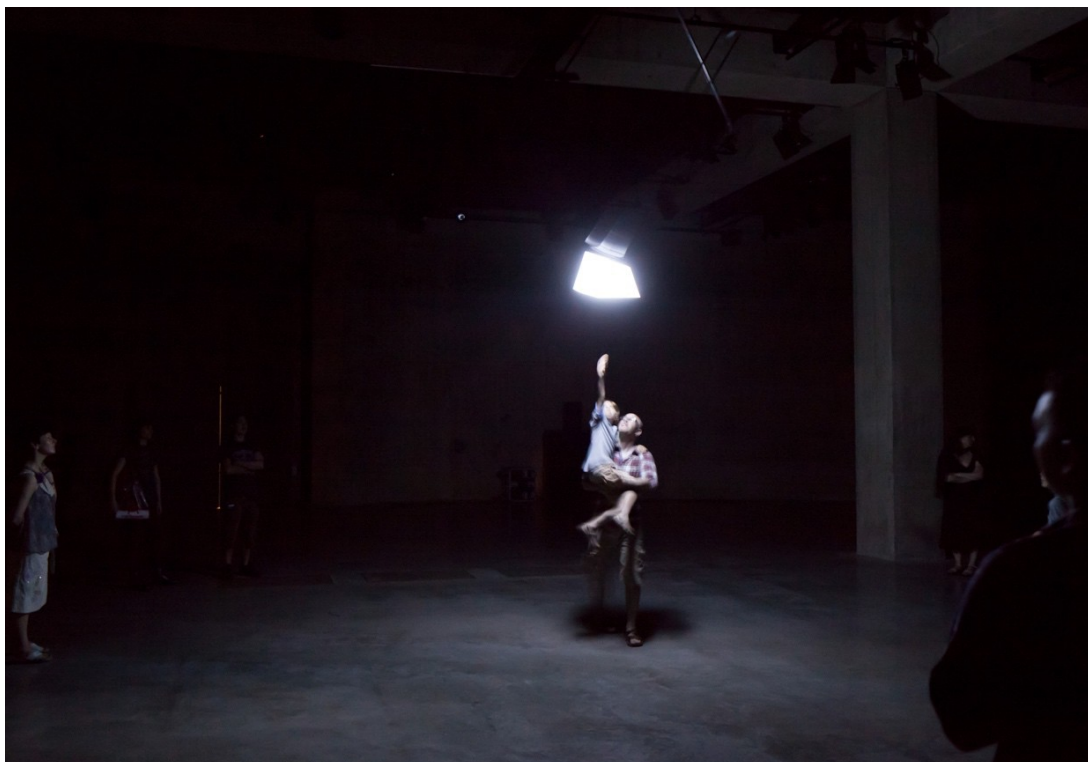
Figure 86. Participants perform centre stage in interaction with Fearful Symmetry, while other visitors spectate hidden in darkness

As an abstract entity and, simultaneously, a performative installation, the work resonates with some of the theatrical ambitions of avant-garde pieces, such as Enrico Prampolini's *Magnetic Theatre*, Moholy-Nagy's *Die Mechanische Exzentrik* and Oscar Schlemmer's *Living Geometry*. The artists of the Futurist and Bauhaus movements struggled to achieve even primitive mechanical performers – turning instead to geometric costumes, such as in Schlemmer's *Triadic Ballet* (1922). Today, robotic systems seem to offer the possibility of realising these visions - to achieve an aesthetic of what Prampolini called "absolute synthesis", and Moholy- Nagy called a "theatre of totality". The theatre of lively machines foregrounds absolute immersion in light, motion, sound and form, resisting dramatic traditions of narrative plot, and choosing instead the radical aesthetics of abstract performance and primitive universal experience.

Fearful Symmetry, like much abstract animation, is not intended to be viewed 'from beginning to end'. The performance is already in motion when the public enter, and continues when they leave. Duration of stay was also undefined and in some cases people left quickly, intimidated by the darkness. In others people engaged only for a few minutes, while some sat or lay on the ground, occupying the chamber for much longer durations, congregating, taking in the installation, comparing experiences, or watching others' interaction. Regrettably, no record of audience duration was taken. I believe the attraction of the work, for those who chose to stayed for longer periods of time, could be explained by the meditative qualities of the space, compounded by the vivid, hypnotic light, and resonant frequencies of the live audio synthesis performed into the chamber. Here, I think the work touches upon ideas that Maureen Furniss discusses, related to Mandalas.

