DISSERTATIONES
SEMIOTICAE
UNIVERSITATIS
TARTUENSIS
59

J. AUGUSTUS BACIGALUPI

A Biosemiotic Theory of Semiogenesis: Building a Testable Hypothesis for Normative Self-regulation

DISSERTATIONES SEMIOTICAE UNIVERSITATIS TARTUENSIS

59

DISSERTATIONES SEMIOTICAE UNIVERSITATIS TARTUENSIS

59

J. AUGUSTUS BACIGALUPI

A Biosemiotic Theory of Semiogenesis: Building a Testable Hypothesis for Normative Self-regulation

UNIVERSITY OF TARTU
Press

Department of Semiotics, Institute of Philosophy and Semiotics, University of Tartu, Estonia

The council of the Institute of Philosophy and Semiotics of the University of Tartu has, on April 27, 2026, accepted this dissertation for the defense for the Degree of Doctor of Philosophy (in Semiotics and Culture Studies).

Supervisors: Professor Kalevi Kull, PhD, University of Tartu

Associate Professor Donald Francis Favareau, PhD, National University of Singapore and Deep Springs College, USA

Opponent: Professor Yagmur Denizhan, PhD, Bogazici University, Turkey

The thesis will be defended at the University of Tartu, Estonia, on August 18, 2026, at 11.15 Lossi 3-328/online.

This study has been supported by the Estonian Doctoral School; co-funded by the European Union (Project "Cooperation between universities to promote doctoral studies" (2021–2027.4.04.24-0003)). Estonian Research Council's institutional research project PRG314 "Semiotic fitting as a mechanism of biocultural diversity: instability and sustainability in novel environments".

Co-funded by
the European Union

Investing
in your future

ISSN 1406-6033 (print)
ISBN 978-9908-57-244-4 (print)
ISSN 2806-2582 (pdf)
ISBN 978-9908-57-245-1 (pdf)

University of Tartu Press
www.tyk.ee

ACKNOWLEDGEMENTS

Some people listed below have suggested that this dissertation is just the beginning. And, although I agree, it has been a long – and, seemingly to some, meandering – beginning. This project started in earnest in 2003, in response to my World Trade Center Memorial Competition entry. After years of independent research, by 2011, I had a solid draft of a manuscript outlining in detail a research proposal for what I called Synthetic Cognition, much of which will be found in this dissertation.

My family – James A. Bacigalupi III, Christina Alfs and my sister, Jessica – have been supportive and proud of my perseverance over the years, for which I am immensely grateful. They did begin to worry a bit, by 2011, as my source of income – my own architectural practice – competed with my passion: the subject of this dissertation. Through this time, my best friend, John Ellis, provided unwavering support as did Jennifer Hwang, who was my loving and supportive partner for 14 years, and still a priceless friend. Very special gratitude goes to these two non-academics, without whom my sanity would have dissipated years ago. Among many other countless supportive suggestions, not knowing how to proceed with my independent research, Jenn encouraged me to seek out like-minded people I could engage with. Subsequently, it was in 2012 that Terrance Deacon and his wife, Rae, opened their home to me. There I partook in "Terry's Pirates", a living room salon dedicated to discussing his work.

It is through Terry that I met Kalevi Kull and Donald Favareau at the 2018 Gatherings in Biosemiotics at UC Berkeley. After my talk, Don suggested I submit a paper to the Biosemiotics journal, which I neglected to do at the time, because academia was neither something modeled nor particularly encouraged in my family. Nevertheless, Don persisted, which I will forever be thankful. Because some years later – during the pandemic, I believe – I found myself online in Kalevi's "Glade". This virtual glade was a real breath of fresh air and led to giving a talk at the online 2021 Gatherings in Biosemiotics. For this presentation, I received the Jesper Hoffmeyer Award in Biosemiotics, for which I will always be deeply grateful. This recognition was a turning point for me and paved the way for doing a PhD under the supervision of Kalevi, with Don's co-supervision.

And, after four years, I am now completing something that I have been trying to do since the 2000s. In addition to my profound gratitude for thoughtful feedback and support from Kalevi and Don, I wish to thank the Institute of Philosophy and Semiotics, the University of Tartu and Estonia, itself, for hosting and supporting my recent work, which enabled this dissertation: just the beginning, as it were.

In the semiotics department, special thanks go to Ulvi Urm who always had the answer to your question and never made us feel like we couldn't go to her for help. Thanks to Peeter Torop for his insightful comments, as my discussant; to Silvi Salupere and especially Elin Sütiste for attending my course; to Maarja Ojamaa, Ott Puumeister and Silver Rattasepp for running our graduate seminar, which was a really important connection to our colleagues and our department; and Katre Pärn and Lona Päll for their kindness. Thanks to Timo Maran and Tiit Remm for their leadership, as department heads during my tenure. And a special thanks goes to Nelly Mäekivi and Auli Viidalepp, both of whom I consider dear friends, and who have been very supportive in many ways over the last four years.

Still at the "teacher" level, but outside of the department, deep gratitude goes to L'udmila Lackova who invited me to visit her department in Olomouc, at the University of Palacký. Before I officially started my PhD in Tartu, she made me feel welcome in European academia. She also gave me an office in her department in the Summer of 2022, which I shared with Auli. We had a lot of fun at many different conferences. Also beyond the department, but within my discipline of biosemiotics, are Victoria "Tori" Alexander and Yağmur Denizhan, the four of us – including Don – comprising the "gladettes". Co-authoring with Tori was a delight and I'll always be grateful to Yağmur for introducing me to Gilbert Simondon and her colleague Cecile Malaspina. Thanks go to Cecile for including me in one of her collections and introducing me to Xin Wei Sha, who has been very supportive of my work. And I can't forget Joanna Rączaszek-Leonardi, who I actually met years ago through Terry. She has included me in her work over the years, and she is a delight to be around. Another colleague that has included me in her work, and is also a delight, is Jana Švorcová at Charles University in Prague. In what follows this PhD, I look forward to working with them all!

At the "colleague" level there is first and foremost Andrew Creighton, who has been a gracious interlocutor about many topics and also a consistent friend in times when being a legal alien can be a bit lonely. Special thanks also go to Oscar Miyamoto, Hongjin "Jhin" Song, Irmak Ugur, Eleni Alexandri, Pauline Delahaye, Michele Cerutti, Nicola Zengiaro and Eléa Pertusati for erudite conversations and their friendship. Oscar was particularly helpful when I first arrived; he is a very good shopper and helped me get settled. Jhin has been my cohort partner for four years and has been most helpful in navigating our shared PhD journey. Irmak has been a dear confidant over the years. Eleni read more of my work than most and provided great feedback. Pauline very graciously facilitated my acquisition of her apartment, which I will miss dearly. Conversations on anarchy were always enjoyable with Michele. Nicola's shared interest in 'semiotic resonance' has been gratifying. And conversations with Eléa on our shared interests in autonomous agents has been both fruitful and enjoyable.

Back in California, my Studio for Public Spaces (SPS) colleagues (and friends) Shawn Lani, Adam Esposito and Jesse Marsh were partners in expanding the Exploratorium's pedagogical approach to both public space and diverse communities. This work was, and still is, fundamental to the more socio-ethical dimensions of my project, called Sentient Technics, which are only briefly discussed in this dissertation. Nevertheless, these dimensions will figure prominently in what builds upon research in this dissertation. I am grateful to them all for our shared work with SPS and look forward to future collaborations.

