The method of artificial systems

Christopher A. Tucker

cartheur@gmail.com

Abstract

This document consists the basis of my Master's thesis work at the University of Reading, UK from 2006-2008. It focuses primarily on two main concepts: context awareness and choice in artificial systems set within a boundary of available epistemology which serves to describe it. It was hypothesised that such definitions yield a strong adaptation mechanism for an artificial entity to manifest as a consequence of the program's runtime. The problem is presented by discussing different points of view and proposing experiments to demonstrate the complexities of such problems in artificial life in terms of machine consciousness while indicating what a suitable answer might be.

Contents

List of Figures

1 Introduction

This thesis proposes a solution to deep conundrums within artificial intelligence (AI) and artificial life (AL) by presenting the singular argument that machines which express life cannot be designed by making assumptions; rather, they must be designed as life-forms in their own right, subject to a parametric set of rules analogous to living systems stemming from the environment in which they habitate. I believe this is an agreeable tenet across the discipline. Foundations of machine life are imperative to establish in order to facilitate evolution from present-day rudimentary forms into those more advanced. Although numerous forms exist, a proper architecture of similitude, laws, modes, and orchestration needs to be authored to establish baselines for generational development of the artificial life form.

This paper proposes three goals:

1. To establish a methodological and experimental foundation to understand and construct autonomous synthetic creatures of varying purpose. Directed by the application environment, machine types form an active role of technological development and should be categorized if possible,

2. To propose a research paradigm to understand artificial life, and perhaps shed some light on what is life in a more general sense, by designing and constructing mimicking forms,

3. To propose experiments which convey motifs of behavior, to establish a paradigm set of discretionary limits, necessitated by a physical characteristic.

In order to make the topic more familiar, the tone of this document from this point on will be from the first-person. As unorthodox as that may initially appear, I argue that even a dubious intent within the paradigm of a practical engineering point-of-view, will provide unique and useful solutions on how to design and construct autonomous machines possessing ranges of adapted, organically-developed behaviors. This is a keen individual experience which comes to bear on the outcomes.

1.1 Terms

This thesis will deal with loosely-defined concepts nested in objective terms such as 'robot', 'machine', 'autonomous', 'synthetic creature' and the like to describe heretofore abstractly realized phenomenon that which comes so easily for us to recognize when we see it. It is one of the goals of this document to establish a set of terms suitable and narrowly defined to carry specific and targeted meaning of the abstract concepts that will be introduced and explored herein. The terms used widely throughout this thesis are:

Feature: the prominent part or characteristic embedded in both physical and abstract components.

Entity: a dynamic object that possesses behavior forming an commonly-identifiable form.

Robot: I will use this term interchangeably with 'machine', 'autonomous entity', and 'synthetic creature' meaning a composite artificial life form who may or may not bear resemblance to a humanoid form. I do not use it in its original context or in its exact translation.

Controller: an entity that insists on particular machine states based on an external criteria or paradigm.

Orchestration: Cooperation between disparate physical or abstract elements resulting in finely-grained coordination.

Autonomy: A system defined by its own behavior derived from experience.

I employ the terms 'life' and 'living' loosely throughout this thesis. I will use the terms to mean 'any system constructed or natural that interacts directly with a human observer generating interest'. Granted the definition is limited and perhaps flawed, it is for the conclusion of the research during my dissertation that this will be rectified. For now, I don't want to be mired in the metaphysical aspects while just beginning the work, hence the abbreviation here.

1.2 The Reluctance of AI

Artificial intelligence requires three basic mathematical components to make it what it is. The formal science requires a level of mathematical formulisation in computation, logic, and probability; it wasn't until the appearance of George Boole (1815 - 1864) and Gottlob Frege (1848 - 1925) that knowledge representation was defined. Alfred Tarski (1902 - 1983) introduced a theory of reference showing how logical objects could be related to their real-world counterparts. Turing, following Godel's incompleteness theorem, demonstrated what kinds of functions could be computed, expressed as the Church-Turing thesis. However, this introduced a series of intractable problems that would be left until the appearance of complexity theory in the 1970s to be shown how to compute proper solutions from problem instances.

The history of artificial intelligence stretches back to the first doctrines of logic by Plato and the development of mathematics by luminaries such as Archimedes which disappeared until rediscovery in the 18th Century. Part of this thesis will reexamine some of the more intractable problems in AI such as knowledge representation and choice-motivated decision-making by examining them in a geometric light. However, this has not been developed far at the time of the writing of this document and will be included in future revisions. Nevertheless, a comprehensive look of assets and alternatives is due the field wherein new theoretical, abstract, and experimental paradigms can be generated.

I will take the time to mention here that a series of confessions have bled into the media of late. One of the more notable was one by Rodney Brooks that caught my attention. However, the reluctance of AI can be traced back to the Lighthill Report which can be summarized as a critical review of the power of AI professed by its earliest proponents in the mid 20th Century. The result was that many programs were closed in the University system and others were renamed to keep them going. However, the shadow of failure seems to still permeate to this day. If the recent confessions are an indicator of the validity of the Lighthill Report then Brooks' confession of failure "in solving the AI problem",[2] might indeed point to a fundamental flaw in the field that should be identified before any further work is conducted–hence why I addresses this issue in the first section.

I don't think this is a failure of the individual research in question, but is indicative of a more endemic problem buried deep in the field, something between those properties discussed at the earliest conferences in the late 1950s–hosted by von Neumann and expounded by Turing–and how they were manifest in technology decades later. Norbert Wiener comes to mind who prophesied many types of intelligent machines and started a conference track attended by the future founders of cybernetics: W. Ross Ashby, Grey Walter, and Warren McCulloch. However, despite attention given to this field, many works did not persist beyond their creators. There was, of course, some dissemination of concepts such as homeostasis by Ashby and the circuits of Walter's tortoises–specifications of which were reexamined in 2003[3]–however, it could not be discovered if their works made their way into commercial projects. This does not imply that the founders of the field necessarily failed; there were some interesting and successful developments in robots for space exploration beginning with the Luna Project by the Soviet Union that cumulated in the Mars exploratory robots that have shown how robust such a system can be made not to mention adaptive to deal with the conditions on a hostile planet so far from its source. So there have been some shining examples and some catastrophic failures–was Big Blue really intelligent? I argue that it wasn't. Some applications are simply misguided and I point to the lack of continuity in the field; although Wiener's machines were behemoths, Stanford Beer's economic and business derivations were sublime. Somewhere between creating theory and the delicate operation of putting the theory into operation lies a serious rub that can be solved in a myriad of ways. There must be a way to derive a language framework wherein to eliminate trivialities of semantics to unite a field as disparate and wide-reaching as cybernetics.

So what kind of machines will be discussed here? I will focus on a single realization, robotics, which will yield three questions:

Aspect: Robots who are made to be independent, work collectively in sharing functions yet relying explicitly on human interaction to "survive" socially and to derive purpose, from this,

1. How do socio-robotic colonies form and what are their structures?
2. Are there biological analogues that can be modeled and used to the project's advantage?
3. Will there be a socio-collective bond between the intelligent machine and its human analogue?

I believe that with the proper time and budgetary requirements, I can fulfill the dream of robots closely interacting with humans in our global society. I expect then, a direct consequence of this, the porting of technologies to human-machine hybrids such as intelligent medical devices, replacing biological organs with artificial ones, and custom-tailored enhancements.

So why hasn't this already happened? Why don't we see robots around in our cities? I argue that the technology is sophisticated enough to make a reasonable facsimile of a humanoid-style machine to behave in a human-like away that would be able to interact. I say it has already been done in a rudimentary sense within the past five years; commercial projects such as those out of iRobot and Sony speak volumes about the technology, so what is holding us back intellectually from accomplishing it? Is there some unconscious block preventing us from building robots such as those depicted in science-fiction?

These 'reluctances' provide insight into knotty problems; from assaying the strengths and failures of historical works, I believe the problem can be rendered geometrically. I will address this later in the thesis.

1.3 Words

Not withstanding this general survey, let me now take the time to examine most closely the specific inspirational sources for this work and where my notion of choice in the machine as a quantifier for true artificial life has derived from.

2 Literature Survey

I would like to set the scene for this thesis, what has inspired it, and where it will be going based on some more detailed sources.

2.1 Living Systems

I suppose the most unavoidable direct question is: *What is life?* Although there are a myriad answers, since this will be a scientific thesis, the point of view of a physicist seems a reasonable place to begin. I introduce a essay by Erwin Schrodinger (1944) titled appropriately.

In that a person in cybernetics, in such an encompassing field that attempts to bring together numerous scientific principles and ideals, it is truly the attempt noted:

> We have inherited from our forefathers the keen longing for unified, all-embracing knowledge. The very name given to the highest institutions of learning reminds us, that from antiquity to and throughout many centuries the universal aspect has been the only one to be given full credit. (Preface).

And at this point in the evolution of cybernetics in the present era of the early 21st Century:

> We feel clearly that we are only now beginning to acquire reliable material for welding together the sum total of all that is known into a whole; but, on the other hand, it has become next to impossible for a single mind fully to command more than a small specialized portion of it. (Preface).

Herein lies the quandary experienced by the student of cybernetics, specifically artificial life. Leaving that the quandary is native to the field and a pitfall to be wrestled, how is life understood as a concept?

> The large and important and very much discussed question is: How can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry? (Chapter 1).

I offer:

> Today, thanks to the ingenious work of biologists, mainly of geneticists, during the last thirty or forty years, enough is known about the actual material structure of organisms and about their functioning to state that, and to tell precisely why present-day physics and chemistry could not possibly account for what happens in space and time within a living organism. (Chapter 1).

It is reasonable then, to look toward biological analogues and the work in the biological and ethological fields wherein to derive hypotheses with a high degree of reliability and purpose. How is this information compiled? In other words what is a *quid pro quo* of life relating to any form functioning in an environment? I quote at length:

> We are thus faced with the following question: Why should an organ like our brain, with the sensorial system attached to it, of necessity consist of an enormous number of atoms, in order that its physically changing state should be in close and intimate correspondence with a highly developed thought? On what grounds is the latter task of the said organ incompatible with being, as a whole or in some of its peripheral parts which interact directly with the environment, a mechanism sufficiently refined and sensitive to respond to and register the impact of a single atom from outside? The reason for this is, that what we call thought (1) is itself an orderly thing, and (2) can only be applied to material, i.e. to perceptions or experiences, which have a certain degree of orderliness. This has two consequences. First, a physical organization, to be in close correspondence with thought (as my brain is with my thought) must be a

> very well-ordered organization, and that means that the events that happen within it must obey strict physical laws, at least to a very high degree of accuracy. Secondly, the physical impressions made upon that physically well-organized system by other bodies from outside, obviously correspond to the perception and experience of the corresponding thought, forming its material, as I have called it. Therefore, the physical interactions between our system and others must, as a rule, themselves possess a certain degree of physical orderliness, that is to say, they too must obey strict physical laws to a certain degree of accuracy. (Chapter 1).

So a creature with a set of rigorous functionality, i.e. suited to its environment to a reasonable approximation of regularity or possessing a homeostatic point:

> When the dynamic system can vary continuously, small disturbances are, in practice, usually acting on it incessantly. Electronic systems are disturbed by thermal agitation, mechanical systems by vibration, and biological systems by a host of minor disturbances. For this reason the only states of equilibrium that can, in practice, persist are those that are stable in the sense of [invariance to disturbance]. States of unstable equilibrium are of small practical importance in the continuous system though they may be of importance in the system that can change only by a discrete jump. The concept of unstable equilibrium is, however, of some theoretical importance. (Ashby 1956, p. 78).

Which shows how physical laws are expressed internally and externally to the entity considered to be living, with an acceptable range of what causes can be known and compensated for–stable–and what causes remain unknown–unstable. This implies the physical phenomena of order, disorder, and entropy all play a role in the living system; I would argue whether organic or technic.

> From Delbruck's general picture of the hereditary substance it emerges that living matter, while not eluding the 'laws of physics' as established up to date, is likely to involve 'other laws of physics' hitherto unknown, which, however, once they have been revealed, will form just as integral a part of this science as the former. (Chapter 6).

Leading that not everything (or maybe does not necessarily need to be known) for a system to 'take on' the form analogous to a 'living' system, i.e. found in nature and existing as part of an evolutionary line–an ordered system taking on a lineage of creatures comprising an evolutional cycle regardless of the origin (known or unknown, *a priori* or *a posteriori*):

> The physicist is familiar with the fact that the classical laws of physics are modified by quantum theory, especially at low temperature. There are many instances of this. Life seems to be one of them, a particularly striking one. Life seems to be orderly and lawful behaviour of matter, not based exclusively on its tendency to go over from order to disorder, but based partly on existing order that is kept up. To the physicist -but only to him -I could hope to make my view clearer by saying: The living organism seems to be a

> macroscopic system which in part of its behaviour approaches to that purely mechanical (as contrasted with thermodynamical) conduct to which all systems tend, as the temperature approaches absolute zero and the molecular disorder is removed. (Chapter 6).

And tied into a living system's status of persistence:

> It is by avoiding the rapid decay into the inert state of 'equilibrium' that an organism appears so enigmatic; so much so, that from the earliest times of human thought some special non-physical or supernatural force (vis viva, entelechy) was claimed to be operative in the organism, and in some quarters is still claimed. How does the living organism avoid decay? The obvious answer is: By eating, drinking, breathing and (in the case of plants) assimilating. The technical term is metabolism. (Chapter 6).

Where for the purposes of this thesis *metabolism* for an artificial system is the exchange of information and growth of its program complex in the most rudimentary terms of the concept, which means that an artificial system is privy to the forces of entropy:

> ...a source of variety such as a Markov chain has zero constraint when all its transitions are equally probable. It follows that this condition (of zero constraint) is the one that enables the information source, if it behaves as a Markov chain, to transmit the maximal quantity of information (in given time). Shannon has devised a measure for the quantity of variety shown by a Markov chain at each step—the entropy—that has proved of fundamental importance in many questions relating to incessant transmission. (Ashby 1956, p. 174).

The information flow inside the artificial system would qualify as incessant transmission and entropy is quantified as the dropping of bits in a sampling process. As the entity co-exists with its environment, order is maintained by the input flow of information–negative entropy–creating a balance or state of theoretical equilibrium that could be calculated for a given artificial entity.

To leave this part of the survey by a quick summary, what Schrodinger imports is the look of life in terms of its subsistence and resistance to entropy or decay. He makes the comparison of a purely mechanical system, a clock:

> Let us analyze the motion of a real clock accurately. It is not at all a purely mechanical phenomenon. A purely mechanical clock would need no spring, no winding. Once set in motion, it would go on forever. A real clock without a spring stops after a few beats of the pendulum, its mechanical energy is turned into heat. This is an infinitely complicated atomistic process. The general picture the physicist forms of it compels him to admit that the inverse process is not entirely impossible: a springless clock might suddenly begin to move, at the expense of the heat energy of its own cog wheels and of the environment. (Chapter 7).

The final word is that if we even think of an artificial system as a purely mechanical thing, devoid of even the most intrinsic bits of how we philosophically imbue *life*, it can never exist outside of the definition; i.e. it can never die but simply turn off.