5.4 Conclusion

My purpose at this point, in elucidating the experiential stimuli of the installation, is to draw out the fundamental difficulty in making comparisons between the highly reductive environments of perceptual psychology experiments, and the complex conditions found in the installations I have produced. Such a direct comparison between a simple screen-based environment and a complex built environment has its limits, but in the field of perceptual science, I have found a very useful means to unravel the complexity of encounters within my work, and better understand how primitive cues in motion begin to shape our experience.

How much a perceptual scientist could learn reciprocally from observing human response to my work is untested, however, I believe it seems unlikely. Discussing the experimental

method of field of visual motion perception research, Graham cautioned that, "we must take care that parameters are not confounded, a danger that arises only too readily from the fact that velocity itself involves the variables of distance and time. In any given experiment the variables of time, distance, interval between stimuli, and cycle of repetition of stimuli must be clearly analysed before we can be confident that unequivocal conclusions may be drawn"[642] .

Research in visual motion perception has, in the context of modern computing, benefitted from the use of parametrically generated animations allowing for precise modification of stimuli and measurement of response. Brain imaging has also facilitated an added layer of reading. An interesting, currently unexplored, potential benefit might be the quantifiable behaviour parameters, if they can offer useful transferable data, to be fed into the behaviour of physical objects.

Returning to Tremoulet and Feldman's single moving object, we can see that impressions of animacy can occur by virtue of motion alone. *Fearful Symmetry* neither supports or casts doubt on this research. What *Fearful Symmetry* does highlight, however, is that perceptions can be very different when spatial, and causal inferences can be made. This suggests that the use of parametric data, derived from perceptual research to drive lifelike behaviour, is limited in its application to complex environments. Conclusions on approaches to designing Lively Artefacts discussed in chapter two, and in chapter five, are brought together in the following final chapter.

6. Conclusions

6.1 Introductory Restatement

The makers of animate machines, or what I have called Lively Artefacts, have long had a difficult a relationship with academia. Take, for example, David Brewster's 1832 *Letters on Natural Magic,* where he describes the performing automata of the period, "Ingenious and beautiful as all these pieces of mechanism are, and surprising as their effects appear even to scientific spectators, the principal object of their inventions was to astonish and amuse the public" [643]. Brewster isn't alone in looking rather disparagingly on the frivolity of their application. Henry Hodge's, *Technology in the Ancient World [644]* also reflects with some bewilderment at the early automaton makers Ctesibius and Heron. Despite the intelligence, skill, and sheer brilliance that these men displayed in their inventions, many historians have regarded the great Alexandrians as pas serieux" [645]. In Grey Walter's lifetime his tortoises, built with clear theoretical motivation, were often "dismissed by professional scientists as mere robotic 'toys'" [646]. What is perhaps too often missed is how the motivation to imitate life or particular features of living behaviour has inspired many of the innovations that have shaped the modern world. Vaucanson is cited most often for his *Digesting Duck*, not his contributions to the loom, the precursor the modern computer. De Kempelen, famous for the performance of his mechanical *Turk*, also invented printing methods to make books for the blind [647]. The list is long, and a full account of the innovations that have emerged from the human impulse to imitate life could fill volumes. It seems the allure of machinic life is ancient and irresistible. The issue of seriousness might, in part, be in the perceived naivety of the subject that makes some serious academics across arts and sciences nervous. Editor of Animation Journal, Suzanne Buchan argues that the naive delight of animation is in fact its psychological strength rather than a regressive feature of the art, and needs scholarly study [648]. In theatre, puppetry was historically a somewhat diminutive or childish art form, but in the 20th century it found its own unique aesthetics and theoretical discourse in the avant-garde, and in the 21st century, as I have discovered in the process of this thesis, will find new purpose in the emerging age of robotic agency.