Also in California, I must mention all the friends and family that listen to my stories of the Eastern front when I visit. Christopher Sozzi has probably believed in what I’m doing before I did, and his wife Sarah has always been a good friend and a gracious host. Krissy and Christien Olson have also been particularly supportive of the more social aspects of my project, support that has always encouraged me greatly. Some of my oldest friends, Greg and Kerry Benoit, are always ready to open their home when I visit, which makes me feel loved after all these decades.

As for extended family, special gratitude goes to uncle, aunt and cousin George, Margerie and Billy Alfs who all help keep an eye on my mom. Also, great thanks goes to my uncle Rick Bacigalupi who has been supportive of my project since its beginning when he helped me do early videos about my project in the 2000s. My uncle Barney Alfs has also been supportive in many different ways throughout my life: from taking Jessica and I to Yosemite when we were kids to hosting many visits to LA to material support. Caroline and Charlie Moynagh have also been very gracious hosts over the decades and are fun to be around. Elizebeth Titus was supportive of my writing when it mattered. And Kate and Rich Wafer have been very gracious hosts countless times when visiting LA. Even though I have not chosen the conventional path, hoping to contribute something truly novel and of value to our collective knowledge, all the support from the colleagues, friends and family above have made this, sometimes lonely, journey possible.

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

I. Bacigalupi, J. Augustus. 2013. "Refinement: A Rigorous Description of Autonomous Adaptive Agents." Edited by Prof. Ranulph Glanville and Prof. David Griffiths. *Kybernetes* 42 (9/10): 1313–24. doi:10.1108/K-10-2012-0065.

II. Bacigalupi, J. Augustus. 2022. "Semiogenesis: A Dynamic System Approach to Agency and Structure." *Biosemiotics* 15 (2): 261–84. doi:10.1007/s12304-022-09494-8.

III. Bacigalupi, J. Augustus. 2023. "Creativity: Transcending the Cybernetic Mode via the Virtuality of Relevant Noise." Edited by Cecile Malaspina. *Angelaki* 28. doi:10.1080/0969725X.2023.2216550.

IV. Bacigalupi, J. Augustus, and Donald Favareau. 2023. "The Physiology of Coordination: Self-resolving Diverse Affinities via the Sparse Order in Relevant Noise." *The Journal of Physiology*, December, JP284418. doi:10.1113/JP284418.

    Authors' contribution: J.A.B. was responsible for the proposed heuristic model and its application to coordinative dynamics in living systems. D.F. contributed expertise in relating the application of this model to the discipline of biosemiotics in the introduction and the section 'Semiotics in coordination'.

0.0 INTRODUCTION

0.1 Research Motivations

The central question of this dissertation is how adaptive meaning-making is possible in living systems. In the discipline of semiotics – in particular, bio-semiotics – this question is focused on how semiosis can generate novel physiological energy patterns and behaviors able to sustain an unbroken lineage of living processes for over 3.8 billion years. It will be argued that this well-above-chance tendency to adapt is only possible via a thermodynamically grounded normative generativity that can neither be reduced to mechanism nor chance alone. To validate this argument, this dissertation proposes a means to build and test a novel technology able to provide empirical evidence for the Normative Self-regulation of *semiogenesis*, which can be informally defined as:

> A process whereby a system increases its average Relevance (viz., engagement, sensitivity, or "awareness") to its surroundings by increasing its own internal capacity to resolve internal disorder, which is the result of increased Relevance, into a higher-order internal structure able to increase capacity to do useful work.

Normative Self-regulation is the capacity for that system to intrinsically choose how to navigate the internal disorder, i.e., *tension*, cultivated by the semiogenesis of living systems.

The central research question above, prior to my current course in semiotics, was how human creativity is at all possible in this thermodynamic universe? This led me to attend lectures at the Helen Wills Neuroscience Institute at the University of California, Berkeley. What became immediately clear is that empirical observations of neurobiological physiology are many orders of magnitude more complex than the models being used to implement Artificial Neural Networks (ANN), the basis for all so-called Artificial Intelligence (AI) today. Neurobiological examples – such as Local Field Potential (LFP) (Anastassiou et al. 2010; Buzsáki, Anastassiou, and Koch 2012; C. G. Hales 2014; C. Hales and Pockett 2014; Herreras 2016; Weiss 2010), Spike Timing Dependent Plasticity (STDP) (Buonomano and Carvalho 2009; Mishra et al. 2016; Radman et al. 2007), ephaptic coupling (Anastassiou et al. 2011; Anastassiou and Koch 2015) and the highly non-linear behavior of biological neural networks (Noble 1920; 2012; 2022) – challenged the computational approaches to cognition prevalent both then and now. Based on this evidence, it seemed reasonable to suspect that a physically grounded explanation for human creativity was not to be found down the path of computationalism.

But this suspicion was, and still is, not the majority approach to models of living cognition and creativity. Many very serious efforts for almost a century have been committed to an algorithmic framing. Schrodinger (1944), Turing (1950), Wiener (2000), von Foester (1984; 2003; Weston and Foerster 1973), Bertalanffy (1968) are just a small handful of well-respected early researchers that have forwarded functionalist models and methodologies for understanding life and mind. Bertalanffy's *General System Theory* was particularly articulate in outlining how a system of simultaneous differential equations could, in principle, fully describe living systems and their creative behaviors. Nevertheless, nearly a century of earnest effort has yet to explain life and mind with algorithms alone. Perhaps there is a relatively simple change in mindset that can open up an entirely new set of productive hypotheses, such as when the Earth was unfixed from the center of the universe in the Copernican revolution or when space and time were unfixed from Euclidean geometry with relativity theory to better explain our observations. But what are these missing observations in the case of living systems?

Arguably, these missing observations are of complex behaviors that are taken for granted in our attempt to understand semiosis in living systems. An architectural design practice, for example, professionalizes a common human capacity for adaptive creativity that we often take for granted: the capacity to create novel, relatively complex, behaviors to resolve many simultaneous and often competing demands. Designers learn how to leverage this human capacity to create complex integrated outcomes when faced with complex *un*-integrated demands and constraints. But all animals have a more ancient version of this capacity: amoeba learn how to respond to simultaneous external stimulations (Alexander, Bacigalupi, and Garcia 2021; Saigusa et al. 2008; Shirakawa, Gunji, and Miyake 2011); termites collectively and continuously coordinate to restructure their mounds (Grassé 1959; Kugler and Turvey 1988)[1]; and humans unconsciously coordinate complex behavior in both bodily and social dynamics (Bacigalupi and Favareau 2023; Haken, Kelso, and Bunz 1985; Tognoli et al. 2020) [Article IV]. These empirical examples demonstrate adaptive complexity, and this complexification is not the exception in living systems; it is the default mode of operation. This default mode of living operation is adaptive complexification.