2.2 Epistemology

A most fundamental viewpoint of this work is epistemology; without a framing the discussion, that is, an agreed framework of how new concepts will be discussed and how they will be manifest empirically, we will never arrive at quantitative proofs of artificial life. I quote:

> Foundational controversies in artificial life and artificial intelligence arise from lack of decidable criteria for defining the epistemic cuts that separate knowledge of reality from (supposed) reality itself, e.g., description from construction, simulation from realization, mind from brain. When a problem persists, unresolved...in spite of enormous increases in our knowledge, it is a good bet that the problem entails the nature of knowledge itself.
>
> Pattee, H.H. "Artificial Life Needs a Real Epistemology"

Pattee (1995) writes at length about how life exists and how life is viewed, the argument he presents is between two limits in the "cut":

- *Life-as-it-could-be* compared with
- *Life-as-we-know-it*

Making the assumption that the failure of artificial intelligence (AI), evidenced by the Lighthill Report, and its offspring, artificial life (AL) to rigorously define the millennium-old question *what is life?* is critical to engineering developments such as the production of synthetic life forms, e.g., a living system that is independent of an evolutionary line, Pattee points to the various flaws in the logic of AI and AL. While agreeing with him during his discussion of autonomous robotics, I offer the assumption it is the control the scientist places over his creation, i.e., the formation of a synthetic life form, is a the root of the failure. In that we lack a foundation of epistemology wherein to discuss the cooperation of symbols in defining what is life. I argue it matters little in quantitatively answering the question; instead, the persistence and evolution of a synthetic life form and the empirical data resulting from it should be driving the research.

An "epistemic cut" was offered by Professor Sir James Lighthill where he tried to define *what is artificial intelligence?*

> The *Lighthill Report* is organized around a classification of AI research into three categories:
>
> Category A is *advanced automation* or *applications*, and he approves of it in principle. Included in A are some activities that are obviously applied by also activities like computer chess playing that are often done not for themselves but in order to study the structure of intelligent behavior.
>
> Category B is defined as "building robots" and "bridge" between the other two categories. Lighthill defines a robot as a program or device built neither to serve a useful purpose nor to study the central

nervous system, which obviously would exclude Unimates (sic) which are generally referred to as industrial robots. Emphasizing the bridge aspect of the definition, Lighthill states as obvious that work in category B is worthwhile only in so far as it contributes to the other categories.

Category C comprises studies of the *central nervous system* including computer modeling in support of both neurophysiology and psychology.

If we take this categorization seriously, then most AI researchers lose intellectual contact with Lighthill immediately, because his three categories have no place for what is or should be our main scientific activity - studying the structure of information and the structure of the problem solving processes independently of applications and independently of its realization in animals for humans. This study is based on the following ideas:

1. Intellectual activity takes place in a world that has a certain physical and intellectual structure: Physical objects exist, move about, are created and destroyed. Actions that may be performed have effects that are partially known. Entities with goals have available to them certain information about the world. Some of this information may be built in, and some arises from observation, from communication, from reasoning, and by more or less complex processes of retrieval from information bases. Much of this structure is common to the intellectual position of animals, people, and machine which we may design, e.g. the effects of physical actions on material objects and also the information that may be obtained about these objects by vision. The general structure of the intellectual world is far from understood, and it is often quite difficult to decide how to represent effectively the information available about a quite limited domain of action even when we are quite willing to treat a particular problem in an *ad hoc* way.

2. The process of problem solving depend on the class of problems being solved more than on the solver. Thus playing chess seems to require look-ahead whether the apparatus is made of neurons or transistors. Isolation of the information relevant to a problem from the totality of previous experience is required whether the solver is man or machine, and so is the ability to divide a problem into weakly connected subproblems that can be thought about separately before the results are combined.

3. Experiment is useful in determining what representations of information and what problem solving processes are needed to solve a given class of problems. We can illustrate this point by an example from the *Lighthill Report* which asserts that the heuristics of a chess program are embodied in the evaluation function. This is plausible and was assumed by the first writers of chess programs. Experiment showed, however, that the procedures that select what part of the move tree is examined are even more important; i.e. when a program errs it is usually because it mis-evaluated a final position.

4. The experimental domain should be chosen to test the adequacy of representations of information and of problem solving mechanisms. Thus chess has contributed much to the study of tree search; one Soviet computer scientist refers to chess as the *Drosophila* of artificial intelligence. I think there is much more to be learned from chess, because master level play will require more than just improving the present methods of searching trees. Namely, it will require the ability to identify, represent, and recognize the patters of position and play that correspond to "chess ideas", the ability to solve some abstractions of positions and to apply the result to actual positions. It will probably also require the ability to analyze a problem into subproblems and combined separate results.

> McCarthy, John. (2000) "Review of 'Artificial Intelligence: A General Survey"'.

My approach during the subsequent pursuit of this thesis will attempt to derive an epistemology, a way of speaking about the subject and a manner of defining experiments–coupled with the attempt to ascertain a reasonable model of synthetic life. In this way, I can begin with a solid foundation and extend a bundled prospectus of my line of inquiry and applying to models that have appeared in the history of cybernetics.

2.3 Models for Consideration

In casting a glance into the past, I have found the work of W. Grey Walter to be particularly useful as a means to understand machine behavior based on physical models of the brain. Water (1953) in *The Living Brain* talks at length about how, through the lens of cybernetics, living systems are organized and how they are related to each other. What is gleaned most exactly is his categorization of artificial life forms with their biological analogues, in the greatest breadth of the word. What is crucial and how Walter's work has influenced this thesis is:

> ...Grey Walter's principled interest in building physical working models to test hypotheses; and his theories about brain function. (Holland 2003).

His strength was in the position that the machines, Elmer and Elsie, possessed behaviors unaccounted for in his theory, i.e. emergence. He also expressed the concept of *free will* observed in his experiments. These two concepts I find intrepid would like to pursue them in how I would go about solving the problem: postulating theory and empirical experiment. However, I must first look at researchers who have reexamined Walter's "tortoise" experiments to see if my ideas of testing choice in the machine under the auspices of Walter's general body of theory can be supported.

I point to the work of Owen Holland of the University of Essex. There are two significant works (among many) to be illustrated here:

- The Legacy of Grey Walter
- Could We Build a Conscious Robot?

Holland (2003) , poses a critical review of the work of W. Grey Walter's tortoises, giving sound background information to discussing the technical aspects of the machines, where science emerged in spite of showmanship, and he was able to demonstrate via artificial entities the psychological concept of the *free goal-seeking mechanism.*

> The first notion of constructing a free goal-seeking mechanism goes back to a wartime talk with the psychologist, Kenneth Craik, whose untimely death was one of the greatest losses Cambridge has suffered in years. When he was engaged on a war job for the Government, he came to get the help of our automatic analyser with some very complicated curves he had obtained, curves relating to the aiming errors of air gunners. Goal-seeking missiles were literally much in the air in those days; so, in our minds, were scanning mechanisms. Long before the home study was turned into a workshop, the two ideas, goal-seeking and scanning, had combined as the essential mechanical conception of a working model that would behave like a very simple animal.
>
> Walter *The Living Brain*, p. 125.

Holland communicates a rich appreciation and great insights into Walter's machines. I quote a short article by Holland *Elmer the Tortoise*:

> I knew that in 1949 Grey Walter had built a robot to demonstrate his ideas about how the brain worked. He did not think humans were intelligent just because they had ten billion brain cells, but rather because their brain cells were connected up in many different ways. So he built his first 'model animal'–Elmer the tortoise–using only two electronic brain cells, connected together in several different ways. Not much of a brain, but Grey Walter had designed it very cleverly. Elmer would explore a room, looking for lights, moving towards them, circling them, and then wandering off in search of more. If he found a mirror, he would do a dance in front of it; if he came across his sister, Elsie, he would dance with her. If he came across an obstacle he would try and push it out of the way; if this didn't work, he would go round it. And when his battery began to run down, he would return to his hutch, and plug himself in to his power socket, setting off again in search of lights when his battery was fully charged. Grey Walter had proved his point–two richly connected brain cells were enough.

What is striking here is the intention of Walter to reproduce, by modeling, living systems and that emergent behavior was observed by the utility of rather simple parts. But was this really true? Was Walter's work and assumptions independently verified?

Maybe.

What conclusions did Holland reach? I cite–Holland 2003: What what was Grey Walter the first to do?

> Walter's list of firsts in biologically inspired robotics and the related areas is impressive. The tortoises were designed to test a biological

hypothesis about how combinations of relatively few elements might give rise to complexity of behaviour; they were probably the first biologically inspired robots of any real interest. The robots were intended to produce behaviour characteristic of animals, and Walter was the first to emphasize the importance of behavioural completeness:

> "Not in looks, but in action, the model must resemble an animal. Therefore, it must have these or some measure of these attributes: exploration, curiosity, free-will in the sense of unpredictability, goal-seeking, self-regulation, avoidance of dilemmas, foresight, memory, learning, forgetting, association of ideas, form recognition, and the elements of social accommodation. Such is life." Walter (1953, pp. 120, 121).

And looking at the tortoises in the light they were working under:

> The tortoises had to exist in a normal everyday environment, rather than in some special environment created to take account of their limitations. He was the first to implement a self-recharging robot. He made the first observations of emergence in robotics, both in the sense of the designer being pleasantly surprised at the unanticipated appearance of some useful side effect of his design, and in the sense that the interaction of two or more behavioural subsystems could produce a distinct and useful additional behaviour. The second sense is clearly demonstrated by several of his remarks in Walter (1960); in fact, they amount to the earliest formulation of the basic idea of behaviour-based robotics (Holland 1996). As noted above, he was the first to show how a robot's actions on an environment could change it in such a way that the robot's future behaviour was changed in a useful way, and he was also the first to carry out experiments in learning on a behaving robot. Because he built more than one robot, he was also the first in the field of multiple robotics, showing how the behavioural interactions between two robots of the same type would produce emergent characteristics of interest if not utility. He also made the earliest observations in the field of what is now known as collective robotics:
>
> "Simple models of behaviour can act *as if* they could recognize themselves and one another; furthermore, when there are several together they begin to aggregate in pairs and flocks, particularly if they are crowded into a corral. . . . The process of herding is *nonlinear*. In a free space they are individuals; as the barriers are brought in and the enclosure diminishes, suddenly there is a flock. But if the crowding is increased, suddenly again there is a change to an explosive society of scuffling strangers. And at any time the *aggregation* may be turned into a *congregation* by attraction of all individuals to a common goal. Further studies have shown that in certain conditions one machine will tend to be a 'leader'. Often this one is the least sensitive of the crowd, sometimes even it is 'blind'." Walter (1957).

What can I hope to glean from studying, in depth, Walter's work and Holland's analysis? To what extent did Walter's work influence the subsequent course of biologically inspired robotics? A point I will pursue during the course of this thesis.

> This question is somewhat embarrassing for the robotics community, because the answer is that it had very little direct influence. Perhaps the technology of the tortoises was too inaccessible; without a grounding in the electronics of the post-war world, it can be difficult to understand how their circuits operate. Perhaps the papers and the book are too removed in time, tone and style from modernity; The living brain, in particular, is very old fashioned, but this is perhaps not surprising when one discovers that it was written by his father, who was of course educated in the nineteenth century. Many of what are regarded as the key achievements within biologically inspired and behaviour-based robotics have involved techniques and observations with which he was familiar, but which have had to be painstakingly rediscovered in modern times. His technical priority does not of course diminish the credit due to the modern investigators, especially since one of his most important texts (Walter 1960) was first published less than a decade ago. However, one wonders whether robotics in general, and biologically inspired robotics in particular, might have advanced further and faster if his work had not been allowed to fade away quite so fast. (Holland 2003).

And lastly, how has his influence been felt and is my thinking in the right direction to understand my models under consideration?

> On the other hand, the indirect effects of Grey Walter's work may have influenced modern robotics in a number of ways. The publicity the tortoises received encouraged many technically inclined individuals to try and build similar machines; the electronic hobbyist magazines of the period record many such projects. In particular, Rodney Brooks recalls attempting to build his own version of the tortoise after reading *The Living Brain* (Brooks 2002). Later, while Brooks was working with Hans Moravec on the Stanford Cart, the tortoises again came to mind:
>
> "Despite the serious intent of the project, I could not but help feeling disappointed. Grey Walter had been able to get his tortoises to operate autonomously for hours on end, moving about and interacting with a dynamically changing world and with each other. His robots were constructed from parts costing a few tens of dollars. Here at the centre of high technology, a robot relying on millions of dollars of equipment did not appear to operate nearly as well. Internally it was doing much more than Grey Walter's tortoises had ever done– it was building accurate three-dimensional models of the world and formulating detailed plans within those models. But to an external observer all that internal cogitation was hardly worth it."
>
> Rodney Brooks, *Robot: The Future of Flesh and Machines* (2002, p. 30).

Less than a decade later, Brooks's own design principles were producing simple reactive robots within the new behaviour-based philosophy. (Holland 2003).

2.4 The Simple Conclusion

I see now that Walter is a solid source of inspiration and a place to begin my thoughts on my own theories and machines. I will not leave the position that the natural world is an inspiration for efficient problem solving and will discuss what will seem to be contradictory arguments of artificial systems that mimic biological counterparts. I will not argue for each in their totality, but as branches of the foundation wherein to explore if a mimic-purpose machine, i.e., a mechanical owl can be made

1. to behave like its natural analogue in a close an approximation as possible (where available), and,

2. allow the machine to develop independent behaviors as a consequence of its own experience by making choices.

while simultaneously serving to give insight into how an artificial system would evolve in its "genetic" isolation while cooperating with other entities in an environment within the range of its experiential ability. But where does it all rest? I will argue the dynamics of choice and by quantifying them, a series of study can unfold to get at least the smallest definition of *free will* and what it means to artificial systems and their adaptation strategies in a tangible environment in the operational paradigm described and used by Walter.

With that, I now will turn to discussing the compendium of my body of theory and expression called *The Method of Artificial Systems.*

3 The Method of Artificial Systems

Section Overview: I will start with the basic premise that nothing of relevance to the topic of this thesis can be obtained absent of a cohesive method of expression that will guide all subsequent depictions and models derived as such. I will make a series of arguments designed to illustrate my thinking processes regarding this subject. My first argument is I believe that if a machine is given the ability to make choices and as a consequence of those choices, possesses the feature of the direct experience of entropy, it will foster emergence, manifest behaviors not accounted for in theory or experiment. *Choice* is the key word and will be used as an epistemological foundation for theoretical and experimental manifestation of what I propose in this thesis.

3.1 Method of Expression

It is an expression of the method that the manifestation of the machine in independent articulated form should be autonomous and not privy to interference in learning categories and behaviors from an active outside entity. It consists of three methodological assumptions and the resultant questions that are firstly derived from them.

Method #1: If a machine can be made to mimic biological life, it has access to those kind of experiences attributed to it.

Resultant #1: Will the empirical ability to make a choice and possess knowledge of it foster richer behavior motifs?

Method #2: If a machine can make a choice, it portrays some level of consciousness.

Resultant #2: Does the notion of free-will and the power to make choices foster a rudimentary sense of self-awareness?

Method #3: If a machine has knowledge of its death, it fosters emergent behavior.

Resultant #3: Does the placing of a polar opposite to life preclude an organism to conspire against it?