"At every stage of technique...the ability of the artificer to produce a working simulacrum of a living organism has always intrigued people." 649

(Wiener, 1948)

In the 20th century, the study of feedback control mechanisms in the field of cybernetics led to a paradigmatic shift in how we systematically study biological behaviour, from single cell organisms to social populations, and with the same systematic approaches, the study and building of machines with life-like behaviour. With their disregard for traditional disciplinary boundaries, like the automaton makers before them, cyberneticians also had a difficult relationship with the siloed traditions of academia, inevitably ending in the bifurcation of the field into diverse new areas of study. The progeny includes computer science, robotics, human- computer and human-robotic interaction, machine learning and artificial intelligence. In biosciences, bionics, systems biology and ecology. In management, the study of organisation, and game theory. In mathematics, the study of complexity and non-linear dynamics and, in psychology, the study of neuroscience and cognitive behavioural psychology.

I developed the critical position of this thesis by discussing the work of three pioneering cyberneticians, all of whom who reached across disciplinary boundaries, building machines that imitated animate behaviour driven by adaptive stimulus-response mechanisms. Ross Ashby's *Homeostat*, William Grey Walter's tortoises and Gordon Pask's *Musicolour,* each illustrate how experimental machines shaped a theoretical framework for cognitive behaviour, grounded in a continuous and adaptive, performative exchange with the physical world. Their embodied practices lead to original insights into the self-organising systems of life and mind, that provided the foundations for theories of autopoiesis, and contemporary theories of *embodied, embedded, enactive*, and *extended cognition*. Their pioneering work, embodied in lively machines set in motion discourses that answered the problem of mind-body dualism, and to exorcise what philosopher Gilbert Ryle called "the ghost in the machine" [650].

However, the rise of digital computing in the 20th century precipitated a resurgent Classical Cognitivism seen, for example, in the symbol processing of Herbert A. Simon, or representationalism of Jerry Fodor, and reductionist tendencies of Computation Theories of Mind (CTM). The pervasive culture of computing, reinforced a reductive view of cognition as a rational processing of logical and discrete representations of an outside world, as opposed to an embodied, complex and continuous exchange situated and bound to a physical world. This Computational Cartesianism has increasingly and convincingly been argued to have curtailed developments in artificial intelligence and robotics. As Rolf Pfeifer and Fumiya Iida argue, "the classical approach has not contributed significantly to our understanding of, for example, perception, locomotion, manipulation, everyday speech and conversation, social

interaction in general, common sense, emotion, and so on" [651].

In recent decades neo-cybernetic thinking has found renewed force, supported by progress in connectionist computing strategies and behavioural and morphological robotics. I have pointed to Research at UC Berkeley [652], conducted in the last couple of years, binding visual perception and motor skill training together with deep neural networks. The results, I believe, are compelling evidence that bottom- up strategies first conceptualised in cybernetics, may be to key to overcoming the limitations of classical robot control. It is too early to tell whether connectionist strategies will bring about a wholesale paradigmatic change on approaches to machine intelligence. If they do – and these neo-cybernetic approaches appear promising – then I believe the embodied performance of these machines will play a crucial role in changing popular conceptions of the nature of intelligence, and finally allow Descartes' ghost to rest in peace.

In the arts, where the continuity between our physical and psychological experience of our world is arguably better appreciated, the aesthetics of Lively Artefacts is increasingly appearing in robotic applications in theatre, galleries, public spaces and domestic contexts, from the scale of prosthetics to architectural constructs. In robotic arts, where work focuses primarily on expressive forms of intelligent behaviour, bottom-up, embodied approaches are widespread representing a renewed cybernetic attitude in contemporary practice and discourse. "The art is not in the machine, the machine is the art", states Christian Kroos, Co-editor of the recently published compendium *Robots and Art: Exploring an Unlikely Symbiosis* [653]. Meanwhile, in the engineering departments of academic institutions, Cartesian traditions remain dominant. In Human–Robot Interaction (HRI) research, Computational Theories of Mind (CTM) are commonly employed as explanatory principles for analysing experience, though they remain irreconcilable with contemporary cognitive science. CTM's narrow rationalising account of human encounters with robotic agency fail to account for the visceral embodied and aesthetic effects machines can inspire. Aesthetic experience "is not a theoretical postulation. It is not an equation or an algorithm, it is tangible, embodied, experiential and performative" [654]. It is in the careful control of perceptual qualities, in the production of art, that artefacts can inspire instant, and visceral sensorial experience.