0.2 Research Questions

If the claim of adaptive complexification is warranted, the next question is how this default mode is possible in living systems. The inherited approach is to imagine fixed algorithms – from Bertalanffy's system of differential equations to today's AI algorithms – able to simulate and explain the adaptive fecundity of living systems. But the kind of complexity exhibited by living systems is relatively expensive for our machines to simulate algorithmically, compared to actual living agents. For example, a human body uses about 100 Watts; the brain uses only 10 to 20% of that. There is no computer (or data center) that can simulate a human brain, let alone an entire body. A single living cell has yet to be simulated in all its complexity, because we do not know how it works. This is

---

[1] For example, "the empirically observed 'mound superstructure and internal condition strongly depend on the combined effect of environmental forces' [(Fagundes, Ordonez, and Yaghoobian 2020)], including solar irradiance, solar zenith angle, wind and porosity" (Bacigalupi 2022) [Article II].

not to say that computers are not useful; they were specifically designed to be accurate and controllable. This is the value of their fixed functions. Arguably, however, in such an indeterminate universe, living systems cannot afford to be so fixed at such a high cost. In any case, living systems have persisted continuously for 3.8 billion years. Again, what are we missing?

The preliminary hypothesis for this project, described in section 2, claims that what is missing is the radical[2] generativity intrinsic to *semiogenesis*. My research of neurophysiology at Helen Wills Neuroscience Institute made it clear that neurons need to dynamically rewire themselves in a way that can explain the complex and adaptive learning behaviors above. Bertalanffy's differential equations, on the other hand, do not add new terms, variables, parameters and whole equations to themselves in a way that self-generates adaptive complexity. As will be argued below, however, semiogenesis is an intrinsic source of novel emergent dynamics in the living system and does not presume a fixed system of equations at any point in its operation. The hypothesis to be tested is that the radically generative nature of semiogenesis is necessary to explain how living systems change in a way that is *relevant* to the system: the architect chooses solutions that are *about* the complex design problem; the termite moves dirt in a way that adaptively accommodates many indeterminate environmental conditions and termite needs; and humans continuously coordinate their bodies in ever-novel circumstances for purposes that resonate with their desires. This is *radical emergence* (Longo, Montévil, and Kauffman 2012). The system is not fixed at one layer of abstraction only to be filled with ever-more discrete data; the system itself must physically change itself to constantly adapt to both internal and external contingencies.

The overarching research question is how such living systems are remotely possible. To answer this question is *not* to presuppose more simplicity and fixity than is warranted by the observable ethological evidence. Accounting for this evidence in previous research has led me to two outputs: 1) a novel analog/digital hybrid technology, called Synthetic Cognition, that will exhibit adaptive Complexity and Work – both defined in sections 2.2 and 2.3 – via *semiogenesis*, and 2) a formal theory to test that technology for the Alternative Hypothesis[3],

---

[2] The term "radical" throughout this project is intended to communicate what is analogous to the distinction between weak and strong emergence, the latter of which being *radical*. In terms of dynamical constraints, weak or non-radical emergence is the generation of novel constraints based on the deterministic summation of existing constraints. Strong emergence or radical creativity, in contrast, is the generation of novel constraints that cannot be deterministically presupposed based on analysis of existing dynamical constraints intrinsic to a given system of interest.

[3] The Hypothesis is the formal expression of the more informal (lower-case) hypothesis, referring to (lower-case) semiogenesis. The Alternative Hypothesis (H_1) is alternative to the Null Hypothesis (H_0). As will be discussed throughout, H_1 can be selected when the empirical test for Semiogenesis is positive, otherwise H_0 must be selected. There can be variants on the positive Hypothesis that will have distinct subscripts.

called Semiogenesis[4]: the intrinsic generation of novel patterns of increasingly complex and adaptive behavior in the presence of arbitrary, external and repeated stimulations, as observed in living systems.

The objective of this research project is not to create living systems, per se. It is to emulate attributes of living systems that are not accessible to Turing-equivalent (i.e., digital) strategies. Digital technologies are specifically designed for their accuracy and control of operations; this discrete state-based approach fundamentally limits the degrees of freedom intrinsically available to the system, which are needed to emulate living levels of complexity. Life itself is the ultimate question, but this will take decades or centuries to truly understand. This project aims somewhere in the middle between the fixity of functionalism and the flux of life.

Nevertheless, this "middle" is a non-trivial exercise, as the technology introduced in section 0.3 and further explained in section 2 will attest. As such, my theory of Semiogenesis – the technology and theory to test it – must be validated for feasibility among increasingly wider professional networks. After initial conception in 2011, Semiogenesis was inter-translated with Professor Terrance Deacon's autogenic model (Bacigalupi 2013; Deacon, Srivastava, and Bacigalupi 2014) [Article I], and most recently inter-translated with biosemiotics (Bacigalupi and Favareau 2023) [Article IV], reflected within this dissertation. The next phase in this validation process is the objective of subsequent grants: inter-translation, for example, with the wider theoretical biology (Longo, Montévil, and Kauffman 2012; Longo and Montévil 2014; 2019), philosophy of biology (Švorcová 2024; Švorcová and Markoš 2018; 2023) and enactivist networks (E. Di Paolo, Thompson, and Beer 2022; E. A. Di Paolo 2018; Juarrero 2002; Kelso 2012). These subsequent phases will seek scientific and engineering expertise from within and adjacent to these theoretical biology networks, which ideally may lead to an implementation phase for the technology of Synthetic Cognition.

Summarizing the research questions and claims, this dissertation documents the culmination of two decades of research, which claims to substantively advance the discourse on sentience, cognition and semiosis in biological systems – together referred to as *semiogenesis*. Described further in the next section, this advance will be based on a schematic design for a buildable and testable novel technology – generally referred to as Synthetic Cognition – claimed to implement a necessary dynamical aspect of semiogenesis that will further be shown *not* to exist in any legacy machines, especially digital computers. This research will provide the justification for subsequent grants that can fund the construction of this schematic design and test it for the existence of the Alternative Hypothesis – described in sections 2 and 3 – along with how Normative Self-regulation – discussed in section 4 – can sustain the operation of *semiogenesis* in this project of Synthetic Cognition.

[4] When capitalized, terms such as Hypothesis, Complexity, Work and Semiogenesis will be formally defined within the larger context of a theory of semiogenesis, which remains lower-case to indicate that it is the more general and really existing phenomenon of living systems. The former Semiogenesis is epistemic, whereas semiogenesis is ontic.

0.3 Methodology and Structure

A schematic design for the proposed technology Synthetic Cognition is illustrated in Figure 7 in section 3.1. It proposes how a system can adaptively wire itself based on its own internal dynamics. But this requires an interstitial continuous medium, like water for water waves or free space for electromagnetic (EM) waves. Described in detail throughout section 2, the proposed analog/digital hybrid of Synthetic Cognition employs EM waves to emulate Local Field Potential (LFP) in neurobiological systems. The hybrid system then specifies diversely tuned resonant Primary Nodes, described in section 2.1, whose behaviors both mold and are molded by this shared continuous medium, *simultaneously*. Primary Nodes interconnect to become sensitive to particular frequencies that may occur in their surroundings; once they are stimulated enough by these particular frequencies or other connected Primary Nodes, they will fire, analogous to interconnected neurons. The question posed above, however, is how these nodes may rewire themselves; how do they interconnect with each other based on their shared EM interference pattern? Section 2 will explain in detail a hypothesis for answering these questions.