In order to develop a clear picture of methods concerning my inquires, I will attempt to balance my assumptions with clearly defined concepts from historical renderings as well as those arriving from my own experience. Although neither can be absolutely quantified, where possible I will qualify by juxtaposition with established tenants such as those realized in ethology, fuzzy logic, finite state automata, and self-constructors. It is my sincere hope to explicate a template by which artificial beings can be realized in technology, a set of laws can be authored, and wherein future generations can be established based on a "foundation" theory. I see the current state of AI / AL as a patchwork of theories, experiments, and realizations and I would like to introduce a unified language weighted with concepts narrow enough to allow complex machines to interact with human societies.

3.2 The Choice Methodology

The tenets of biologically-inspired robotics are founded on the principle of robots who mimic typified life forms[8]. The foundation is divided into two principles:

1. Attempts to create functional robots based on living systems,
2. Creating robots to understand biological systems[3].

Let's take a look at the methodological assumptions listed in §2.1:

Method #1: If a machine mimics biological life, it has access to those kinds of experiences attributed to it.

The arguments in this thesis are engaged in the first principle since I am interested in creating functional, autonomous robots who can subsist for themselves in an environment free from human intervention. To this end, the machine must resemble a natural form and function in some sense of the words to make it recognizable when viewed by a participant. In order to necessitate forms and functions, a typography of life forms is required to ascribe relevant behavior necessary to the type of machine desired.

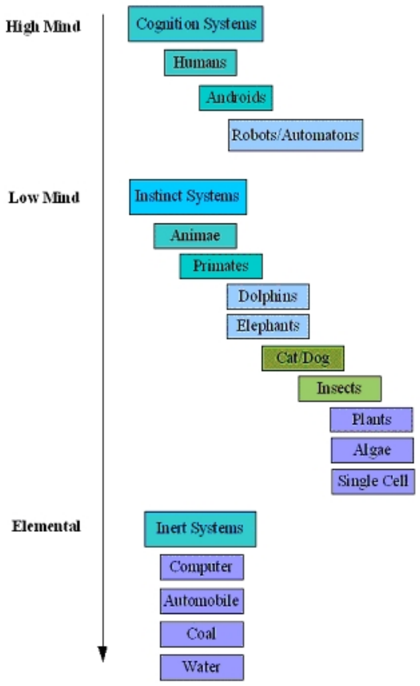

Figure 1: A Cognition Hierarchy

Figure 1 represents a hierarchy of available objects of the systems comprising a planetary body, in this instance a closed system. It is organized by decreasing emphasis in ascribed intelligence. I have divided the continuum of life into three major categories: Cognition, Instinct, and Inert. Within the categories are sub-categories contrasted by their inherent complexity. For example, in the cognition group, humans are at the top of the hierarchy because of their contrasting complexity to the other members in the group. Androids are lesser as they are designed to mimic humans but are not necessarily privy to the level of complexity manifest in humans, however, dependent upon the level of technological development. Robots and automatons fill the rest of the category as they are less complex than androids but more complex than the members of the instinct group. At the top of the hierarchy of instinct systems are animae. Animae are synthesized animals. Ideally and dependent upon the cleverness of the programmer, they are more complex than the other members of its group. Animae can be in the form of cats, dogs, or other synthetic animals. Animae is a noninvasive place to start investigating questions of the properties of what constitutes a synthetic life-form; they are complex enough to inspire interesting research questions. Currently in artificial intelligence, these pursuits are done in instinct systems which may or may not yield interesting enough results for purposes of artificial life. However, it still may be of value, high enough in the list to try to understand agents, particulates of intelligence, as a function of automata entities in computing environments. It should be noted that a third system does exist within the frame of this definition, the inert. In a physical sense, the inert plays only a peripheral role to both systems; however, in an abstract sense, the inert plays a crucial role in establishing a closed-loop context. It aids in ascribing and formulating behavior and choice strategies of the other two systems. In such a view, it is a third-party. Intelligence is ascribed as a sub-property of each system and arranged in a hierarchical form by the entities that fill each of them. This arrangement is by no means authoritative but serves to illustrate the difference between organic and inorganic systems and where the concept of life may be empirically understood.

For the purposes of the research, I make the assumption that cognition is a state of self-actualization[9]. We, as humans, know this phenomenon only from our own experience and can only approximate the experience of others, including other types of living systems. This, however, should not prevent a broader definition since our degree of approximation is limited by the definition itself. Firstly, there is a line of demarcation between a cognitive system and an instinctive system. A cognitive system is the result of a complex evolution of an individual's experience and an instinctive system is the result of the propagation of genetic information between generations of living entities. Secondly, a cognitive system has the ability to extend beyond the quantity of genetic information of an instinctive system and expresses a qualitative difference. Thirdly, this qualitative difference gives rise to two equal yet distinct states of being—the high mind and the low mind. Therefore, cognition is the ability to direct changes on continuous events. Instinct is the inability to cognitively affect the outcome of continuous events. Although there are anomalies that may traverse the definition dependent upon empathetic qualification, I argue it holds for most entities.

3.2.1 Analysis Toolbox, Part A: The Choice Complex

Method #2: If a machine can make a choice, it portrays some level of consciousness.

The question regarding choice is: can a machine make a choice and if it did, would it be a meaningful one? On the condition that artificial life is no different that organic life, if an organism is dependent upon its survival and purpose, i.e., obeys the law of entropy, then it must by default make choices regarding the success or failure of its species. This mechanism is the characteristic theory of evolution[10]. If a species could not make the proper choices, adapt to changing conditions, then it will become extinct. This feature needs to be extended to artificial life forms to see if the quality of artificial life is real or an imagined property in cybernetics. I argue this is the only way to know for certain whether or not the forms are alive and prone to the forces of evolution. An architecture should be designed that sets the purpose of the machine and its behavior as an emergent property exhibited in its choices.

How is behavior generated from architecture, how can the intellectual link be made? I argue that I can test scientifically the concreteness of a finite system comprised of a series of choices that determine life or death. I extend this argument to synthetic machines for if they are to be considered truly alive, then they must obey the basic condition that they can die and that they have knowledge of it. In biology, this trait of death is of a decreasingly loss of faculties or entropy, or in physics, the decay of energy in a system.

In the case of choice, there is the work of William Grey Walter. His experiments were the result of his curiosity of how the brain resulted behavior.

To this end, he constructed three-wheeled automatons donned with lights that searched out other lights. They were analog devices which used triodes and amplified feedback to mimic types of behavior. The feedback between the circuits caused the machine to display four distinct types of behavior qualified by the observer. The problem with Walter's analysis was that many of his assumptions were not tested outside of his own research and when they were in the late 1990s by Owen Holland, many of Walter's assumptions were wanting[3]. However, what is interesting here is Walter's notion of 'free-will', or choice, exhibited in his machines.

In commentary from O. Holland:

> In his writings about the tortoises, Grey Walter gave much weight to an attribute he called 'internal stability'[1]—the claimed ability of the tortoises to maintain their battery charge within limits by recharging themselves when necessary. A feature of the tortoises' circuitry was that, as the batteries became exhausted, the amplifier gain decreased, making it increasingly difficult to produce behavior pattern N (negative phototropism). Holland (2003, p. 2108-9)

Which is the attribute to avoid the light in the charging station where the 'feeding' took place[8]. I am extending this notion to the theory presented in this paper and postulated experiment.

Method #3: If a machine has knowledge of its death, it fosters emergent behavior.

This theoretical assumption is simple: If a machine know it can die, this knowledge and direct access in manipulating it physically, will cause emergent behavior. Emergence is a property apart from the collection of quantification of its parts. In the following section, I will delineate a design that will facilitate the principles set forth in this methodology. Physically, this is realized in what I call 'The Entropic Circuit' which will be introduced in §4.2.2.

3.2.2 Analysis Toolbox, Part B: Architecture Theory and Design

The design of the artificial life system is firstly defined as a series of goal-based assumptions that guide the development of the methodology. I will outline a set of four goals that will foster a successful synthetic animal or animae.

1. The first goal of a successful cybernetic system is that it should be fully autonomous. That is, once the system is started, it should require no further input from an external source or operator. In order to be autonomous, the system should be self-sufficient; i.e., have all the components necessary for its operation installed, variable in component and configuration depending on the expertise of the engineer. But when the system is brought online, it should run continuously and without fail.

2. The second goal of a successful cybernetic system is that it should exist in situ or in context with its environment. It must be able to access experience from a native stimuli-response model with which to compose unique algorithms.

[1] Walter borrowed this concept from his contemporary W. Ross Ashby who performed an exhaustive treatment of it he called the homeostat.[12]

3. The third goal of a successful cybernetic system is that it should possess a system of behaviors relevant to its being. It should also have the ability to evolve and eventually reproduce.

4. The fourth goal of a successful cybernetic system is that it must be in behavior indistinguishable from any other living system it mimics.

3.2.3 Analysis Toolbox, Part C: Automata- and Agent-Based Domain Considerations

Automata-based systems are the core of the programming domain. They serve not only as descriptors for the system logic, but for matters of reflection as well. Automata are most powerfully realized in the architecture of both the hardware and software design paradigms and it is here where they will be more directly applied. As automata can lack the appropriate control factors, it is the introduction of agents that will express this desire in the software code.

Agent-based systems are also being considered as they possess the required features in their functional programming tasks: they have the ability to acquire data from sensors, express that data in code, and can act upon it by using effectors, which are simply a sensor device that has an I/O capability such as vision or movement. They are best deployed as efficiency monitoring programs concerned primarily with system robustness. As the new architectures are developed, the will be explored and deployed to delineating the analysis of choice and the subsequent discoveries deriving from it.

3.3 The Problems Under Consideration

This thesis can be broken down into the study of the following problems:

1. The Problem of Energy

2. The Problem of Communication

3. The Problem of Coordination (Control)

4. The Problem of Raw Materials (Construction and Reproduction)

These problems will be delved into at different points in this thesis by references to various features present in the designs I proffer, the theories I propose, and the postulates I suggest. I firmly argue that all research into aspects of AI / AL fall into one of these four problem-categories.

3.4 The Conclusions

The combinatorial and multi-faceted approach will yield successful results.

4 Orchestration and a Feature of Choice

Section Overview: This section addresses the research question: Can a machine make an aesthetic choice based on a nondeterminate conditioning in a collected and coordinated learning environment? Coordination/Orchestration: Robotic colonies are becoming of more interest and of more value technologically than other problems in automation. It is the task represented in the concept of orchestration that is of non-trivial interest in this paper. Here there will be an honest attempt to insure the problem is NP-complete and exhaustive of the purposes outlined here. However, briefly stated, most of the efforts classified as AI or AL will be concerned with constructing automata- and agent-based programs.

4.1 What is Orchestration?

Defined simply, orchestrated robotics is a means of distributing energy and information across a network of social robots. The caveat here to note is the distribution of energy clause[2] which, in order to be true orchestration, must contain a central computing complex[3] and a series of mobile automatons that exchange the power and information wirelessly[4]. Such an enterprise can be complex and, in terms of physics, it relatively is; I say 'relatively' because once one grasps the basic concepts, it is understood that extending them to multiples and a means of achieving a wide enough resonance width wherein the power is transferred and acts as a carrier for information can pass through at the appropriate distance is a powerful solution. However, realizing that the orchestration might exceed the limitations in the middle range exchange factor of the transmission, the use of transponders seemed a reasonable solution. They are simple: binary and trinary coils with large surface area antennas to pass the signal to the robots extending the mid-field and reducing the work required by the core to generate less stable signals in the far-field.

It is highly advantageous to apply agents which would mitigate the architecture of the system and execute a program based on the locations given to them through their percepts and sensors, perpetuated though their effectors and actions.

Orchestration in this unique instance takes the form exhibited in the following figure:

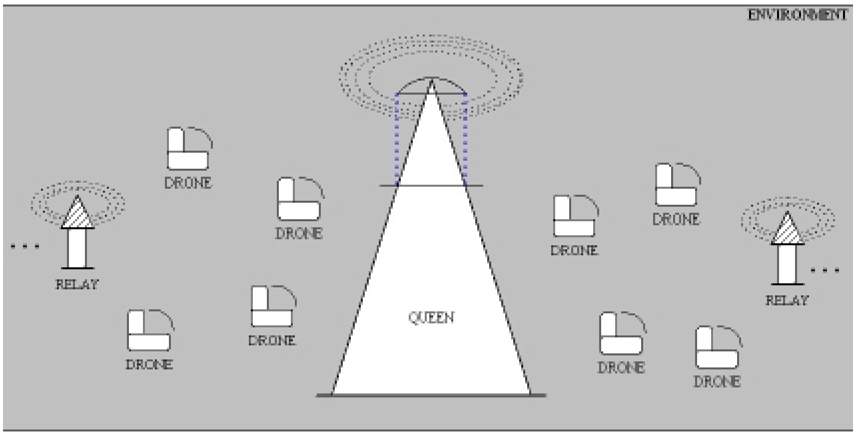

Figure 2: An Orchestrated Robotic Network

[2]The first problem under consideration from §2.3.
[3]The second problem under consideration from §2.3.
[4]The third problem under consideration from §2.3.

Such a system would be capable of operating in remote or hostile environments too dangerous for humans while at the same time compatible socially to cooperate internally and externally with those providing the system directives and instructions.

4.2 Choice Featured Runtime

The feature of choice can be measured as a consequence of causality, what reactions were observed following certain empirical actions. Coordination at runtime of a robotic colony controlled by a centralized computing machine (e.g., the queen) engaged in a many-parallel I/O with worker robots (e.g., the drones) not dissimilar to colonies of this type seen in the wild is the first step to understanding orchestration. Some examples include bee or ant colonies. The problem can be broken down into its component sets by following the biological models and mimicking them in technology.

4.2.1 Choice Features

There are a deterministic set of features which can be obtained by quantifying behavior in the relativistic natural system considered for replication. Features present in the natural system can necessarily be considered for replication if they can be quantified into an automata state-machine logic.

Choice is narrowly defined as a pathway entity toward a goal-seeking behavior. Behavior is defined as a collection of choices requisite to a pathway solution dependent upon environmental factors weighted by an acasual mechanism called free-will. Testing these paradigms is irrelevant as these systems can be widely observed in nature; however, quantifying them into a software domain is a non-trivial task.

4.2.2 Choice Quantification

There must be two features in tension against one another to allow choice:

1. Instinctual runtime,
2. Cognitive runtime, whether a conscious or unconscious stub.

These two parental categories rely on the creation of events to flow from one state to another; these events are either triggered by external or internal stimuli. Each state is available for analysis at any linear time by reflection into the code blocks created as a function of the placement of them at the time of creation, and as a function of reaction to external stimuli. The culmination building a unique new feature which replaces the previous state. This is called experience. Each experience is contrasted by the tension between the two parent categories based on range governance (see §5.3.7) and through feedback, presents a cognitive workflow which is a hybrid of the two original features. However, a caveat of the system is that the hybrid state cannot be subject to analysis within the host system; instead, it must be analyzed by impassive observation initialized by a third party resource.

This precludes that in order to study choice in quantified terms looking for the *motivation* of the choice and not the assemblage of choices themselves, that several individualistic or autonomous systems must be harmoniously cooperating in some sort of orchestration. This eliminates most robotic systems now in use that look only to autonomy and social interaction; this also eliminates most of the adaptive machines currently under experimentation. I argue in this draft setting that hive-based automata state machines are the only structures able to withstand the conditions of stress in the environment and are subjected to the forces of evolution with as much import as their natural counterparts to human societies.