However, in robotics design, aesthetic concerns are all too often reduced to matters of appearance. Hence, roboticists work with only a narrow-limited framework for understanding human-robotic interaction, both as experiences and as a design space. These limitations not only negatively affect robotics research, but also the application of the technology into the arts.

In the context of designing with robotics and experiences understood through contemporary cognitive discourses, this thesis asks the following questions:

1. How do we perceive life in moving human artefacts, and are there notions of cognition that explain these perceptions?

2. Why are perceptions of life so irresistible, both in the sense of being uncontrollable, and aesthetically enchanting?

3. How might one go about making objects that are perceived as animate?

6.2 Results

I have interwoven two research methodologies throughout this thesis - one is scholarly and the other practical, involved the building of machines that I call Lively Artefacts, and that have been exhibited in public gallery contexts, internationally.

This work has been grounded by what I have characterised as a neo-cybernetic approach, which has some key characteristics:

1. Interdisciplinarity in the study of behaviour.

2. A bottom-up approach to understanding and designing animate behaviour.

3. A constructivist and ecological approach to analysing and discussing experience.

4. The ability to describe systems in first-order and second-order modes.

A first-order can produce a description of a system and its control arrangements, such as its various goals, mechanisms and stimulus relationships to its environment. In a limited technical role, this is useful for describing and building systems, such as robots. A second-order includes the observer of a system and is able to address questions of the individual's constructed experience of an observed system.

This study includes first-order analysis, exploring the systems driving my robotic installations, and second-order analysis, incorporating observer experience. The first-order descriptions are straightforward and provide useful technical suggestions for others, on animating machines. The results of the second-order shift away from objective and reductive analysis, to examine the complex, layered experience of Lively Artefacts, foundationally based upon perceptual reflexes that build bottom up into higher-order cognitive processes that, in some cases, construct aesthetic experiences. Having first-order and second-order analysis does

not indicate a chronological sequence, nor that these are separate enquiries. Rather – to borrow Kenny Chow's phrase – I see them are two sides of the same spinning coin.

Below, I have chosen to structure these results by first examining experiences of animate artefacts from the bottom up, then sharing technical insights into making machines that elicit these animate aesthetic experiences. Taking a bottom-up approach, I take as a starting point the cybernetic research of Lettvin, Maturana, McCulloch and Pitts [655], and their observation that the visual cortex of the vertebrate eye includes active feature-detection for animate agents in our environment. An ecological perspective on cognition reveals there are clear evolutionary advantages to detecting life quickly, without the need for conscious processing. Due to the social nature of human beings, the eye has evolved not only to perceptually construct spatial, colour and motion information about the environment, but also its causal and the social structure.

How do we Perceive Life?

"As we enter a room full of people, we instantly have a number of social perceptions, and most fundamentally, we know which objects in the room are animate and which are inanimate." [656]
(Rutherford and Kuhlmeier, 2013)

Motion perception of animacy is a primary percept upon which more complex social cognition arises. The experience of perceiving life in moving artefacts is generated by a heterogeneous group of interconnected phenomena, with qualities of ambiguity, presence and the uncanny, as central features.

Movement has primacy in visual perception, and animacy detection is a priority in our processing of visual information. Our visual perceptual systems are highly attuned to cues for social cognition that can uncover not only the conscious, but also the unconscious state of other animate agents in our environment. Specialised heuristic traits of the human cognitive model have a deep evolutionary history, that automatically, or one might say irresistibly, trigger perceptions before conscious reasoning occurs further down-stream. These fast heuristic traits operate in visual-cortical hierarchy with parallel asynchronous computation. The eye can recognise animate behaviour through motion alone. There is an evolutionary advantage to this, and the architecture of the human eye detects motion information independently to colour and formal information in early visual processing. Causal and

animacy perception appear innate. Even with a lifetime of experience understanding the ontological differences between living and non-living entities, innate reflexes continue to interpret visual motion information and shape experience. As a result, robots, kinetic art, and geometric animations, can all appear irresistibly animate, without even the visual appearance of living entities.