As a brief introduction to this proposal, imagine that three different frequencies from the environment stimulate the 16 Primary Node array, contemporaneously – explained in Figure 3 of section 2.2. Initially, there are no interconnections. But, when certain nodes – that resonate with the environmental perturbations – are stimulated to fire, they create a unique interference pattern with constructive and deconstructive interference. This self-generated energy pattern – sparse order in a sea of noise – can be sensed by Secondary Nodes, which are the basis by which Primary Nodes can be wired. Having been self-biased with these connections, the proposed system will be preferentially sensitive to the co-occurrence of that pattern of frequencies, if such environmental stimulation should happen again. This acquired "sensitivity" has thermodynamic implications: more work will be able to be done by those particular nodes in the presence of that "learned" pattern, should it reoccur. This is adaptive Work, as characterized in Equation 1 in section 2.2. Bertalanffy's system of equations, if used to describe the system, will have changed after re-wiring. This exemplifies, in particular, Longo et al.'s concept of *radical emergence* (2012) and, more generally, my concept of *semiogenesis*.

But the above is just the first level, because arbitrarily many distinct patterns can be "learned" by this very finite array of 16 Primary Nodes; once learned, they are called *attractors* in Figure 4 in section 2.3 and can be considered "signs" in a Peircean sense. Imagine that two unique patterns have caused the system to rewire itself so that there are now two distinct 1st level attractors. Subsequently, these two distinct patterns can occur coincidently; this is illustrated as a 2nd level interference pattern as will be further explained in Figure 4, which, in turn, generates its own unique circuit connections. And these ordinal layers of adaptive

Complexity can go on. Complexity[5] is formalized in Equation 2 in section 2.3. In Equation 2, the first term sums the standard deviations of all the 1st level attractors; the second term sums the standard deviations of all the 2nd level attractors; and so on. And, once again, the system of differential equations needed to characterize the behavior of these complexifying circuits will be completely unique to these specific configurations. Physically, the system is embodying ever novel constraints based on its own intrinsic sympathies. Modeled mathematically, the system can be observed to have acquired novel dimensions without the intervention of an external designer or programmer.

This growth is illustrated in Figure 5 in section 2.4, which suggests how actual empirical data might look if the Alternative Hypothesis of Semiogenesis is to be accepted. Assuming such adaptive complexification can be emulated, the parabola in Figure 4 will be shown to grow with exposure to arbitrarily many diverse patterns over time. The curved regression of what the proposed theory calls Relevance is Semiogensis. Importantly, Complexity is a necessary, but not sufficient, basis for accepting the Hypothesis of Semiogenesis, because living systems have to do Relevant Work in a thermodynamic universe. This is reflected in Equation 4 for Relevance in section 2.4. Equation 5 defines Semiogenesis as the curved regression of Relevance, which is expected to oscillate, as illustrated in Figure 5.

The above hypothesis was first published in Bacigalupi (2013) [Article I]. Its subsequent development and inter-translation with the discipline of biosemiotics is published in the following articles: (Alexander, Bacigalupi, and Garcia 2021; Bacigalupi and Alexander 2021; Bacigalupi 2022; 2023a; 2023b; 2024; 2025; Bacigalupi and Favareau 2023; Bacigalupi 2026) [Article II, III, IV]. This dissertation claims to translate the scientific background summarized above through the lens of Semiogenesis in order to advance our understanding of adaptive creativity intrinsic to living systems.

The hypothesis introduced above, and discussed in detail in section 2, describes life's productive tension in terms of physical concepts such as work, entropy and complexity. Intuitively, this can be thought of as a perpetual struggle between order and disorder: coherent "structure" (analogous to decreasing entropy) and decoherent "noise" (analogous to increasing entropy), respectively. Order and disorder could be – and often have been – conceived as *extreme terms*[6]: the former is often maximized, whereas as the latter is to be minimized in the machines that we have inherited from this thinking. On the contrary for this project, such extreme states will be considered death-states; no semiosic life is

---

5 Complexity is an independently derived definition similar to Tononi's measure of *phi* in his Information Integration Theory (2004).

6 Simondon considers the separation of *matter* and *form* – *extreme terms* for Simondon – in Aristotle's *hylomorphism* to be problematic; he goes into great detail on the process of brick making to illustrate how, in actuality, *matter* cannot be considered separate from *form*, *a priori* (2020: 21–47). Throughout this dissertation, I will extend this critique to other *extreme terms*, or concepts, such as law-like algorithms and randomness; discreteness and continuity; internal and external; etc.

either of these extreme states, in of themselves. Living processes must embody these distinct tendencies simultaneously, "each to different degrees" (Lotman 1990: 15) depending on where life is in its ongoing process and its contextual contingencies. As will be discussed throughout, structure both generates and constrains noise, while noise both enriches and dissolves structure. Each tendency waxes and wanes in a continual dance with the other, as long as life persists. Although not the focus of this dissertation, these two co-constitutive tendencies – analogous to noise and structure – are metaphysically characterized as Virtuality and Affinity, respectively, in Bacigalupi (2025).

When noise and structure cease to co-constitute each other, living dynamics and semiosis also cease. This back-and-forth tension between these ostensibly orthogonal tendencies is reflected in Figure 5 as an oscillation in the Relevance curve. Its polynomial (i.e., curved) regression was originally called Refinement in Bacigalupi (2013) [Article I]. In more recent publications, Refinement has been equated with Semiogenesis (Š), explained in section 2. This preliminary hypothesis, adapted from Bacigalupi (2013) [Article I], characterizes semiogenesis as a series of developing Umwelten over time, the horizontal axis in Figure 5. With learning, the living agent embodies ever more Complex structures. These structures constrain subsequent operational dynamics in the living agent to do ever more Adaptive Work. Relevance, the vertical axis, is a function of Complexity (Č) and Adaptive Work (∑W). But the empirically observable Semiogenesis is incomplete with respect to really existing *semiogenesis*, because the preliminary hypothesis of this oscillation was not rigorously characterized in the earlier research. This capacity to self-regulate between these orthogonal tendencies must be explained in terms of a third intrinsic dynamic: Normative Self-regulation. Section 4 will expand upon the provisional hypothesis in section 2 and its implementation in section 3 to frame the question and possible answer to the intrinsic self-regulation of semiogenesis, most generally.

Informally, this hypothesis of semiogenesis was defined above at the beginning of section 0.1. More formally, Š is an index for this more general semiogenesis. The latter is the really existing ontological phenomena intrinsic to living systems. For example, after section 3 explains how the proposed analog/digital technology can be built and tested for Š, section 4 will discuss how self-regulation is not expressed in any of the formalizable equations presented in section 2, and that this dynamic must be embodied in a thermodynamic system, as proposed in section 3. In other words, a fundamental unanswered question in Figure 5 is why and how the Relevance curve oscillates as illustrated. Why this needs to happen is, at least, two-fold. Firstly, the system needs to re-organize itself to embody more complex and informed attractors. As will be discussed in sections 2 and 3, the disparation among dynamical attractors at an earlier stage of development will need to dis-order themselves to some non-zero degree before they can re-order themselves at a higher level of complexity.

And, secondly, this (dis)ordering habit is intrinsic to the tendency for life's extant lineages to avoid death-states. As a living system veers too close to either over or under-coherence in its dynamic operations – either too much order or too little, respectively – there must be some intrinsic means by which the system alters its own internal dynamics away from such death-states. The hypothesized observable result, Š, of this really existing semiogenesis will be the curved regression illustrated in Figure 5. This emulation of semiogenesis and its measurable Š is a *preliminary* hypothesis, because *how* an actual system implements this intrinsic self-regulation is itself a non-trivial question, which will be explored in section 4. While aspects of the process of semiosis may be observed, it is important to emphasize that this project claims that actually embodying the process of living semiosis is fundamentally indeterminate and therefore intractable. In other words, *simulation* of semiosis is not *duplication* of living systems. The goal of this project is somewhere in between: *emulation*.