4.3 The Relevancy of The AI Problem in Orchestration

AI systems are classified into one of four categories:

1. Systems that think like humans,
2. Systems that act like humans,
3. Systems that think rationally,
4. Systems that act rationally.

Although there is some fuzziness that exists between the types that are exploited in this thesis, conditioning the relevancy of the problems I mention will not be.

5 Testing Choice: The Robot and Featured Power

Section Overview: This section is divided into two distinct categories, the robotic platform, responding to the Problem of Energy[5], and the onboard system inclusive of hardware and software. The onboard systems will be further divided into subcategories of platform hardware[6] and system software[7]. Featured power is a generalized term that expounds upon the conditions set forth at the beginning of this thesis and inspires a control system based on the parameters it allows for.

5.1 Featured Power

I offer the following experimental design to empirically test the notion of choice, survival, and the possible consequence of emergent behavior. I designed the Featured Power Environment (FPE) as a means to substantively give the machine the ability to make a choice between types of operational power necessary to its onboard components. The hardware design is based on transformational, structural logic approach[12]. I argue that an understanding of such a transformation logic system will illustrate empirically the relation of choice to behavior in the machine and to test whether or not the notion of the survival complex is a mechanism that will lead to emergent properties. The general schematic of the system is illustrated in Figure 3.

[5] Please refer to §2.3.
[6] Relevant to Problems #2 and #4 of §2.3.
[7] Problem #3 of §2.3.

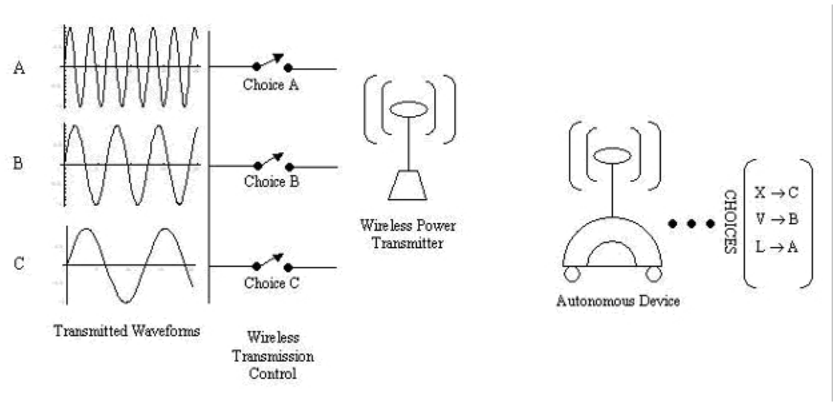

Figure 3: Featured Power

The waveforms to the left of the figure are a spectral view of the transmission representing the total power in watts. The spectral forms are real power to be consumed by the machine. Depending on its current task and necessary power to perform its programmed task, the machine is allowed to estimate its consumption and make a choice as to the type and amount of power it needs. Listed to the right of the figure, Level 'A' is the highest power level energising all onboard systems. 'B' is mid-range powering motor functions and a some sensors. 'C' is sleep mode. These three hierarchical functions form a trinary computational system in addition to the more generalized binary modes of the generic computing device.

There are three modes of operation for the device shown in Figure 3. Sleep, average, and high power represented by C, B, and A respectively. At a given time, the machine receives a level of power necessary for its operation. For example, if a general-purpose robot has a power consumption rating of 15VDC with a current draw of 0.125A, it is necessary to calculate the consumed power at an instantaneous time in watts:

$$P_s = ExI \tag{1}$$

Considering the type of transmission and the necessity to transmit only the proper amount of power, a pulsed system would be preferred to a constant wave (CW) system to have the machine consume power at intervals instead of in a stream[13](438-43). Nevertheless, a pulse period of $10\mu s$ should suffice to power onboard components. Clock speed of the processing bus (for example 1 MHz) should be made to agree with the pulse period to keep the power flow symmetric with its computational speed. In this way, unless the power is used by a loaded circuit, it will not transmit more than the quantity we have set for it by the frequency of the wave. For example, the power of each waveform is:

Waveform A: 15 volts x 1.0 amperes = 15 watts,

Waveform B: 15 volts x 0.500 amperes = 7.5 watts,

Waveform C: 15 volts x 0.200 amperes = 3 watts.

In the early part of the experiments, I will expect to send a higher quantity of power than what is anticipated by the system. This is to account for loss in the transmission. The method is prone to some leakage and specific features of the utility of the prototype will be included in §4.3. Briefly, though, it is advantageous to choose a carrier frequency and have the bandwidth resonance include the likelihood of feedback, allowing messages to be included on the transmission.

5.1.1 The Robots under Test

This system has been designed to fit with *any* type of robotic system currently on the market and inclusive of those machines under development for future release. If what is discussed and subsequently deployed cannot be made universal, then I argue it is worthless. Subsequent, then, there are two different kinds of robots under test:

1. Generalized platforms,
2. Specific components (hardware and software).

I will discuss these types in the following sections and delineate how each are interconnected to form complex loops that can aspire for a rich tapestry of intention, response, and behavior.

Although philosophically I ascribe to Platonic dualism, I will not argue for emergence based on these or other philosophical treatments. In contrast, I would like to see such a feature quantified with rigid experimentation and proof. However, I cannot discount the appeal of a system that experiences an inner world of metaphor and imagination not unlike ourselves–if only given the freedom to allow for it. Therefore, while I will strive in the belief that a system complex enough experiences emergence directly, I will not anthropomorphize the features I argue. Instead, I will use them as the driving force for the abstractions in software coupled with the ability of the machine to make its own choices regarding whether or not to implement such conditions directly. It is for future research on tangible machines where such fuzzy concepts can be better illustrated to a wider audience.

5.2 Robotic Software Abstractions

Based on §3.2.2, the necessary software abstractions are the meat of this work and the works that will extend beyond it. At the time of writing, these abstractions are rigidly-defined but loosely-coupled to real-world interface development environments (IDE). However, these abstractions are well-understood in an empirical sense and will find their way into software as the technology allowing for their functions to come to fruition.

5.2.1 How Successful software abstractions can lead to interactive machines.

The Software Paradigm

The software architecture possesses the same transformation-logic array of the hardware model. The software paradigm is a modular, domain-specific programming language; it parses, sorts, scripts, compiles to objects, transforms, and generates input and output channels. A domain-specific language (DSL) is created specifically to solve problems in a particular domain and, in the general case, is not designed to solve problems outside of it. In contrast, a general-purpose language (GPL) is designed to solve problems in many domains with an extensive toolbox that does not necessarily focus on the specific case. Many DSLs do not compile to byte-code or executable code like GPLs, but to various kinds of objects. DSLs have exposed APIs that can be accessed from other programming languages without breaking the flow of execution or calling a separate process. Thus, they can be designed to operate as programming libraries[14].

5.2.2 What kinds of abstractions are we talking about?

Functional libraries derived from abstractions in automata-based programming corrected and moderated by agents. This insures an onboard self-correction mechanism in place in the earliest prototypes that can report the internal homeostasis point in order to generate scientific data. From the earliest works, the data can then further the advance of studies. These sections will be better supported in future versions of this draft.

5.2.3 How independence can insure long-term perpetuation of intelligence.

Autonomy is a fundamental foundation of intelligence which will be emphasized at the duration of this work.

5.2.4 Learning survival at the cost of existence–The Entropic Circuit.

One of the most striking features of this design is that experiments can be conducted continuously and without limit. As long as the transmission system is powered, the machine will remain online. In this way an equilibrium can establish a baseline between life and death. If the machine does not make the right choices to enhance its survival, it turns off and effectively dies. If it does not send the proper signal to the transmitter, it will not receive the proper power. A small capacitor contains enough charge to keep it active for a 90k mS countdown once the power is too low or not available for it to further perform. The experience gained from its life cycle is held in a volatile memory device that will be erased if the power is off. An additional strength of the design is since it remains online continuously, observation of long-term behaviors can lead to advances in understanding artificial ethological concepts in the model under examination. The physical realization of entropy is designed to be an add-on to the existing general robotics platform. Called the Entropic Circuit, it is part of what I term a domain-specific robotics platform, similar in breadth and scope to a domain-specific computing language. It is illustrated in Figure 4.

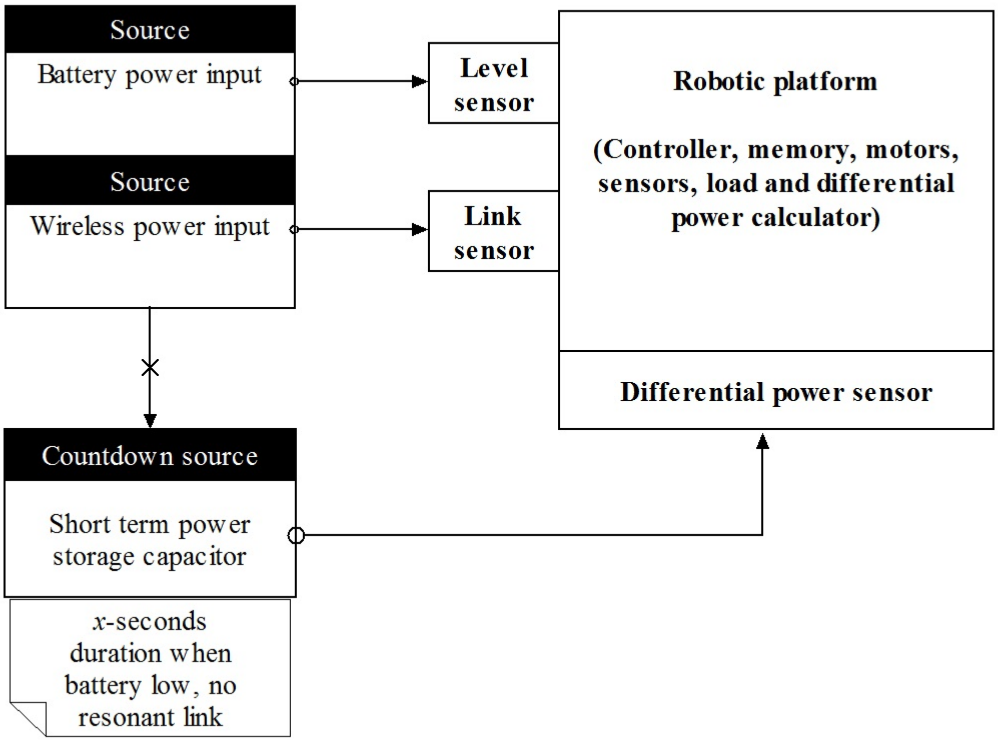

Figure 4: The Entropic Circuit

5.2.5 Scenario Coding

A notion discovered during the research of this thesis is a concept called 'Scenario Coding'; this was created to allow for the increasing levels of complexity realized in software programming. Scenarios, or programmatic layouts, are similar to the creation of landscapes in artistic or engineering activities.

Scenario coding is a concept I imagined as a consequence of reading fiction or listening to music and coming to the understanding of the substance 'between the words', i.e., the inherent meaning extracted from the words, enhanced in some cases by distinctive music at certain tones designed to give the reader / listener an experience. Casually noticing that a combination of sensory input patterns can inspire a richer experience that each independently and in some cases enhance intelligence through stimulation of curiosity driving ambition, I wondered if I could capture the essence of 'between the words' in a software archetype. It this aesthetic that I would like to somehow contain in a logical programming domain in a variety of contexts as discussed in this thesis.

I will leave this subject for now and continue to pursue it as my education continues. Next I will address more physical designs, experiments, and some proposed avenues to proofs I anticipate I will traverse.

5.3 Wireless Power: The Queen-Drone Transmission System

The idea of what I call 'The Queen-Drone Transmission System' stems from a series of prototypes constructed between the years 1996 - 2004. The most influential of these was the Model 'F' Wireless Power Unit built January to April 2004. Based on Tesla's wireless patents #645576(US), 'System of Transmission of Electrical Energy' and #723188(US), 'Method of Signaling' the prototype showed that a sufficient amount of power in the form of an electromagnetic carrier wave could be transmitted from point to point powering a small off-the-shelf robotic called 'i-Cybie'. As further investigations and tests were accomplished, I discovered that the transmission was mathematically rendered using a calculation of areas. The power was distributed over an area dependent upon the surface area of the transmission pad and a summation of the receiver pads. Barring leakage (transmission loss), the total receiver area was proportional to the transmission area forming a linear relationship between them. What proved to be the most interesting aspect of this work was the discovery that signals could be passed between a central core (a queen) and a series of smaller mobile 'worker' robots (drones) allowing for more complex hardware and software configurations forming the basic of orchestration, a novel and strongly defined concept in this thesis. Although not well understood experimentally, it is for the work to be conducted while researching this thesis, to conduct the experiments, render findings, and publish results. This requires the input of funding as well as laboratory space; it would be of substantial interest to generate monetary assistance from the European Union (applied for June 2007) to gain experience and develop this unique technology.

A discussion of the system in relevant to illustrate how the theories of examination, relevant to creating a computational model, have been conducted leading to the proposed comprehensive prototype.

The Model 'F' is a mulitvariable electromagnetic field generator, the principle of which, has been captured by a research group at MIT[16] providing an independent proof of the viability of this type of technology. Such a system was exemplified by Asimov[17], as an inspiration and visualization exercise, it helps to objectify the machine. Figure 5 is a picture of how the MIT system works; the Model 'F' and the Queen-Drone system behaves in a similar manner save that my system can additionally carry information to waiting groups of machines.