Entities that accelerate and change direction the greatest amount, have the highest animacy ratings. When an entity appears aligned to its direction of motion, particularly if it changes direction, it produces higher animacy ratings than misaligned movement. A small number of cues are central to fast heuristic detection of animate motion. Primary parameters are speed, acceleration and deceleration, change of direction, and orientation to direction of travel. These cues can function context-independent, however, context can intensify and supress perceptions of animacy. Animacy perception is increased, where there is perceived correlation between a subject's movement and features of its environment indicating purposeful motion.

The field of social perception, specifically visual motion perception has accumulated a variety of statistical information on motion profiles that trigger perception of animacy. In addition, primary behavioural typologies, such as chasing or evading, have been parametrised. Gravity also affects our perception of motion, which is likely a result of the gravitational environment in which this perceptual trait has evolved. Entities that move upward against gravitational force are more animate than those moving downward. Animacy perception, in itself, is not the end state of perceptual visual processing, rather it is only the beginning of downstream heuristic detection of a variety of behaviour typologies that remain under-researched. Some perceptual phenomena that may powerfully shape our experience and interaction, are likely undocumented, such as the only recently discovered Wolfpack Effect. In their own experimental practices, artists are discovering and manipulating a variety of currently undocumented perceptual cues, which could be of benefit to scientific research into the perception of animacy.

Why are Perceptions of Life so Irresistible?

There's a striking visual overlap between early 20th century abstract arts, from animation, to kinetic sculpture, and the scientific perceptual and psychophysical experiments that began to appear in the latter half of the century. Neuroaesthetic theory suggests artists are unknowingly experimenting with the organisation of the visual brain, and that abstract artists focus on particular stimuli, much in the same way scientists may try to limit variables, in order to test their affects. In puppetry, for example, the abandoning of figurative dolls, in favour of

found objects, abstract and non-anthropomorphic forms, embodied a searched for its own identity separate from theatre, with its own unique psychological effects – its 'puppetness'.

Neuroaesthetic theory proposes that, by isolating and amplifying particular sensory stimuli, aesthetic experience can be magnified. I have shared my concerns about using such a reductive theory to study an aesthetic experience, but from my own research and experience, I find the premise of reflex perceptions as aesthetic to be plausible, and as part of an aesthetic analysis, I find them provocatively useful. At the heart of puppetry, are effects that I believe are closely related to psychological affects of robotics, however, this is not appreciated in a field largely lead by engineers.

We find ambiguity at the centre of all animated art forms. In the event of limited stimuli with which to make judgements on the status of objects in our environment, we rely on reflexive responses to these primary cues, and they are most powerful in these conditions. Ambiguity emerges within the conflict between fast heuristics and slower, higher-order cognition. The human mind is remarkably flexible in how it negotiates judgments of uncertain stimuli, be they visual, spatial, or social. When two interpretations share equal validity, we find our mind oscillating between competing perceptions.

In animated art forms, the convergence of our instinctive and naïve perceptual reflexes meet contradictory rational understandings of the world. Ambiguity also drives participation, encouraging observers to seek to resolve the uncertainty through their own action. Abstract animated art forms whether spectated or actively interacted, shirk conceptualisation for the immediate - the essential bargain between performer and audience being a willing embrace of a naïve vision, an act unadulterated by intellectual rationalisation.

Across the animated arts we find the common continuum between formal anthropomorphism and abstraction. In puppetry, on one side we have the illusionist and, on the other, the primitivist camp. The illusionist's intention is to produce a stabile continuous life, the primitivists embrace fragmentation and instability, seeking short episodes or vignettes. The animate abstract, non- figurative objects require greater energy and commitment from the puppeteer and greater leaps of imagination in the audience. The result, puppeteers have argued, is more sophisticated and more intense. The audience's oscillation of perception of life exaggerated, the object itself becomes a self-reflective device for questions about the vitalist nature of the objects and the "theatre of the possession".

The uncanny is a feature of ambiguity that has particularly strong aesthetic potency. In robotics, the uncanny is associated with Mori's *The Uncanny Valley,* which is a narrow

reading of a richer phenomenon that is extensively discussed in animation and puppetry theory. The uncanny can be magnified by careful staging. Freud repeatedly mentions darkness in relation to that the uncanny. It is perhaps no wonder then, that in darkened theatres, the life of puppets draws out childhood fears of toys coming to life at night.