For historical context, a draft of this preliminary hypothesis was completed by 2011. This initial effort explained that there is a necessary tension between coherence and decoherence, which is rigorously characterized via Complexity (Č) and Adaptive Work (∑W), both concepts of which will be described in section 2. However, there was an underdeveloped part of the model that described how Complexity and Adaptive Work operated to remain in a "sweet zone" between over and under-coherence, i.e., the death-states. A preliminary matrix in section 4.1, specifies in general how the proposed technology needs to regulate itself to avoid the death-states where semiogenesis terminates. Section 4.2 extends the preliminary hypothesis in section 2 to describe how the self-regulation matrix in section 4.1 could be implemented via the proposed circuits in section 3, without resorting to just random or algorithmic mechanisms. If successful in physically implementing and empirically testing for this extended hypothesis, Normative Self-regulation (Ř) will have been achieved and the Alternative Hypothesis, H_1, can be accepted.

1.0 RESEARCH IN CONTEXT

1.1 Hypothesis in Context

The preliminary hypothesis above raises a number of questions that will be explored through this thesis. Of primary concern to semiotics is the paradoxes intrinsic to the idea of a "sign"[7]. As Kull and Favareau (2022: 21) remind us: "A principal feature of the sign *relation* is *aboutness* – the property of a sign *being about* something other than itself." As will be explored throughout this chapter and the entailed publications, the semiosic self will be understood as not being identical to itself, which seems paradoxical. Nevertheless, these are just some of the attributes of the so-called "sign" and semiosis we need the hypothesis of semiogenesis to bring together into a complete and internally consistent processual model. To set the novel contributions of this thesis into context, this section will start by describing where biosemiotics is now and go back from this contemporary context just far enough to highlight where biosemiotics, as a discipline, and more orthodox approaches to living systems diverge. And, to further constrain what would otherwise be an overly ambitious historical exegesis, the next section will focus on cybernetics. The legacy of this discipline has the unique attribute of both being largely extant in contemporary machine learning techniques and having had a shared history with the Moscow-Tartu school, which sets the stage for contemporary biosemiotics.

To frame the more focused discussion on cybernetics, this section will first outline some commitments that are usually left either unsaid or, more often, unexamined. This will help situate this project in the larger scholarship while also helping to avoid typical logical fallacies in one's arguments. There are three main philosophical commitments that both align this project of semiosis with a select legacy of thought while distinguishing it from others. These commitments are: 1) *irreversibility*: continuous processual novelty; 2) *irreducibility*: distinct and seemingly incompatible attributes, such as chance and determinism, that coexist in the process of semiosis simultaneously; and 3) *affinities*: diverse positive sympathies, *sensu* Peirce (1893: 189), that both affect and are affected by semiosis, again, *simultaneously*.

Henri Bergson nicely presages many key attributes of these commitments that will be rendered more rigorously and shown to be central to the thesis of semiogenesis, such as *irreversibility*. Relating each of these commitments via the continual novelty of irreversibility is the claim of *radical generativity*. For example, in developing the ideas presented at the "philosophical meeting" at Oxford in 1920 (2010: 73), Bergson writes of "the continuous creation of

---

[7] Semiogenesis is a process of semiosis that creates novel attractors able to do adaptive work, as argued throughout. A "sign", per se, can be considered equivalent to such emergent attractors. This project is committed to a process-oriented ontology, whereby there does not actually exist a so-called "sign" that exists in of itself, which is why it is in quotes. Such phenomena, although distinct, are always ontically of a more distributed, dynamical and physically implemented process.

unforeseeable novelty which seems to be going on in the Universe. As far as I am concerned, I feel I am experiencing it constantly." In *Creative Evolution* (2005: 14), Bergson similarly states that "The more we study the nature of time, the more we shall comprehend that duration means invention, the creation of forms, the continual elaboration of the absolutely new." Of note, Illya Prigogine, in his Nobel acceptance speech[8] cites this last passage as inspiration for his own work in dissipative systems.

Extolling *irreducibility*, Lotman in (1990: 232) quotes Prigogine and Stengers (1984: 176) as follows:

> "Self-organization processes in far-from-equilibrium conditions correspond to a delicate interplay between chance and necessity, between fluctuations and deterministic laws. We expect that near a bifurcation, fluctuations or random elements would play an important role, while between bifurcations the deterministic aspects would become dominant."

Similarly, Lotman states: "Chance and determinacy, therefore, cease to be incompatible concepts and can now be seen as two possible states of one and the same object." What is explicit for Prigogine and Stengers in far from equilibrium systems is implicit for Lotman in meaning-making systems: chance and determinacy are not mutually exclusive of the other. One or the other attribute may be "dominant" at any given moment, but neither state excludes the other in vital semiosis. Each distinct phenomenon, although typically conceived as incompatible concepts, is an attribute of the same process, *simultaneously*.

Along with the novelty of *irreversibility* and the *irreducible* co-constitution of chance and determinacy, there is a third commitment of this project that is rarely represented in contemporary models of living systems: *affinities*.[9] And, moreover, these affinities – or *positive sympathies*, as in Peirce (1893: 189) – must emerge during semiosis to often pragmatic, or adaptive, outcomes. Section 2 will introduce radically emergent *attractors* as the physical realization of such positive sympathies in living systems. The technological implementation of this theory will be outlined in section 3. The emergent attractors that are instantiated by this technology are radical because the system of simultaneous differential equations,

---

8 See: Ilya Prigogine – Biographical. NobelPrize.org. Nobel Prize Outreach AB 2023. Tue. 15 Aug 2023. <https://www.nobelprize.org/prizes/chemistry/1977/prigogine/biographical/>

9 Even in the discipline of semiotics, for example, there exists no *positive sympathies* or even *iconicity* in Krampen's chapter on *Models of Semiosis* (1997), which endeavors to create a common vocabulary for integrating the semiotic models of Saussure, Uexküll, Peirce, Hjelmslev and many more. Specifically, Krampen's common vocabulary on page 248 in his *Models of Semiosis* has no item for how similarities, sympathies or iconicity is graphically tracked. Section 3.4.5, on page 281, does make a fruitful distinction between "coded", the main focus of his analysis, and "non-coded properties". Nevertheless, how pre-coded properties become coded properties is not sufficiently explained. In contrast, this dissertation claims that *positive sympathies* and a *continuous common medium*, i.e., Peirce's *continuum*, are necessary attributes of any semiosic system able to implement adaptive meaning-making processes, both attributes not available in most semiotic models, excluding Peirce.

which Bertalanffy's General System Theory (GST) proposes to characterize a dynamic system, must fundamentally change throughout its development, as in living systems.

It is important to credit GST with inspiring the project entailed within this dissertation. GST expanded science's frame from closed to open systems and from discrete relata–relations, as in Newtonian mechanics, to a more wholistic and more simultaneous relata–relations (Bertalanffy 1972; 1968). Nevertheless, their toolkit to characterize the generalizable aspects of these discovered phenomena is systems of simultaneous linear and non-linear ordinary and partial differential equations, which, again, expands the scientific frame, in principle. However, in practice, implementing such *simultaneity* in modern technology is not possible, because extant technology remains in the Newtonian stepwise "mechanical" paradigm of strictly efficient causality. Bertalanffy likely understood and appreciated this limitation. Nevertheless, this tradition is still limited to this frame, which for Bertalanffy, et al., is *a priori* systems of simultaneous equations realized on discrete-state – and therefore necessarily – sequential processors. This thesis endeavors to ameliorate this mismatch between the simultaneity Bertalanffy recognized in living systems and the stepwise sequential tools we have inherited to simulate these observed phenomena.