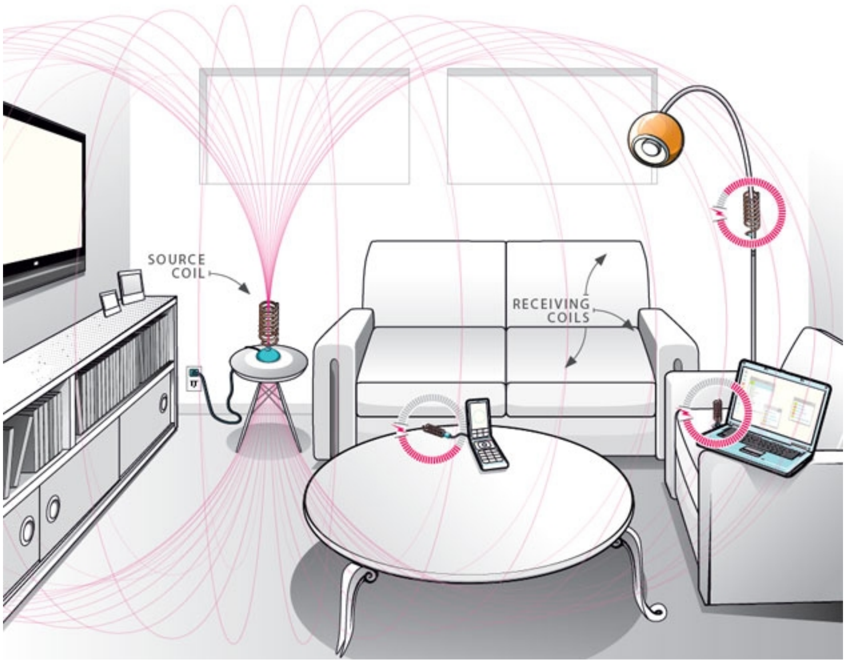

Figure 5: The WiTricity (MIT) Transmission System

My intention was to use my prototype to power a robot whose power demands would rise and fall dependent upon the work done. This meant that the voltage would stay relatively constant, but that the current would change. The thin winds of the spiral couldn't generate enough energy at the surface as the impedance was quite high. I discovered a solution that would allow the power to transmit through a third coil and allow me to embed its receiver inside the robot itself, replacing the battery pack. The Model 'F' wireless power transmission system is illustrated in Figure 6:

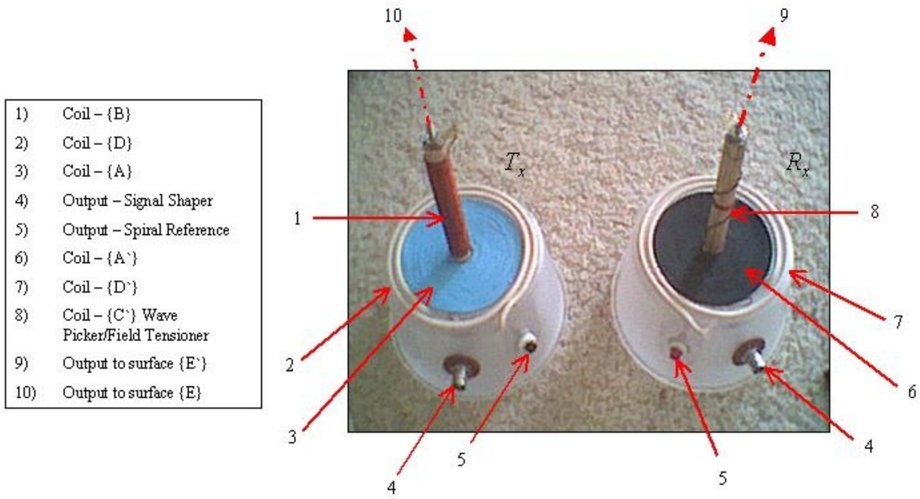

Figure 6: The Model 'F' Transmitter

And the i-Cybie battery compartment showing the card installed (Figure 7).

Figure 7: i-Cybie and Receiver Card

The original Tesla system transmitted power from transmitter (Tx) to receiver (Rx) only. Both systems used rather large spiral coils (around 40cm in diameter) and were too large to be hauled around by a robot. I understood that if the spiral windings could be tied to linear coils, they energy could be transferred at higher power and introduced the coil (B) on upward shaft in the center of the spiral in agreement with the operational band of the tuned system. This meant there was a third component of the design; power would travel in the same manner, from spiral A to spiral A', but the magnitude of the energy was shifted in phase to an ancillary card onboard the i-Cybie (Figure 7). The operational frequency was set to 78MHz, the amplitude to 24VAC at .125A, which was enough power to provide 6VDC (1.15 to 2.80W converted by external circuitry) necessary for the robot's operation. Operational threshold was a maximum of 50VAC at 0.06A.

While conducting these experiments, I discovered that the behavior of the wave was a function of the space inside the receiver bay and not a direct function of the surface of the coil. I had to revisit my extrapolation of the theory and take a look at how I was describing the geometry of the system architecture.

5.3.1 The Geometry of the Problem

Consider a transmission *space* equally divided into geometric blocks in three-dimensions, a container, as illustrated in Figure 8:

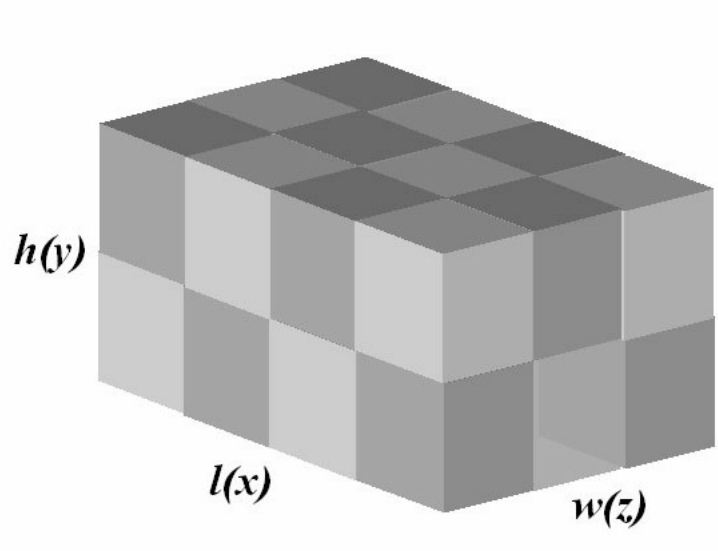

Figure 8: Blocked Spaces

Within this space lies the intersection of three planes representing the charge surfaces of the vectors of the transmission waveform:

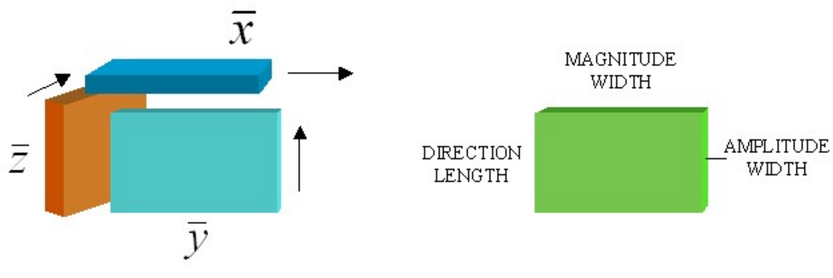

Figure 9: Transmission Planes

That intersect with the geometric blocks according to the number of surfaces available to interact with the planes lying along each trajectory.

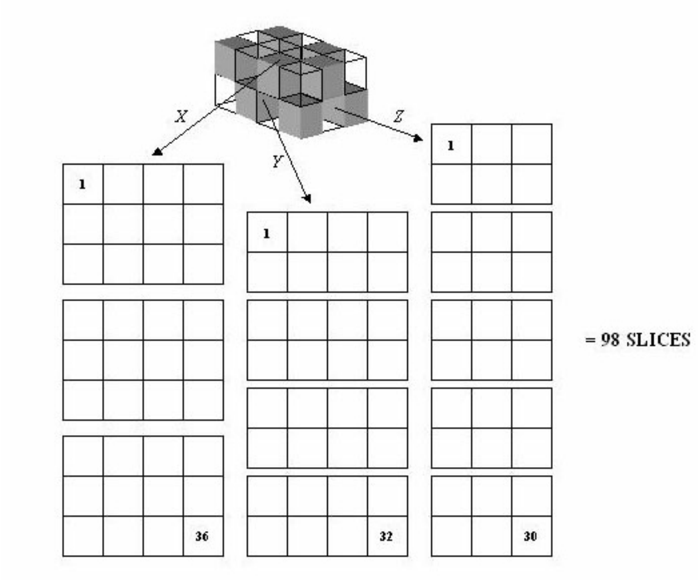

Figure 10: Container Slices

Each of the slices is organized by their orientation to the planar axes. For example, slices oriented along the x-axis would absorb energy from the planar wave traveling along the x-direction. The slices are from the top, middle, and bottom of the cubic structure. Slices oriented along the y and z-axes would absorb energy from the planar wave traveling along the y and z-directions. The equation describing this relationship is a simple algebraic representation:

$$\hat{X} = l(x) \cdot h(y) \cdot w(z) \tag{2}$$

Where:

$$l(x) = 4, h(y) = 2, w(z) = 3 \tag{3}$$

Solving this relationship provided the value of 24cm^3. To calculate the effectiveness of the space as a measure of usable charge density, I need to calculate the number of non-redundant slices in the container. For that I use the formula:

$$X_s = (l \cdot w)n_h + 1 \tag{4}$$

$$Y_s = (l \cdot h)n_w + 1 \tag{5}$$

$$Z_s = (h \cdot w)n_l + 1 \tag{6}$$

Solving:

$$X_s = 36, \quad Y_s = 32, \quad Z_s = 30$$

There are 98 non-redundant two-dimensional surfaces in the container. The next step is to alter (2) and multiply the solution by a potential given by the rating of the robot's battery potential:

$$\phi_T = \frac{\rho}{\psi}[X_s + Y_s + Z_s] \tag{7}$$

Where ρ is measured in volts and ψ a dimensional factor. Solving the equation at the potential of the i-Cybie:

$$\phi_T = 588V$$

The solution is valid only at a fixed point when the system is asked for a measurement. Within the transmission environment, the equation behaves as:

$$\phi = \frac{\rho}{\psi}\int(X_s + Y_s + Z_s)dt \tag{8}$$

Disseminating the planar waves along each of the quantiles aligned with the coordinates in the Cartesian system:

$$a = \int 36x\,dx, \quad b = \int 32y\,dy, \quad c = \int 30z\,dz$$

Solving:

$$a = 18x^2, \quad b = 16y^2, \quad c = 15z^2$$

The use of the indefinite integral defines the finite values within it as the system is not infinite. What do the integrals look like?

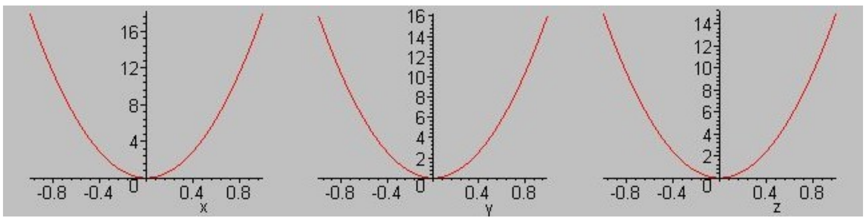

Figure 11: Mapped Integrals

As expected, each is a parabola. Since the system's core equation is generating a parabola, it is a non-trivial to visualize in a polar grid which here is especially useful where we want to express the relationship between points–translated into areas–expressed in terms of angles and distance for a spherical coordinate system in three dimensions, which in this case, is a spiral:

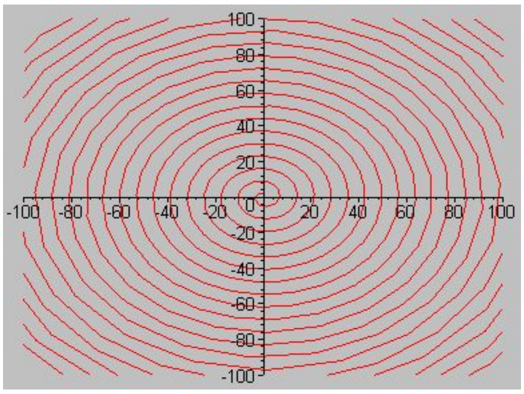

Figure 12: Characteristic Spiral

However, the system is a little more complicated than that and would be served better if a governing or characteristic equation could be discerned.

Consider an Archimedean spiral r_s with a number of turns n where the distance s between each of the arcs is constant, that is, dependent on some relation of $\int n\ dn$. The mean capacitance $\overline{C}$ on the antenna increases with n as well as the mean impedance $\overline{Z}$ over a nearly constant transmission time t. The equation governing this system is:

$$r_s = \sqrt{t} - t - n \tag{9}$$

The inner radius is given by:

$$r_i = \sqrt{t} - n \tag{10}$$

A more accurate representation of the system, now under governance[8] appears as:

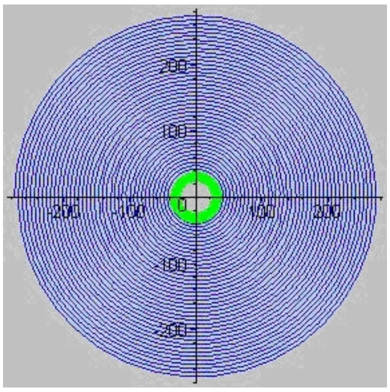

Figure 13: Optimized Spiral

[8]The principle of a functioning dynamic system must obey a core or characteristic equation that determines its array of subsequent behaviors.

Which is not unlike the physical windings of the system. I now want to assemble a composite solution and find an implicit solution to the equation with the right-hand side being equal to the potential of the system such that:

$$18x^2 + 16y^2 + 15z^2 = 588 \tag{11}$$

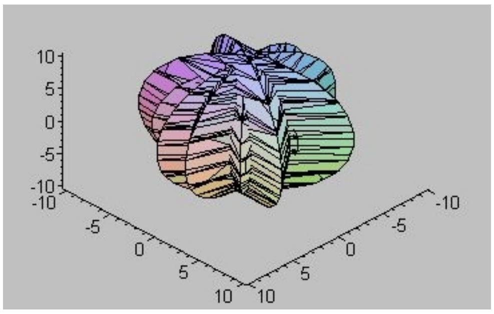

Figure 14: The Waveform

Inputting different stimulus values at the receiving port of the transmitter–#4 in Figure 6–shows the system is susceptible to range limits for differing values of ϕ.

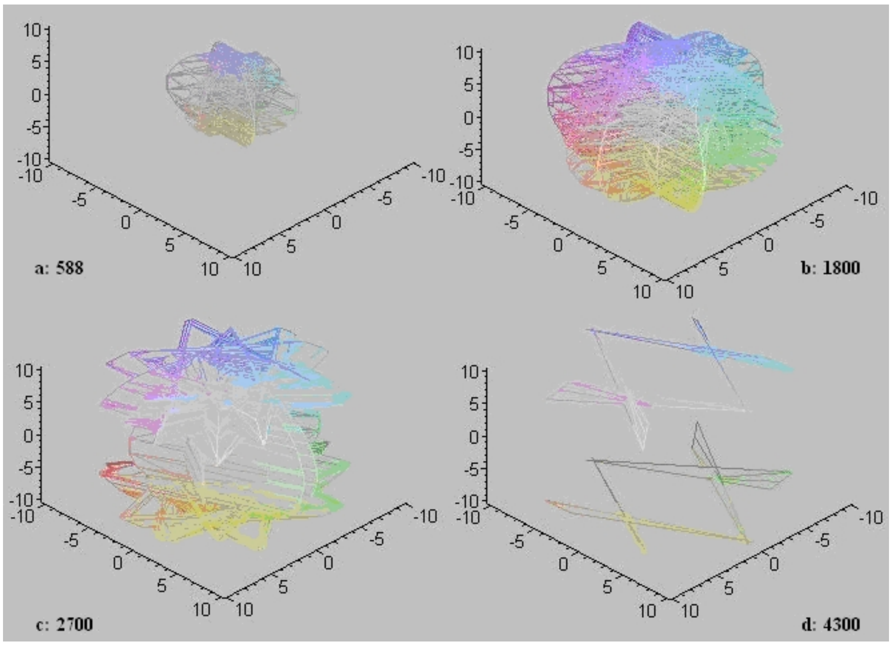

Figure 15: Range Limits

Which demonstrates it is a closed system at a specific resonance bandwidth which I recommend be studied in greater detail as this work progresses.

5.3.2 The Role of the Queen in the Colony

The queen represents a centralized computing complex that contains all the substantive hardware and software necessary to drive the system forward in operation, task, growth, evolution, and generational advances in the form of a rudimentary form of reproduction. A parameterized device, it responds to the programmed core of its design, behaviors, and paradigms without deviating beyond the bounds of a governing apparatus such as a bounded equation. This 'fail-safe' is built into the system to prevent undue or erratic evolution extending the colony beyond its intended purpose.