Today, the venerable art form of puppetry finds new purpose in filling a theoretical vacuum surrounding the aesthetics of robotics. Largely a subject examined by engineers and social scientists, robotics fundamentally misunderstands aesthetics as only a matter of appearance. Aesthetics in robotics often leads to discussion about the uncanny valley and its aversion to it. The uncanny is often treated as a problem to engineer out of a design. Puppetry, by comparison, understands the uncanny as a source of a strange pleasure both frightening and at the same time compelling in its playfulness. It understands that fearfulness is overcome in the imaginative participation of the puppet performance, in the embrace of the spectacle and its artificiality. In this way, the puppet can invoke gasps of anxiety and moments later turn us to laughter, or even the sublime. Contemporary puppetry seeks to do more than merely imitate life, aiming instead to find freer, livelier, and surprising sensations of intelligent behaviour. It is my strong belief that the field of robotics would benefit greatly from examining this ancient art form to better understand its own potential.

Perhaps less immediately obvious to roboticists, is the knowledge latent in the work of more experimental abstract animation. While orthodox animation seeks to sustain the life of moving characters, the appearance of lively artefacts in experimental work are more often unstable, fleeting and strange. Artists, architects and designers working with robotics may find the work of experimental animation offer a richer palate of inspiration for non-figurative, rhythmic and non-linear behaviour. Equally, I believe that cognitive research could benefit from drawing on experimental animation to discover stimuli that widen and deepening our understanding of what motion characteristics shape social perception.

How to Make Artefacts 'Come to Life'?

Two factors are critical to making lively artefacts. The mechanisms that govern behaviour and motion qualities. These are not independent issues and overlap, but I will begin by highlighting key aspects of behaviour design, and finish with some observations about motion, drawn from different disciplinary perspectives.

Lively Artefacts can be built as 'Trivial Machines' or 'Non-Trivial Machines'. Purposeful motion is perceptually highly animate. For example, the ability for Grey Walter's robot tortoises to steer towards light and avoid obstacles gave them a compelling appearance of

animacy, not previously available in predictably performing automaton.

Trivial Machines, with the most primitive of fixed goal-directed behaviours can still exhibit complex animate behaviour, by being responsive to stimuli of a complex environment. A designer can craft animate behaviour through the design of an agent, but equally through the design of that agent's environment. Cybernetics encourages designers to balance attention to problems of behavioural design between agent and environment.

Complexity of behaviour is available with Trivial Machines, using the following approaches:

- Human players often feed complexity into the system, and this is reflected back at them in the complexity of agent response.

- Using multiple simultaneous goal-directed behaviours in a single agent can increase the complexity of behaviour.

- State-Machines can store sets of rules that are transitioned between offering a multi-dimensional set of behaviours.

- A random function can introduce indeterminacy in 'Trivial Machines', modifying motion parameters, or rules of behaviour, or both. My experience tells me that the degree of random fed into control systems is best decided through observation.

- Indeterminate motion can increase animacy perceptions, too much indeterminacy and behaviours appear chaotic, and inanimate.

- In many situations trivial machines are sufficiently animate to not warrant the use of more complex Non-Trivial techniques. These include scenarios where human experience is relatively short, such as gallery visits.

Complexity of behaviour is a feature of Non-Trivial Machines because they are adaptive to a history of interactions with their environment that makes behaviours purposeful, yet indeterminate. Simple statistical techniques can be used to give machines behaviours governed by a history of previous interactions. Looking to what governs living beings, we can also harness artificial life techniques, such as genetic algorithms and neural networks.

- Non-Trivial machines with adaptive behaviours are more likely to maintain perceptions of animacy for longer.

- They open up the potential for longer experiences of animate interaction and even emotional attachment, where human behavioural tendency toward nurturing infants is manipulated. Looking at the latest developments in embodied adaptive robotics, there

is something viscerally engaging about seeing a robot solving a visual-motor skill with uncanny similarity to an infant. It creates a deeper sense of an entity with its own life, making sense of the physical world, move by move.

- The behavioural possibilities of self-generated motion strategies in robotics are fascinating on a functional level, for their ability to compensate for changing circumstances, whether this is mechanical damage or a change in their environment. They are also fascinating in my opinion on aesthetic grounds for the qualities of behaviour that we find emerging out of their embodied interaction with the world.