In the biosemiotic tradition, some of the more "radical" models, as exemplified by René Thom's Theory of Catastrophes (Bundgaard and Stjernfelt 2010), involve bifurcation. Mathematically, these models can be characterized with a logistical map, which will go from a finite number of solutions, given a certain range of parameters, to chaotic outcomes. This deterministic chaos is considered "emergent" behavior by some. This project is even more radical, as it not only posits indeterministic chaos, in principle – whereby the boundary and initial conditions are continuously changing – but that the proposed technology in section 3 will actually implement such indeterminate and simultaneous chaos towards adaptive ends, in practice.

The above argument is likely related to *radical emergence*, as argued for in Longo, et al.'s, paper about *No Entailing Laws* (2012). And it is most certainly related to the emergence of "new *dimensions*", as in Simondon's work on Individuation (2020: 9,13–14)(emphasis in original):

> "[…] affectivity and perception are integrated in emotion and in science, both of which suppose a recourse to new *dimensions.* […] transduction is the correlative appearance of dimensions and structures within a being in a state of pre-individual tension, i.e. in a being which is more than unity and more than identity and which has not yet phase-shifted with respect to itself in multiple dimensions. […] its dynamism stems from the initial tension of the system of the heterogeneous being that phase-shifts and develops dimensions according to which it will be structured; […] In the domain of knowledge, [individuation] defines the veritable measure of invention, which is neither inductive nor deductive, but transductive, i.e. corresponds to a discovery of the dimensions according to which a problematic can be defined [and then resolved via *internal resonance*];"

Much could be said about how the above excerpts align with the project proposed in this dissertation. To highlight a few points: *new dimensions* emerge from a necessary tension in the vital being; this tension is interpreted to comport with Lotman's tension between untranslatability and translatability, along with Peirce's necessary tension between chance and determinism, i.e., flux and fixity; Peirce's abduction comports with Simondon's transduction (Karatay, Denizhan, and Ozansoy 2016) and is a result of this radical emergence from the tension of what Simondon calls the "pre-individual tension"; this project instantiates this pre-individual tension in a distributed milieu, called a *continuous interstitial medium*, similar to Peirce's *continuum* (CP 4.512): "This continuum must clearly have more dimensions than a surface or even than a solid; and we will suppose it to be plastic, so that it can be deformed in all sorts of ways without the continuity and connection of parts being ever ruptured."

The arbitrarily many novel forms that can be entailed in this "plastic" continuum, i.e., the continuous interstitial medium, are able to conjure novel "signs" – i.e., attractors or affinities that emerge after "the heterogeneous being […] phase-shifts and develops dimensions according to which it will be structured" (Simondon 2020: 14) – from within themselves, having cultivated a necessary tension between flux and fixity, also simultaneously within the living being. This conjuring of such novel affinities is one of the central contributions of this project and, by far, the most problematic concept to communicate. Nevertheless, having identified this creativity in living systems, it is relatively easy to see which projects entail this radical generativity and which do not.

For those that do not, there are two main kinds: the mechanistic and the pan-psychic. The former will be discussed in the context of biosemiotics' cybernetic heritage in the next section, while the latter can be exemplified by the Resonance Theory of Consciousness, which purports to leverage a kind of affinities, in their case, that "synchronization, harmonization, vibrations or simply resonance […] seems to have an integral relationship with consciousness itself" (Hunt and Schooler 2019). Extending this analogy of resonance, their model assumes "panpsychism, the notion that all matter is associated with at least some degree of mind/subjectivity/consciousness". Therefore, "Positing panpsychism avoids the problems of emergence because under this approach consciousness doesn't emerge" (Huang and Gunji 2026: 2). Consciousness was, and is, always every-where, per panpsychism: all the little bits of consciousness in all the little bits of matter just need to be connected together. However, once emergence is explained away by one's metaphysical commitments, there is no way to explain how "new dimensions" emerge to resolve the internal tensions continually and necessarily generated by the semiosic being in its ever-novel and indeterminate milieu. The physical phenomenon of resonance is an aspect of affinities presented in this thesis, but such physics must be implemented in a very particular way to cultivate, not only the tension between fixity and flux, but the capacity to harness the novel, unprestatable and indeterminate asymmetries, i.e., sparse order, that emerges in the so-called noise.

Two other projects that do not entail radical emergence, but do appeal to resonance, are Raja's Theory of Resonance to explain cognition in an enactivist context (2018) and Cariani's work with neural code architectures (Cariani and Baker 2022). Raja's work is explicitly based upon Bertalanffy's GST, and, as such, has more in common with semiogenesis than Hunt et al.'s theory above. Nevertheless, as discussed above, the commitment to GST assumes that there exists some fixed set of differential equations that, once discovered, will have always and already explained cognition, life and semiosis. Cariani's project is even more aligned with the central analogies used in this dissertation: e.g., interference patterns, resonances and the inter-causal relationship between these two physical phenomena with neural firing patterns. Nevertheless, it appears to this author that these relationships, once observed and characterized, can be converted into a generalized set of equations that will heretofore explain neural coding. Assuming this is a correct interpretation of Raja and Cariani's work, this thesis does not make the same assumptions. The semiosic being, per semiogenesis, will continually generate ever-novel, unprestatable and indeterminate behaviors in the embodied dynamical living system.

Another contemporary project that does not appear to make these assumptions and *does allow for radical generativity* is the work of Alessandro Sarti and colleagues (Sarti, Montanari, and Galofaro 2015). This project explicitly aligns itself with the work of Simondon and forwards a theory of semiogenesis, as articulated in a paper titled, *Individuation and Semiogenesis: An Interplay Between Geometric Harmonics and Structural Morphodynamics* (Sarti and Piotrowski 2015). The title itself already hints at Peirce's plastic continuum that "must clearly have more dimensions than a surface or even than a solid", as quoted above (CP 4.512). René Thom also employs geometric surfaces. However, even though Thom was also inspired by Simondon, he was committed to fixity in such a way as *not* to allow for radical generativity, as Sarti et al., explain (2015: v)(emphasis added):

> "Simondon's philosophical perspectives on science were further developed in René Thom's mature analysis. Key-concepts as information, metastability and individuation opened new issues for discussion. In particular, even though Thom's concept of morphodynamics provided a topologic categorization of the spatio-temporal configurations, *it left several problems open, such as the constitution of singularities*[10] *starting from a multiplicity of elements, as well as the genesis and evolution of the space of control, that in Thom's approach is a priori given.*"

The project of semiogenesis described in this dissertation is a buildable and non-exotic technology, specified in section 3, which can be experimentally tested, via the theory in section 2, for "the constitution of singularities starting from a

[10] The term "singularity" is not used here in the strict mathematical sense of an infinitesimal point that is either under or un-defined. Instead, it is used in the Simondonian sense of localized dynamics with distinct and characterizable "spatio-temporal configurations".

multiplicity of elements, as well as the genesis and evolution of the space of control" (Sarti and Piotrowski 2015: v). The "singularities" are emergent *affinities*, i.e., attractors; the "multiplicity of elements" is the matrix of diversely tuned Primary Nodes; and "the genesis and evolution of the space of control" are the emergent constraints – i.e., the self-biasing circuit attractor dynamics – via the sparse emergent order in the interference pattern of the continuous interstitial medium. Assuming this experimental methodology is able to accept the Alternative Hypothesis of Semiogenesis described throughout, the other philosophical commitments of *irreversibility* and *irreducibility* can be shown to empirically follow.