5.3.3 The Role of the Drone in the Colony

The drone represents a singular entity replicated in orders of hundreds or thousands to fulfill the role, task, and purpose of the colony. Contrasted with a single queen, they carry only the components necessary for their given tasks as created when the system was originally designed and proposed for operation, behavior, and environment.

5.3.4 Choice & Orchestration

These two concepts are irrevocably tied together and form two parts of a symbiont circle in this system. More to come.

6 Results and Discussion

Section Overview: Here I examine how to employ the data gather from experiments to support my hypotheses.

6.1 Numerical Components of the Theory

What constitutes the numerical domains of the problems discussed in this thesis are those dealing primarily with problems similar to those found in geometry, topology, anthropology, physics, and computer science. Each numerical relationship is derived from the balance between the machine under analysis and the human interacting with it forming a closed system subject to definable rules and an applicable ranges of limits.

6.1.1 Experimental Setup

The transmitter discussed in §4.3 was analyzed in a carefully designed experimental environment.

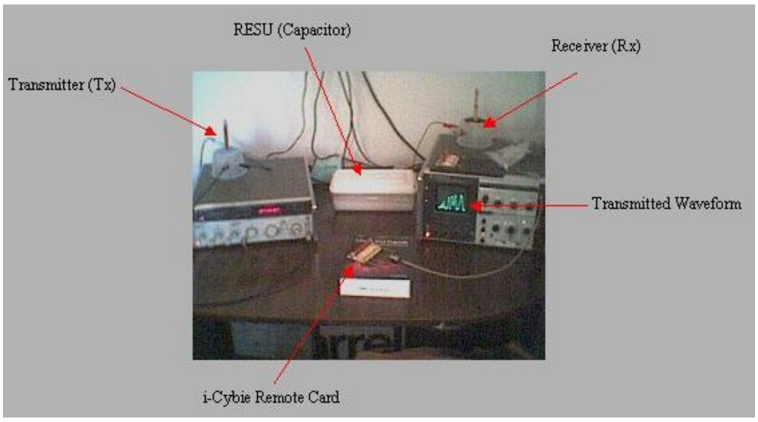

Figure 16: F Experiments

For this set of experiments, the setup was explicitly designed to gather reliable functional data of the Model 'F' transmission broadcast. This included the following test equipment:

- Hewlett-Packard (HP) 8640BOPT001 Signal Generator. Range (f): 10Hz to 512MHz, Range (p): -75 to +20dBm,
- HP4192AOPT001 Impedance Meter 5Hz to 13MHz,
- HP8553A, HP8555A with 141T display Spectrum Analyzer

Special attention was given to the calibration of the devices which was personally conducted by the author 14 months before the experiments were conducted. Each of the components in the system–cables, adapters, connectors, stop and feed-through terminations–were checked for their accuracy where appropriate or for their network values in both inductance and capacitance quantities as well as impedance and reactance values.

6.1.2 COMSOL Multiphysics Modeling

Simulation is an important consideration of the concepts comprising this thesis. A relatively new tool, Multiphysics modeling, implies that meaningful simulations of today's complex systems require arbitrary couplings between different physics phenomena in one and the same model. Such couplings in this thesis section denoted 'Wireless Power for Robot Orchestrated Colonies (WPROC) will attempt to analyze such a complex system and demonstrate tools for analysis. The coupled multiphysics models will be arbitrary couplings between:

- central transmitting complex (queen),
- mobile receiving swarm quad/bipeds (drones),
- control and orchestration of power distribution model.

Some more detailed questions relevant here are:

- What are the geometries of the system under study?

- How can the problem be broken down into manageable pieces for grant-based experiments, and into publishable results?

Referring back to Figure 2, in the discussion of orchestration §3.1, the description of the system under consideration for multiphysics modeling is a cavity-resonant conical transmitter/receiver with an extensible conic cap.

The queen is coupled (as a whispering gallery with ellipsoidal transmission pathways) to a collection of social autonomous robots, drones, who's quadruped bodies form a conductive shape and surface area creating a means of an inductive potential. They're body shape can transform its length along the x-axis and the z-axis by mechanical means of standing upright bipedally in an equidistant fashion. The purpose of the morphology is to allow more directional receivership at a cost of mobility speed. Some of the features are that this is a high capacitance, high impedance system—to aid in powering devices in the far-field where the edges of the eddy currents will be boosted in range by the placement of signal relays—of two flavors, coupled and uncoupled fields. Coupled uses a series of concentric circles on the charge and uncoupled uses a contiguous spiral.

Model Requirements: An electrically charged conic section powered by a single n turn Archimedean spiral coil coupled to a linear coil (filament) running its length along the z-axis. The spiral's outer radius $\mathrm{r_s}$, and inner radius $\mathrm{r_i}$ are arranged such that the radius of the filament $\mathrm{r_f}$ with length $\mathrm{l_f}$, is related to the spiral as: $\mathrm{r_f} << \mathrm{r_i}$. At the apex of the filament lies a conic section acting as a transmission antenna $\mathrm{T_a}$. The field is (smoothed / amplified / radiated) by an outer conic section $\mathrm{T_b}$. Consider the figure:

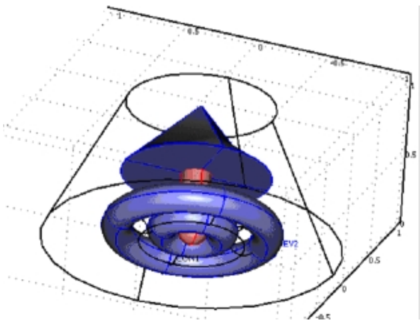

Figure 17: Primitive Model State

Here is expressed the queen transmitting apparatus. This model is simply a mock-up, to get a sense of how the functional model should appear resulting from the conceptual sketch exhibited in Figure 2. A more concise model, including the capacitance hooks and more detailed charge distribution is:

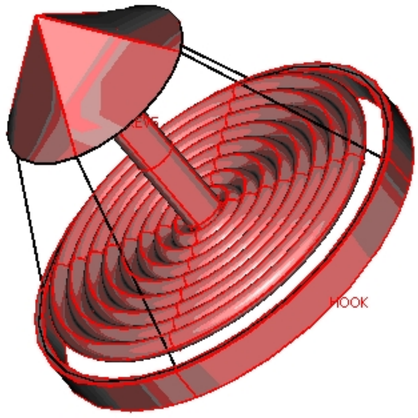

Figure 18: Composite Model State

This is the current state of the model at this time. It is for the continuation this thesis that it will be more worked out. However, it is also necessary to mention that the model provides no insight into its function without reference to an environment of some kind. In this instance, it is simply an area surrounding so that the equations can operate.

Figure 19: Simplified Model in an Environment

Figure 19 expresses the core as a function of its limit—at transponder minimum placement where the relays would be placed. The next task is to add the material and electrical characteristics.

6.2 Controllers

Here we discuss some of the ways the controllers for the system were virtualized and understood under such terms.

6.2.1 Visual Robotics and Virtual Controllers

In the Summer of 2006, Microsoft introduced a software development system called 'Robotics Studio', it offered a means of simulating the strongly parallel operations indicative of robotic architectures. Services could be manipulated and demonstrated on the computer's local server while simulation was hosted through a game accelerator called Ageia PhysX. While at the time limited to a few graphics cards, by the Spring of 2007, with the introduction of Active X plugins to the Ageia PhysX engine, the simulator was available to a more diverse population of Intel chip machines save those able to run virtual machines hosted within their operating system (OS). Coupled with the interface development environment (IDE) of Visual Studio (VS), controllers could be made completely virtual and highly modularized so that they could coordinate with other controllers and interfaces including those present in stimuli-response, audio-reactive, voice-command, and visual-stimulus models.

A direct result of working with this software is a controller method built in visual basic and XML manifest files not wholly unlike complex software entities used in commercial enterprises. This points to an interesting insight is a wide-scale commercialization of robotics maybe starting to occur now and continue on a path of evolution over the next decade. If this assumption is presented as true, then it is a race to create a motif of classification of differing types of robots categorized by their objectiveness in interfacing with humans–I argue a substantial measure of the effectiveness of machines. The future looks very clear that robots will form a niche in society; it is for us to determine what kinds of robots will be filling what niche by centralized manufacturing and custom-developed, common-usage software typologies.

The notion of building virtual controllers is much more streamlined than working with real ones; it is apparent that the field of virtualization and simulation will be the preferred method of prototyping new types of technology. It will be during the term of this thesis approaching dissertation that this notion will be explored further. However, to the present point in development here and for reference to these ideas, consider the following figure:

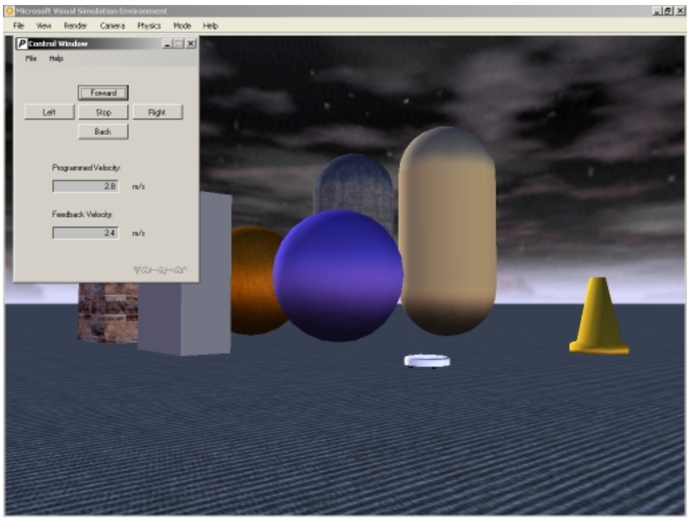

Figure 20: Simulation of Environment & the Virtual Controller

Here is shown a sample robot–a Roomba in this case from iRobot, Rod Brooks'[9] company–in an environment similar to that of earth in that it has the same gravity. The light conditions were programmed by myself and the objects

[9]http://www.irobot.com

are part of a catalogue available to the developer. In this case, I programmed the reaction of the robot to the objects in its environment, as a function of the motors. In this way I could understand if I applied a force to the motors propelling the robot, what kinds of shearing effects were present due to the surface of the ground and gravity? The result was a compensation mechanism that could measure the difference between these two numbers (shown in the figure). What would be the next step here would be to program an onboard camera with a visualization window (a window that would show the display of the camera) to 'see' what the robot sees. By performing these kinds of experiments, I can understand what is necessary to prototype a robot for particular environments. I can change the environment to simulate, say, the surface of Mars and include the necessary conditions the components of the robot would be subjected to.

Additionally, it is advantageous to work with programming 'blocks' when coding robotic architectures; it is apparent from works from Breazeal et. al. that the behavior required of a human-machine interaction and the associated emotional-logical capacities cannot be simply programmed in typical C++ manner. Despite objectification, a staggered tier of complex software concepts is becoming necessary. Memory management needs to be smarter and can self-adjust operations coming from heaps to stacks, the emotive responses of the machine to human expressions and tones needs to be represented in terms of entities. There are numerous ways of accomplishing this that will be addressed as the thesis progresses, however, it is a crucial affair to find an appropriate IDE wherein to code the abstractions of what will be the outwardly observed behavior of the robot. Granted, all the concerns I address are supremely complex to say the least, but if I can start to think about how a creature would compile facts about the real world, I cannot help but to try to address the abstractions represented in the software domain; as a domain-specific language that should be mapped functionally managed by intelligent agents. This is the point wherein I will begin this part of the problem.

6.2.2 Agents and their Effectors

Agents are a concept on the road to artificial consciousness. Coupled with the notion of autonomy, an autonomous agent is a powerful concept that can lead into many very interesting avenues of research. Stan Franklin (1995, 2003) defines an autonomous agent as possessing functional consciousness when it is capable of several of the functions of consciousness as identified by Bernard Baars' Global Workspace Theory (1988, 1997). Effectors are the parts of agent programs that interact with outside software components. Connections are made between the operator within the agent and the operation it needs to be performing.

6.3 The Choice Complex

This section will detail a set of proposed experiments–a consequence of the Choice Methodology–to test said hypotheses. I will detail here the extensions of the wireless power system outlined earlier in this document and I will reference where appropriate to give the reader a sense of how I plan to pursue the goals I have set out for this work.

The Featured Power Environment (FPE) is a design for a physical system to empirically test the aspect of choice in the machine.[10] It is inspired by the idea of Grey Walter's ideal of "free will" and its suggestion of the role of choice leading to emergent behaviors in the autonomous machine[18]. The experiment will consist of tests for consistency of a wireless power apparatus denoted the Model 'F'.[11]

I propose to set up and experiment to demarcate the details of the functions of the A, B, and C and the corresponding L, V, and X modes.[12] In order for this to be accomplished, there are two systems that need to be constructed to test the theory, a hardware and software prototype. The system I am authoring is quite unique and methodologically based, that is, it is designed to follow exactly the principles and tenants necessary for true artificial life. Additionally, I am deploying a method of transmission that uses musical structures transmitted at intra-audio frequencies via the computer's sound card to understand the features of resonance and communication between the stationary computer and the mobile robot. These structures will not be delved into with any great detail at this point as they are only postulates after the initial tests.

There are three modes of operation available: high, average, and sleep denoted A, B, and C respectively. In order for this two-way system to function—information one direction, power the second—there are two distinct circuits involved to satisfy the configuration: one residing in the transmitting array (queen) and the other in the receiving array (drone).

6.3.1 The Transmitting Array (Queen)

The Tx circuit is the first half of a resonant system. It contains a primary P and secondary S circuits shown in blue Figure 6. The windings are placed in a right-handed manner where P = 2 and S = 40. Tied to the tower are three differential power circuits that regulate the stimulus to Tx. A switch is placed at the end of the voltage circuits and before Tx so that the array is only energized once the stimulus is applied. There are four positions on the switch—A, B, C, and D. (High, mid, low, and null.) Control of the switch is dependent upon the collection of frequencies sent in the transmission and modeled in the software. When a switch position is engaged, the circuit between Tx and Rx is closed by its resonance at the given frequency. Power is then delivered at the chosen level. The polling time is 10 seconds, this means the array will transmit power for a duration of 10 seconds once a request is received then it closes (resets) the switch to the null state. This feature is subject to change as the system is constructed. Only when the switch resets to null will it listen for requests.

6.3.2 The Receiving Array (Drone)

The Rx circuit is the second half of the resonant system. It also contains a primary P and secondary S circuits shown in black in Figure 6, but is wound symmetrically opposite. At its output is the received power which, for the purposes of this experiment, is sent via wire for signal processing in a stationary

[10] See §2.2 for referrals to The Choice Methodology.
[11] See §5.1.1 regarding the Model 'F' experiments.
[12] Please refer to Figure 3.

computer. After processing, the data from the waveforms is sent for manipulation and handling in the software structures. The software is the predominant force in controlling the behavior of the hardware. It is envisioned that the control paradigm will be the responsibility of the mobile machine, or drone, to properly poll for energy and to communicate with the central fixed-computing nexus or queen. It is my intention once the software model is proven that the software can leave the fixed machine and migrate to a mobile machine.