- The growing number of institutions and companies, including Google, now taking bottom-up approaches, like those discussed at UC Berkeley, demonstrate a neo-cybernetic shift towards cognition through embodied interaction built upon connectionist computation. The aesthetics of this shift are far more animate than those that have characterised robots in the 20th century.

Cybernetic machines pursue the manageably complex from the chaotically complex, through continuous feedback control, in contrast to Classical Cartesian AI and digital ALife that pursue complexity from discrete simple rules. My observation in making machines has been that cybernetic bottom-up approaches seem to easily 'come to life' in complex environments, while top-down methods to intelligent behaviour can struggle to negotiate the complexity of analogue physical environments, and are better suited to computational simulations. The great virtue of developments in adaptive embodied robotics is that they can make explicit the relationship between the body and its intelligence.

The parametric analysis available in scientific study of animacy perception is a useful resource for designing the behaviour and motion characteristics of virtual and physical agents. It can be combined and correlated with knowledge from animation that increasingly harnesses parametric techniques, to develop motion profiles that are highly animate. Smooth motion techniques are more animate than 'mechanical' motion. These are now easily accessed in animation software and can directly drive robotics.

Animation techniques are typically useful for 'canned motions', where a library of behaviours have been pre-programmed and are performed linearly like mechanical automata. We have recently seen elements of the Principles of animation employed in robotics research projects [657] and commercially available social robots like Jibo [658]. Formal lessons from character animation have also encouraged robotics designers to appeal to our innate responses to childlike appearances. They can appear repetitive after extended periods of interaction.

Generative motions based on code, allow for a continuous responsiveness rather than a series of pre-choreographed performances.

Accelerations in speed motion quickly illicit readings of animacy, but benefit from moments of relative stillness in between - although maintaining some hint of motion is recommended if the intention is to keep a continuous impression of life. When changes in speed and direction occur simultaneously, they appear to be controlled and more purposeful, so rules about changes in behaviour should adjust orientation and motion together. Upward motion, moving against gravity are most animate so a sense of lifting up as a starting move can add a sense of animacy. When an agent is not travelling, changes in orientation alone can create strong impressions of intention, and a sense of anticipation and tension. Motion profiles that are smooth may produce continuous impressions of animate behaviour, but stronger aesthetic responses can be elicited by exploring the contrasts of stillness and motion, as well as varying degrees of motion smoothing. These contrasting impressions can increase the oscillating experience of animate and inanimate perceptions, which adds drama and appears to increase aesthetic potency.

6.3 Contribution

Embodied cognitive theories of agency perception hypothesise a direct empathic corporal interface between our own bodily agency and that of other human beings, as well as animals, animated characters, puppets and robots. Moving bodies, that are not anthropomorphic, can still illicit visceral perceptions of life and emotional character. We feel, emotionally, the behaviour of others, not solely through rational reasoning, but also through deep unconscious processes of perception - both innate and learnt heuristics. Only through investigating these complex heterogeneous phenomena from a variety of disciplinary perspectives, do we come to a deeper understanding of what shapes the aesthetics of animate art forms.

Simon Penny's publication earlier this year lays out a much-needed general theoretical framework for a post-cognitivist 'Aesthetics of Behaviour'. As he himself admits, it only lays out the 'rudiments' of an aesthetic theory and is directed towards behavioural art forms in the many formats that new media arts manifest. The heterogeneous nature of behavioural media, the heterogeneous nature of contributing disciplines, and the challenges of synthesising disciplinary knowledge, expertise and technologies, makes a project of this type formidable, and necessitates focused contributions.

This thesis makes a contribution towards an 'Aesthetics of Behaviour', in the critical sub-domain of animate behaviour in physical artefacts, limiting itself to the visual motion perception of animacy. Missing from Penny's general theoretical framework, this contribution focuses upon puppetry, animation and visual perceptual science, working bottom-up from psychophysical responses to motion, to reflex-perceptions of social motion stimuli, to cross-disciplinary discourses on fleeting qualities of presence, and to the uncanny and ambiguous animacy present in what I have called Lively Artefacts.

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