Until then, the more rigorous theoretical case for *irreversibility* and *irreducibility* are made in Bacigalupi (2024) and Bacigalupi (2026), respectively. For now, these concepts are being introduced to illustrate philosophical commitments that are handed from one thinker to another through this very specific scholastic lineage, for example, see John Duns Scotus (1300). This is a lineage of perspectives and ideas that, although arrived at largely independent of these thinkers, nevertheless animate a shared conversation over generational time and inform the approach to semiogenesis advocated in this dissertation. The model presented in section 2 will contribute to the claim that *irreducibility* – the simultaneity of seemingly contradictory tendencies – is intrinsic to meaning-making semiosis. This will serve as a prime premise that will, more times than not, align this project with some authors, while distancing it from others, as outline above more broadly and below with respect to biosemiotics.

Given this ontological stance, this dissertation will endeavor to render more rigorously the characterization of semiogenesis, as outlined by others. For example, in Bacigalupi (2023b), some researchers in biosemiotics characterize semiogenesis as follows:

> "As novel habits in an ecosystem emerge, they tend to become signs for organisms in that ecosystem (Emmeche, Kull, and Stjernfelt, 2002: 20). This idea can be traced back to Jesper Hoffmeyer who writes: 'Whenever there has developed a habit there will also exist an organism for whom this habit has become a sign' (1997: 937). Emmeche et al. define this tendency as *semiogenesis*."

In general, it is likely that this dissertation will be able to contribute to this scholarly lineage from Hoffmeyer to Emmeche, Kull and Stjernfelt, because there is a similar ontological commitment to *irreducibility*. For example, both Hoffmeyer and Emmeche, in their discussion on *code duality* (1991), argue that analog dynamics are involved in digital dynamics and vice versa, *simultaneously*. More will be said about these ideas below; the important point now is that these attributes of semiosic systems are not mutually exclusive of each other. They are not *strictly* hierarchical because these distinct attributes are not reducible to each other; the system is never just one of these attributes.

In contrast, other biosemioticians who have used and defined the term *semiogenesis* have ontological commitments that appear to differ with those introduced above. On a surface level, there is agreement that *semiogenesis* is the "emergence of new kinds of sign relations", but they also state that this semiogenesis is a "special kind of semiosis" and that it is opposed to a kind of "routine semiosis" (A. Sharov and Tønnessen 2021: 25:197). On the contrary, this thesis will argue that semiogenesis is co-extensive with semiosis and that non-mechanistic semiosis is furthermore co-extensive with the emergence of life itself. This disagrees with Sharov's earlier claim that there is a discrete type of *protosemiosis*, which is more "mechanical" as compared to what he calls *eusemiosis,* since the former does not involve, in the way that Sharov et al. understand the term, a Peircean *object*. This dissertation will make no such distinction and will, in fact, argue against the thesis that *eusemiosis* is hierarchically built upon a degenerate and mechanical type of semiosis in more ancient and simpler organisms, such as procaryotes, as argued by Sharov and Vehkavaara (2015).

The claims of Sharov, Tønnessen and Vehkavaara compete against both *irreversibility* and *irreducibility*. Whether these authors are aware of it or not, this is because the strict hierarchical and mereological architectures employed by their model relegate the radical novelty of *semiogenesis*, defined herein, to a special status that is mutually exclusive of deterministic and "routine semiosis". This mechanical semiosis is often devoid of novelty and is able to revisit previously held states, which is therefore *reversible*. These mechanical – e.g., strict hierarchical and mereological – commitments also require that "chance and necessity", in Prigogine and Stenger's sense, remain mutually exclusive of each other just as they are in received understandings of neo-Darwinian evolution, which has yet to explain semiosis and meaning-making. Models with such commitments are *reducible*, by design, and cannot be the a priori foundation for veritable semiogenesis. Such a foundation modeled to be tractable and calculable – i.e., fixed functions that intermittently and sequentially evolve randomly – are mutually exclusive of semiogenesis, as defined herein, because such mechanistic building blocks have no discernable pathway to categorically non-mechanistic processes.

The project herein, on the other hand, agrees with Lotman's interpretation above of Prigogine and Stenger's insights: "Chance and determinacy [i.e., necessity], therefore, cease to be incompatible concepts and can now be seen as two possible states of one and the same object." It is tempting, given orthodox metaphors, to think that these "states" are mutually exclusive states, but this would be a mistake in Lotman, Hoffmeyer or Peirce's case. *Veritable* semiosis – meaning really existing semiosis intrinsic to living systems – is distinct from *degenerate* semiosis in that the former explicitly entails each attribute – such as chance and determinacy or untranslatability and translatability – "each to different degrees" (Lotman 1990: 15), *simultaneously*. Given these commitments, the central lacuna biosemiotics seeks to resolve is the question: how can a semiotic understanding of living systems move beyond the cybernetic legacy, which imprisons meaningful creativity between mutually exclusive chance and determinacy; continuity and discontinuity; potentiality and actuality; operation and structure; becoming and being?

1.2 A Cybernetic Inheritance

Persistently occluding this question above are the philosophical commitments of humanity's cybernetic inheritance: a metaphor by which orthodox scholarship partitions the world into knowable mechanical structure and unknowable randomization or contingencies, each in their own incompatible realm. It is a secular, or cryptic, dualism whose artificially dialectic oscillations between chance and algorithm automate the optimization of our alienation.

Discussed in Bacigalupi (2023a) [Article III], this automated alienation will be referred to as the cybernetic mode, which is arguably as old as humanity. Today, it is effectively implemented via artificial neural networks. From Bacigalupi (2023a), these "AI" technologies are:

> "a stepwise alternation between structure and randomization. Initially, the network's architecture is structured so that it may entail an astronomically large number of *possible* permutations of distinct weights and biases via a fully connected network. Then these weights and biases are initialized pseudo-randomly, reducing the astronomically *possible* set of weights and bias settings to just one *actual* configuration. Each weight is a real number, to some finite decimal place, typically between –1 and 1."

Of note is how the dichotomy between algorithmic structure and randomization echoes Peirce's degenerate states of *agapasm*: law-like *anacastic* and chance-like *tychastic* evolution, respectively (CP 6.302), a dichotomy between *fixity* and *flux* that will be discussed throughout. And this furthermore echoes the theoretical frame that constrains Darwinian evolution between random and deterministic causality, a state of affairs acknowledged by Uexküll (1926: 320):

> "All the physical and chemical agencies are supposed, by their external influence, to carry out the creation of form on a substratum to which no properties can be ascribed other than great power of *reproduction* and *variability*. As soon as we presume any tendency whatsoever in the *fermentative* process to have a goal or give a direction, we are forsaking the Darwinian basis. […] The direction followed by the shaping is exclusively dependent on external factors." (emphasis added)

Here, Uexküll is critiquing Darwinian evolution because all it admits is mechanical reproduction and random variability, and that the genesis of form and shape in evolution is "dependent on *external* factors." He goes on to argue that there is something further that exists *intrinsic* to the cell's protoplasm, being both generative ("fermentative") and directed: a teleology of emergence that is wholly ignored, if not actively resisted, by such mechanistic theories. This section will come back to Uexküll's "super-mechanical properties". However, for now, note the persistent and rather pervasive theoretical inheritance of these degenerate forms of evolution from at least the time of Jakob von Uexküll's *Theoretical Biology* in 1926 to how today's neural networks function. Of course, it is notable that Peirce had already presaged, not only the degenerate dichotomy of law-like (anachastic) and chance (tychastic) evolution, but a solution in his *agapasm*, which is akin to the emergent sympathies of *affinities* in my model, discussed in detail in section 2 and 3 as emergent attractors.