6.3.3 The Software Model

In order to properly engage the model, a framework and feedback relationship is first established as a relationship between hardware elements. A sensor is installed between the capacitor storage system and the feed-through line in the Entropic Circuit. Please refer to Figure 4. It monitors the state of the energy stored in the capacitor and receives information from the load sensor which monitors energy consumption and sends periodic data samples when requested. The system strives for a state of stability[19]; dependent upon data received from the load sensor and the decision it makes, the power monitor sends a command to the controller that generates bits in one of three variations X, V, or L which corresponds to C, B, and A respectively. Computationally, X, V, L represent 2, 3, 4 in a $base_5$ number system designed as an extension, in this instance, to the binary environment.

6.3.4 The Experiment

I propose is to perform an experiment to test the notions I have set forth in a 'The Choice Methodology: A New Foundation of Structured Machine Life'. It is my intention to prove my theory by performing an experiment to legitimize my artificial life claims.

- Construct the data handling structure, a layered controller, and server distribution.
- Construct a method and testing environment for Model 'F'.
- Chart the operation frequency of the transmission system and test software integrity by sending processed information generated by the dynamic data structures.
- Discern the breadth and clarity of signals transmitted and received.
- Simulate the switching array and the Entropic Circuit.
- Test the virtual components and publish the results.

I expect the duration of this experiment to be one-year.

6.3.5 The Hardware Experiment

I will begin by using a laboratory setup in the following manner:

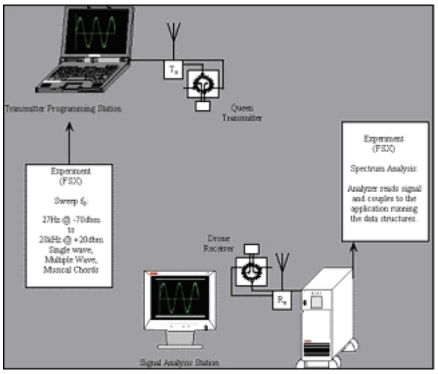

Figure 21: Choice Experimental Setup

The Transmitting Programming Station will simulate the queen by deploying software that uses the sound card as a signal generator coupled with the system clock crystal as an oscillator[13] to insure frequency accuracy of a minimum resolution of 0.005. The system clocks of most computers manufactured within the last few years can hold this accuracy[14]. Actual waves will be synthesized in the audio range by the sound card. A minimum expectation of accuracy of cards made within the past three years is 16-bits. The sweep range of the transmitter is $2^9 \mathrm{A_m}$ or nine octaves.

For purposes of calibration, a frequency counter is used to measure the accuracy of the signal generator. The counter is a device that measures frequency of oscillation of an incoming signal compared to a crystal oscillator as a reference. This is exactly opposite a signal generator. To properly task the system, two computers should be used that have comparable accuracies. To establish the measurement calibration, a self-reference will be taken by connecting a wire from sound_out (speaker) to sound_in (microphone) on the single computer, then to sound_in on the second computer to set a baseline of the difference (error) compared to the reference. I do not make the claim that this experiment will generate any absolute measurements, but relative in when the drone sends information on a particular frequency band to request power that it will be recognized by the queen.

The Signal Analysis Station will simulate the drone in software and test the functioning of the coupled apparatus. It also will simulate the components represented in the Entropic Circuit. The station will measure the incoming signal to Rx and pipe it to the software application.

At the present time, I plan to separate Tx and Rx by a distance of three meters.

During test, specific forms will be used to take observed data that will later be transposed into a digital document pursuant to publication. Digital pictures and movies will also be recorded.

[13]http://superpositioned.com/articles/2006/01/24/sound-card-based-signal-generators
[14]http://www.securityspace.com/smysecure/catid.html?id=51664

6.3.6 The Software Experiment

The first step is to create a database. I postulate that information storage and management is the most critical feature of a thinking machine.

Pursuant to the theory, the database structure contains a structured query language (SQL) corresponding to a set of tables with frequency, power, parameters, decision, and foreign keys linked to all the notes within octaves that can be generated within the range of the computer's sound card. The range of tones available is 13, or between the start of one octave and the next, taking $\mathrm{A_m}$ as the lower limit and $\mathrm{A_n}$ as the upper limit. Coupled to the hardware system, there are nine octaves available, the range represented by $2^9\mathrm{A_m}$. The hardware will be allowed to transmit up to four tones simultaneously to investigate the possibility of a method of information transport in the resonance structure of the chords for communication in future incarnations of machines. So that at the value's assignment X, V, or L (representing A, B, and C in the choice complex), is in breadth no greater than double the lower-limit frequency.

In choosing the database technology, cost and usage factors were considered. I made the decision to use a relational structure under open-source packages in SQL. Pursuant to this, I am using MS SQL Server Manager 2005, and EMS SQL Manager 2005 Lite in tandem with SQL Server Express v9.0.2047. A deeper understanding of the structural aspects of the database logic and the associated mathematics comes from Edgar F. Codd[20]. Applications that couple to the database will either be C#, Ruby, XML, or Java depending on design parameters.

The crux of the experiment is to understand why the structure of how the data is queried by the robot is of critical importance to having it understand the choices it has the ability to make contrasted with the failure penalty of death.

6.3.7 The Governing Equation

The software architecture possesses the same transformation-logic array of the hardware model. The software paradigm is a modular, domain-specific programming language; it parses, sorts, scripts, compiles to objects, transforms, and generates input and output channels. A domain-specific language (DSL) is created specifically to solve problems in a particular domain and, in the general case, is not designed to solve problems outside of it. In contrast, a general-purpose language (GPL) is designed to solve problems in many domains with an extensive toolbox that does not necessarily focus on the specific case. Many DSLs do not compile to byte-code or executable code like GPLs, but to various kinds of objects. DSLs have exposed APIs that can be accessed from other programming languages without breaking the flow of execution or calling a separate process. Thus, they can be designed to operate as programming libraries.

The domain in this specific case is a synthesized core governed by a simple parametric equation which would yield complex behavior:

$$y = \mathrm{a}\ \cos(\mathrm{t}){+}\mathrm{b}\ \sin(\mathrm{t}) \tag{12}$$

on a limit between 0 and 4, whose solution generates objects, tables, data structures, tools, and transformations. It additionally manifests channels that allow generic software to compile against its libraries. In this way, it seamlessly integrates with the generic robotics platform and its onboard default language set.

The domain consists of the following members:

- data elements,
- tables,
- parameters,
- an engine (virtual processor),
- an assimilation mechanism—the absorption of data from external data sources such as a remote server or computing nexus.

A further breakdown of how each of the members fits into the composite schema can be seen in Figure 22. At this time the structure is completely hypothetical and unique in this field.

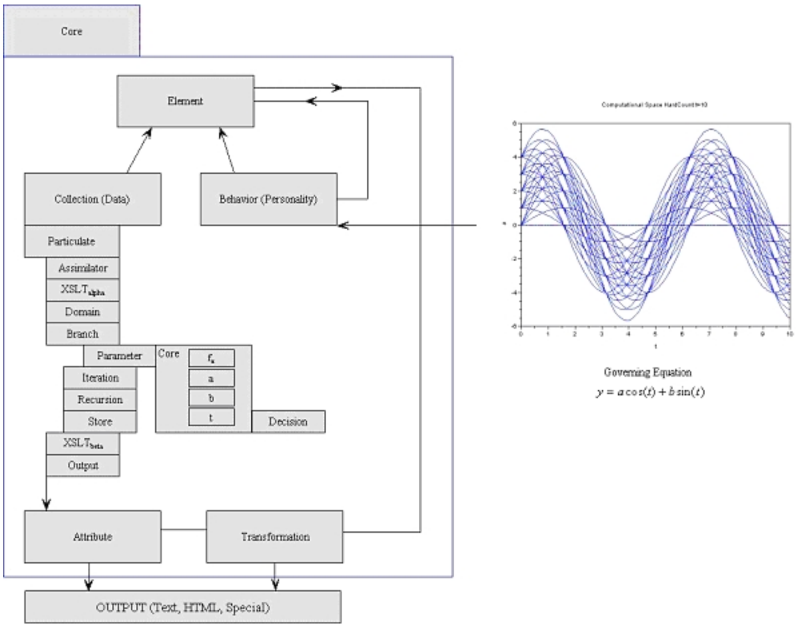

Figure 22: Software Structured Choice and the Governing Equation (Concept)

6.3.8 Some Anticipated Conclusions

It is a goal to create a subjective model of artificial experience in a natural environment by establishing an asymptotically-bounded region in where to make a choice. Depending on its response to data will establish a pattern of behavior (summation of choices). This dynamic task, synthesized here but present in all living systems, cognizant or instinctual, I argue will follow the same functional pattern:

data $\rightarrow$ information $\rightarrow$ knowledge $\rightarrow$ decision $\rightarrow$ action

This flow process shows that data is converted into information, and information is converted into knowledge once data has been organized in a coherent and meaningful manner. The key, when a successful adaptation occurs, is where the product *knowledge* has high synthesis of evaluation and organization and used purposefully enough so that the entity survives to the next experience by making effective decisions.

How can this flow process be replicated in a synthetic form? The machine requires a method to successfully manage data it receives from its sensory devices; it requires a data management system (DMS).

The most common DMS today is SQL, a relational database system. Another minor type of DMS is the transactional database system. The model in most common use today is the relational model, which represents all information in the form of multiple related tables each consisting of rows and columns.

At the present time, I am constructing a relational SQL database coupled to a transformation-based XML application structure (Figure 22) to begin writing this artificial life system pursuant to the theme of creating an artificial life form. I am confident I can establish a solid empirical results about the phenomena of choice in synthetic systems by conducting this work in the manner described.

6.3.9 Experimentation Toward Understanding of the Choice Complex and Methodology

There are really two experiments to consider here, the wireless power technology and the associated frequencies of transmission and information transfer, and choice in the machine. I have illustrated the first in the previous section. Now I would like to outline a physical robot wherein to test if choice can be studied empirically.

Consider a simple robot consisting of a hand, an arm and a microprocessor 'brain' with the following specifications:

- 32-bit ARM7 main microprocessor
- 256 KB flash memory
- 64 KB RAM
- 8 bit Atmel AVR microcontroller @ 4 MHz
- 4 KB flash memory
- 512 Bytes RAM
- 100 × 64 pixel LCD matrix display
- Can be programmed using Windows or MacOS (NBC/NXC supports Linux as well)
- Users create a program with new software, powered by LabVIEW from National Instruments
- A single USB 2.0 port
- Bluetooth (Class II) wireless connectivity, to transfer programs to the NXT wirelessly or offer ways to control robots remotely (through mobile phones and possibly by PDA's)

- 4 input ports, 6-wire cable digital platform (One port includes a IEC 61158 Fieldbus Type 4/EN 50 170 (P-NET) compliant expansion port for future use)
- 3 output ports, 6-wire cable digital platform
- Digital Wire Interface, allowing for third-party development of external devices

Using a easily and visually programmed device allows for concentration on the more complex tasks I would like to begin to orchestrate. A proposed and simple task would be: Given a simple task dictated by the 'environment', such as choosing between two different colored balls sitting on stands and moving the 'favorite' to a bin. Listing the input devices required:

- An ultrasonic sensor to measure the field of vision,
- A light sensor to measure the color of the objects in the field of vision,
- A touch sensor to acknowledge whether or not the object has been grabbed.

Each sensor would need to be organized pertaining to its purpose and purported task in this instance. [Remainder not available at time of publication.]

6.4 Some Final Thoughts Regarding the Subject Matter

Considering the vast intertwining of the components listed in this thesis, what kind of lasting impressions can be expected?

1. New and inventive software realizations,
2. New and inventive hardware realizations,
3. Extending commonality of unique ideas of research and commercial projects perhaps changing the field,
4. Advancing the state of robotics, the understanding of humanity, and life in a profound sense.

A set of final thoughts and considerations that are more an extension of the abstractions already discussed here. If a machine could be made complex enough, would it respond to emergence? In other words, would it possess some sense of artificial consciousness? A step in that direction, is to study emotional states of the machine in regard to it having the power to make choices over its interaction with an environment.

How would the machine react emotionally, as an extension of its logic, in the Kismet sense of the transformation?[15] What kinds of pleasure responses are available to a machine? In living creatures, pleasure is marked by the absence of threatening conditions, in other words, the measurement of one in context of another. So, how would a balance of giving / taking away affect

[15]For a detailed discussion of Kismet, see Cynthia Breazeal, her dissertation "Sociable Machines: Expressive Social Exchange Between Humans and Robots" about the relationship between logic and emotion. She argues that they are connected entities and are intertwined in consciousness.

the development and sociability of an artificial life form? If it could be made to understand degrees of entropy by hinting at the meaning of these states, would the machine choose to fight to preserve itself and its consciousness and the assembly of states of pleasure it came to associate with it?

I suppose the burning question is: Can life be understood by placing it in tension with its polar opposite? Or by degrees of entropy? Does the very existence of entropy preclude a life with richer experiences?

Some final words about choice and the directive it takes in this thesis. Life is determined by action-reaction; that is there is only one real Truth in the universe–causality. Some proffer the observation that everything begins with choice, this is a fallacy. Choice is an illusion between those with power and those without. Does this imply that the future roboticist is irrevocably attached to his creations or does this imply a hierarchy of machines is necessary for a division of power or authority in the same manner as human societies for them to be in some sense alive? At this point, I will not pretend to know, but it is something I would like to find out.

7 Conclusions

I believe the most immediate benefit to humanity is the application of wireless power to cybernetic implants, the waves would need to be studied at length to check for any deleterious effect on human tissue but I think its a worthy try. Power for pacemakers and the like could be gleaned from a pack worn on at the surface of the skin–perhaps strapped to the arm–instead of having to be subjected to operations to replace worn out battery cell-packs. Or if the implant is too small to be powered any other way other that wirelessly. The circuitry could be made incredibly small faced with the requisite that the transmission pad be sufficiently large, which preliminary equations seem to be saying the system obeys this principle.

What I have discovered during my time working on this thesis:

- I have discovered that the field of AI/AL is a place of diverse opinion and less of a results-oriented field than more empirical fields such as physics and engineering.
- I find the work fascinating and novel. This is the first time in the history of civilization we have come this close to sentient machines–for better or worse.
- I enjoy the work and learning new things. As such, it has kept my spirit high and my faith in things more or less constant.
- I think it is important to keep in mind that it is the spirit of discovery and to provide some important insights into what it means to be alive and human.
- And for that, I am thankful.

8 Appendix: Replicas–The Plan

8.1 Plan Summary

The project's overall plan and development strategy has been prepared for the period beginning 2007 until 2010. This plan has been subjected to the scrutiny of professional persons and agreed that as a plan, is due to remind the reader that it is only an acknowledgment of the honesty of doing the work required and a benchmark of current expertise. The goal is to place myself at the leading edge of artificial adaptive cognitive structures pursuant to full-blown artificial life forms manifest in a variety of physical manifestations. This goal is purveyed upon the concept of self-replicating machines; however, for these purposes, the scope of such is limited to information self-replication and organization rather than physical implementation. The thought is to prove a template example of how a system (algorithm) would adapt to its environment and self-organize the data received from it.

The idea revolves around the problem of artificial life, which historically can be broken down into four main components:

1. The Problem of Energy (subsistence),
2. The Problem of Communication [inner: connections (wires); outer cooperation (society)],
3. The Problem of Control (manipulation of the environment),
4. The Problem of Raw Materials (reproduction).

In this sphere, the difference between internal processes and external schema are irrelevant as each are strictly dependent on the other. I will define what I mean by this statement shortly.

8.2 Concept

In addressing the problems surrounding artificial life, the predominant question reflects back to the eternal question: What is life? A keyword search of "life" on the Internet will elicit the general characteristics:

1. Homeostasis: Regulation of its internal environment to maintain a constant state.
2. Organization: Being composed one of or more 'basic' units such as cells.
3. Metabolism: Consumption of energy by converting non-living matter into material for the 'basic' units and decomposing matter.
4. Growth: Maintenance of a higher rate of synthesis rather than catalysis in order to increase the preponderance of its parts.
5. Response to stimuli: A autonomous or calculated event causally related to an environmental state.
6. Adaptation: Altering its fundamental processes, including behavior, in response to environmental stimuli.

7. Reproduction: The introduction of new organisms based upon itself.

These being rather general and more of a consensus of opinion rather than based on empirical evidence, a more narrow definition founded in statistical physics can be found based on the concepts of order, disorder, and entropy[22]. The following constitute *Criteria One*:

1. Order based on order: The tendency of an organism to strive for order based on the negative consequence of disorder.
2. Creating order based on disorder: Manipulation by the organism to achieve maximum order by avoiding a decay into equilibrium, or purposefully trying to keep itself away from a permanent state by feeding on negative entropy.
3. Creating order based by extracting order from the environment: The consumption of energy or information as the fuel for the engine of the organism's unique state which remains non-permanent.

For the purposes of this definition of concept particular to this research, I can now address: What is artificial life? Since the form is artificial by nature, that is, reflectively speaking, intentionally created to serve the purpose it was created for, I will argue it is more privy to a statistical definition delineated by Schrödinger than by general characteristics outlined previously. Accepting this as a suitable foundation lacking any further competing hypotheses, what attributes should such a form possess? I offer it should:

1. Strive for order based on disorder.
2. Strive for a successive series of states keeping it distant from equilibrium.
3. Create its own sense of order by extracting information from its environment.
4. Replicate its internal mechanisms to facilitate adaptation.
5. Grow by increasing its composite store of information, enhancing its decision-making faculties.
6. At present: internal replication manifest in a software domain to understand its potential in the model.

In order to generate empirical evidence of the hypothesis I have offered, I insist the first glimpse of artificial life needs to be 'manifest' as a result of self-construction, modification, adaptation, and replication. I will not offer any previous demarcation of how such a process has or should be developed or founded upon any "thought experiments"[23] or any other semblance of such; I will not offer any positioning of my thesis jockeyed as an opposing viewpoint such as anti-Turning, von Neumann architectures or machines, universality or relativism, or entertain by validating any method or charge, as such discourses have not amounted to any significant development[15] and alternatively, have resulted in failure in the general cases. The only pre-foundation reference will be in the language of reconfigurable computing using data counters to generate the addresses of memory blocks that can be clearly illustrated by Uhoo. This may or may not include systolic arrays as a means to allow for parallelism; however, I foresee my own solution in this sphere using the tools that are available to me.

8.3 The First Consideration

Following the path resulting from embracing Criteria One, all work under this tutelage has four features which obey their assignment. These four features are:

1. Self-Construction,
2. Modification,
3. Adaptation, and,
4. Self-Replication.

In considering these features, I foresee the best strategy in manifesting these in union and not independently as these are explicitly dependent upon each other for mutual benefit. Numbers one and four are two facets of the same phenomena, form one-half of the total problem, but have been split for clarity. The same can be said of numbers two and three as adaptation, the second-half of the problem, as the engine of self-modification.

Considering the form in context with its environment and moving in linear time, there are three dynamic features inherent in the life form:

1. Creation,
2. Causality, and,
3. Change.

It must start somewhere, be subject to not only its environment but be responsible for its decision-making, and be able to account for the consequences of its decisions for maximum benefit.

8.3.1 Feature Breakdown

In order to understand, generate empirical evidence of the thesis at hand, and to facilitate the Replica, a model should be designed and tested to meet Criteria One's standards. Specifically, the model should address self-construction and modification based on changing conditions.

A self-replicating machine would need to have the capacity to gather energy and raw materials, process the raw materials into finished components, and then assemble them into a copy of itself. It is unlikely that this would all be contained within a single monolithic structure, but would rather be a group of cooperating machines or an automated factory that is capable of manufacturing all of the machines that make it up. The factory could produce mining robots to collect raw materials, construction robots to put new machines together, and repair robots to maintain itself against wear and tear, all without human intervention or direction. The advantage of such a system lies in its ability to expand its own capacity rapidly and without additional human effort; in essence, the initial investment required to construct the first self-replicating device would have an infinitely large payoff with no additional labor cost. Such a machine violates no physical laws, and we already possess the basic technologies necessary for some of the more detailed proposals and designs. If proof were needed that self-replicating machines are possible the simple fact that all living organisms are self replicating by definition should go some way towards providing that proof, although most living organisms are still many times more complex than even the most advanced man-made device.

8.3.2 Computational Considerations and Engineering Environments

My position in classifying the computational structure of the first iteration, *Uhoo*, is that it is an algorithm. That is, it contains the necessary variables and instructions (procedure) to describe its state and operational domain strictly based upon well-defined parameters. It possesses a finite set of well-defined instructions, based on the work of three agents, accomplishing a given task terminating their work once the sequence is complete—the form in constructed and the data spaces defined and bounded.

As an algorithm based generally on the definitions surrounding Turning machines and lambda calculus, I will not dwell on purely intellectual queries and permutations; instead, migrate the notion to an exemplary development environment to further engineer it.

In order to make the model as general and portable to as many types of computing architecture in a common-use language, I will model the algorithm in Scilab, deploy in SQL with C#.XSD as the primary data handler and an application delivery layer, XML as a higher level organizational tool, XSL to address any reflective transitions, .NET and its open source cousin, Mono, as a framework class library to testing machines and "lite" versions for targeted inexpensive mobile devices such as Lego NXT and RoboSapienv3 (available to be controlled form other mobile devices such as mobile phones with Bluetooth), and a standard .exe format in both local WinForm and WebApp environments for distribution across local and networked computers and testing robots.

Further, I foresee the migration from Scilab-generated code, generally regarded as C, of the original data class to physically testing and generating empirical evidence of the concept with a common use runtime such as SQL coupled closely with C#. The reason for the choice of C# is because of the deployment within Robotics Studio and its built-in toolbox with physical robot units such as many off-the-shelf packages.

8.3.3 Historical Inspiration of the Model for Artificial Life

I tend to believe there is much to learn from history and that it is an important scientific principle to look to see what has already been done instead of trying to reinvent. Time is better spent in the laboratory performing experiments further emboldening the theories.

In trying to define the question: What is artificial life?, I found myself on a multifoil containing at a minimum of six different means to go starting to answer the question. They were:

1. Past works and architectures,[16]
2. Nouveau artificial life techniques and procedures,
3. Past iterations of physical machines,[17]

[16]Inspired by Archimedes, Ancient Greek mathematics, and the Antikythera Mechanism.
[17]The Clockwork Monk by Elizabeth King.

4. Appearances of well-defined machines in science fiction,[18]
5. Philosophy,
6. Thought experiments.

These have extended from recursive functions, the lambda calculus, the Turing and Post-Turing machine, and the "reckonable in the system S_1". An entire paper could be written on the implications of the philosophy of mind resulting from an analysis of the works contained within the Church-Turing thesis; however, it has been and will continue to be my intention to get away from philosophy and focus on the problems of engineering. The historical inspirations, for positive or negative, have effected the outcome of this thesis and my decisions to take such an attitude.

8.4 The Second Consideration

The fundamental definition: life is matter with meaning, will be used as the definitive answer to the question posed earlier in this document. There is mention of an autonomous "epistemic cut" in philosophy that will need exploration to further fill this out. In immediate redress, however, "Unlike physical theory, great discoveries in the evolution of natural and artificial life are closely related to understanding how the description-construction process can be most efficiently *implemented*." [Pattee 28]. Discovery and implementation of a genotype-phenotype transformation is the crux of the problem.

Of course, implementation-independent self-organization may play essential roles in the origin of life and in limiting the possibilities for natural selection. The significance of these roles needs to be determined.

8.5 The Third Consideration

The artificial physical world complete with its own set of laws, descriptions, and sequences. In order for the system to maintain and evolve, the organism must efficiently implement the artificial physical descriptions as constructions.

8.6 The Fourth Consideration

A crucial feature resides in design considerations, how the features are constructed, their methodology, and most importantly, how they are implemented with emphasis upon efficiency.

Considering the choice of the object-oriented C# language, it is wise at this point to demarcate a strategy of what designs are available and the best ones based on empirical tests.

Today, most designers point to GoF, or Gang of Four, referring to the seminal book *Design Patterns*, published in 1995 but still serving as the quintessential reference on the subject. It is a focal point to look at the problem as one of pattern and not necessarily of implementation as patterns can be rendered in a high-level language as long as one understands the criteria involved. Another key point is to realize that reusability of existing code also increases efficiency, i.e., once a task is learned and the code written, the entirety or pieces of the

[18] See the section entitled 'Conceptual Aids'.

experience can be repeated where necessary. As such, there are six major considerations of choosing the proper pattern:

1. Consider how design patterns solve problems.
2. Scan Intent sections. Consider each pattern's intent to find the one relevant to the problem at hand.
3. Study how patterns interrelate.
4. Study patterns of like purpose.
5. Examine a cause of redesign.
6. Consider what should be variable in the design.

Pursuant to this, the following table condenses the above six into a single format.

Creational	Abstract Factory	Families of product objects.
	Builder	How a composite object gets created.
	Factory Method	Subclass of an object that is instantiated.
	Prototype	Class of an object that is instantiated.
	Singleton	The sole instance of a class.
Structural	Adapter	Interface to an object.
	Bridge	Implementation of an object.
	Composite	Structure and composition of an object.
	Decorator	Responsibilities of an object without sub-classing.
	Façade	Interface to a subsystem.
	Flyweight	Storage costs of objects.
	Proxy	How and object is access and its location.
Behavioral	Chain of Responsibility	An object that can fulfill a request.
	Command	When and how a request if fulfilled.
	Interpreter	Grammar and interpretation of a language.
	Iterator	How an aggregate's elements are accessed or traversed.
	Mediator	How and which object interact with each other.
	Memento	What private information is stored outside an object and when.
	Observer	The number of objects that depend on another object. How the dependent objects stay up to date.
	State	The states of an object.
	Strategy	An algorithm.
	Template Method	The steps on an algorithm.
	Visitor	Operations that can be applied to objects without changing their classes.

Figure 23: A Table of Design Patterns

Now it should be determined what patterns to pick and how to use them. There is a eight-point process.

1. Read the pattern once through for an overview of what is available by using it, the costs, benefits, and consequences to the remainders.
2. Study the Structure, Participants, and Collaborations to understand the classes and object and how they relate to one another.

3. Look at available sample code to see a concrete example and test its effectiveness in design and implementation.
4. Choose names for pattern participants that are meaningful in the application context, stay away from naming conventions that are too abstract but hint to their function(s).
5. Define the classes, declare their interfaces, establish their inheritance relationship, and define the instance variables that represent data and object references. Notice now they will effect the pattern.
6. Define application-specific names for operations in the pattern and be consistent throughout.
7. Implement the operations to carry out the responsibilities and collaborations in the pattern.
8. Do not apply the pattern indiscriminately. Understand the nature of the problem and what is absolutely necessary without code "bloating".

Having listed the essentials from the book, it is now time to administer the concepts to the goals set forth in this orchestrated plan.

8.6.1 Specific Considerations Set Forth

One feature that the program, in its current iteration Uhoo, has the ability to write its own code. Generally speaking, it possesses and implements reflective programming. This will be better illustrated during the term of this thesis.

8.7 The Machine

As it is the goal to produce a viable and pervasive machine, how have the previous considerations contributed to the form of the Replica? What have been my successes, my failures, my rewards, my costs, my consequences and how has my first task of reproduction fared? Although this thesis will only try to answer the questions about featured power and choice, how do these ideas and the generated technologies aid in larger frameworks?

I don't want this work to be considered in a vacuum; although I will only deal with two specific technology types, I will from time to time delve into the larger applications and demonstrate some notions where possible. However, at the time of this draft, I include only that which I believe will be relevant herein. Thank you for your consideration and careful attention.

References

[1] Brooks, Rodney. "The Relationship Between Matter and Life", Nature. v409, n6818, pp. 409-411. 2001.

[2] Holland, Owen. "Exploration and High Adventure: The Legacy of Grey Walter". The Royal Society, 20 August 2003.

[3] Walter, Grey, W. The Living Brain. New York: W.W. Norton & Company. 1953a.

[4] Maslow, Abraham, H. Toward a Psychology of Being, 3rd Edition. New York: Wiley. 1998.

[5] Bateson, Melissa, Susan D. Healy, and T. Andrew Hurly. "Irrational Choices in Hummingbird Foraging Behavior", Animal Behavior, 63, 587-596, 2002.

[6] Holland, Owen & David McFarland. Artificial Ethology. Oxford: Oxford University Press. 2001.

[7] Ashby, Ross, W. An Introduction to Cybernetics. London: Chapman & Hall, Ltd. 1957.

[8] Melear, C. "Low-Power Techniques for Modular Processors. WESCON/94. Idea/Microelectronics. 27-29 Sept 1994.

[9] Van Deursen, A. "Domain-Specific Languages verses Object-Oriented Frameworks", SmallTalk and Java in Industry and Academia, STJA'97, pp. 35-39.

[10] Grand, Steve "Communications with Steve Grand" August 2006 to February 2007.

[11] Andre Kurs; Aristeidis Karalis, Robert Moffatt, J.D. Joannopoulos, Peter Fisher, Marin Soljačić. Wireless power transfer via strongly coupled magnetic resonances". Science, Vol. 317. no. 5834, pp. 83 - 86, July 2007.

[12] Asimov, Issac. "The Inevitable Conflict" I, Robot. 1950.

[13] Walter, Grey, W. The Living Brain. New York: W.W. Norton & Company. 1953a, p.290.

[14] Ashby, Ross W. "An Introduction to Cybernetics". London: Chapman & Hall, Ltd. 1957, Chapter 3.

[15] Codd, E.F. "A Relational Model of Data for Large Shared Data Banks". Communications of the ACM 13 (6): 377-387, 1970.

[16] Stanghellini, Giovanni. "Autism: Disembodied Existence". Philosophy, Psychiatry, & Psychology, Volume 11, Number 3. The Johns Hopkins University Press. September 2004, pp. 259-268.

[17] Schrödinger, Erwin. What is Life? The Physical Aspect of the Living Cell. "Lectures: Dublin Institute for Advanced Studies". Dublin: Trinity College. February 1943. pp.69-74.

[18] Von Neumann, John, Arthur W. Burks (ed). The Theory of Self-Reproducing Automata. Urbana: University of Illinois Press. 1966.

[19] Brooks, Rodney. "Rodney Brooks Forecasts the Future". The New Scientist, Number 2578, 60, November 2006.

[20] Grand, Steve. "Growing up with Lucy". London: Weidenfeld & Nicolson. 2004.

[21] Baudrillard, Jean. “Simulacra and Simulation”. University of Michigan Press. 1981.

[22] Kleene, Stephen. (cf Kleene 1952, p320.)

[23] Patee, H.H. “Artificial Life Needs a Real Epistomology”. 1995.