Jakob von Uexküll also proposed a solution to what is in essence the observed teleological attributes of living systems. Throughout *Theoretical Biology* (1926), Uexküll speaks of "plan" and he asserts that "[t]here is never evolution, but always epigenesis" (1926: 124). As with Henri Bergson's *élan vital*, Uexküll's notion of "plan" and epigenesis – almost a century before its common use today – make more orthodox biologists and system theorists very uncomfortable. Nevertheless, this discomfort with teleology has less to do with whether ends exist or not: both disciplines largely agree they do. The difference is how such habits and tendencies towards ostensible ends come to be – their ontogenesis – and how they are maintained – genetically and/or epigenetically. The cybernetic camp tends to place the means of such telos in *deterministic* aspects of the Universe beyond the organism's subjectivity, as will be explored below. And Uexküll's "plan" may be sympathetic to a model of living systems where "nothing is left over to chance" (1926: 127). However, others in the biosemiotic community, such as Kull, tend to place the means of such telos in the *indeterministic* innerverse, or "inner world" (Uexküll 1926: 157), of the organism's subjectivity (2015: 4).

To avoid making the same general mistake of *extreme terms* – such as inside vs. outside or deterministic vs. indeterministic – Lotman provides a means to transcend these precarious dichotomies with the idea that "the combination of translatability – untranslatability (*each to different degrees*) is what determines the creative function" (1990: 15) (emphasis added). Not unlike the distinct attributes of Peirce's various triads, Lotman intends that *translatability* and *untranslatability* shall coexist simultaneously superposed "each to different degrees" in the same system[11]. Of course, Lotman focused these ideas on dynamics at the cultural scale. So, why would cybernetics – a model typically employed to regulate machines – be of interest to Lotman?

"[I]n response to a reader's question, 'What is Semiotics?', Lotman noted that semiotics as a science 'originates from the fifties of our century at the cross-roads of several Scientific fields: structural linguistics, information theory, cybernetics and logic'" (Salupere 2018: 69). In understanding this interest, William Ashby rises to the fore. Salupere suggests that "judging by the notes made in the books and quotes used, the most important cybernetician for Lotman was not Norbert Wiener but William Ross Ashby" (2018: 71). We will come back to Wiener, but, for now, Lotman's interests in Ashby's ideas are illustrated by the highlights in his Russian translation of *Design for the Brain* (Ashby 1966). From this book, Lotman later frequently used such terms "as 'homeostat', 'equilibrium stability', 'homeomorphism' and 'isomorphism', etc." (Salupere 2018: 71).

---

[11] An irreducible concept that will be heretofore referred to as *(un)translatability*.

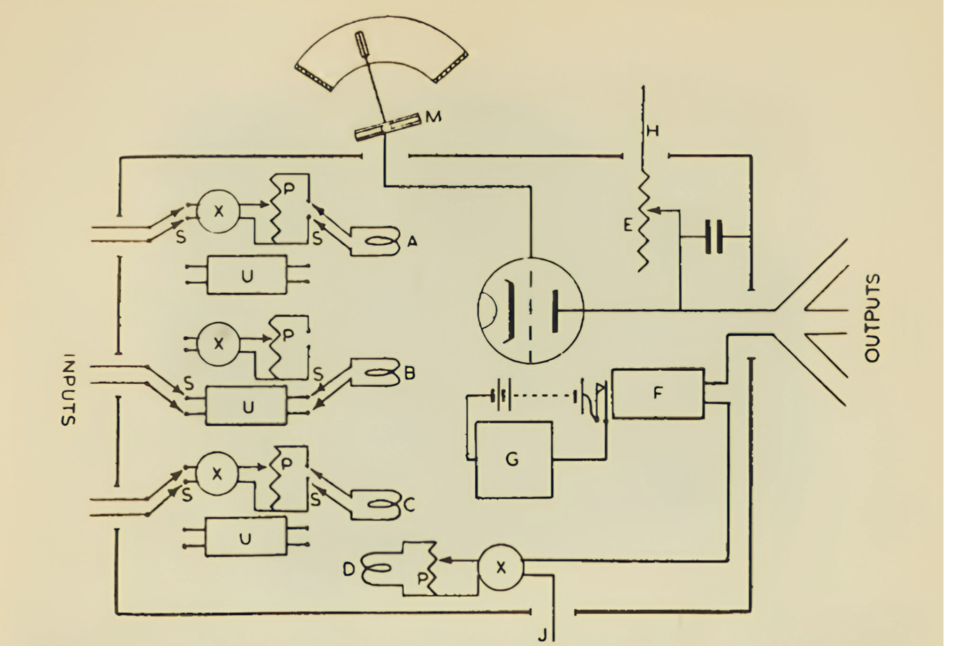


FIGURE 8/2/3: Wiring diagram of one unit. (The letters are explained in the text.)

Figure 1 – W. Ross Ashby's Homeostat. Inputs act on the unit's magnet (M) through the coils A, B, and C, so that the torque on the magnet is approximately proportional to the algebraic sum of the currents in A, B, and C. (D also affects M as a self-feedback.) But before each input current reaches its coil, it passes through a commutator (X), which determines the polarity of entry to the coil, and through a potentiometer (P), which determines what fraction of the input shall reach the coil. (Ashby 1966, 102)

Of particular interest for our historical purposes is Ashby's 1948 homeostat, as diagrammed in Figure 1 (Ashby 1966: 102), which is summarized well by Andrew Pickering (2009: 217–19):

> "The homeostat was a baroque electromechanical device which took up to four electrical inputs and converted them into an output […] How it did this does not much matter for present purposes, but the point to note is that the position of a pivoting needle on top of each unit both measured and controlled the current passing through the unit. Any unit on its own did nothing, but when several were connected together as in the [diagram], the outputs of the other units constituted the inputs to any one of them, and the whole set up would then find itself in one of two conditions. It might be in a condition of stable equilibrium, meaning that the needle on each unit would come to rest in the middle of its range, and return there whenever any of the needles were given a small push. Or the set-up might be unstable, meaning that all of the needles would be driven to the limits of their ranges and stick there. In that event, the key bit of the homeostat's circuitry came into play – an electrical relay would trip and drive a uniselector or stepping switch to its next position. These

> switches had 25 positions, and onto each position was soldered a resistor, whose resistance Ashby picked from a table of random numbers. So, when the relay tripped and the uniselector moved to its next position, one resistor would be taken out of the circuit and replaced by a different one. The homeostat, one could thus say, would randomly reorganise its circuitry […]".

The reason for such detail in a section about history is to make a distinction that highlights a significant divergence between cybernetics, as it is practiced today, and biosemiotics: a difference in relationship between a system and its ends. Because, as mentioned earlier, each discipline embodies a teleology whether its practitioners are aware of such commitments or not. For example, cybernetics today, in the form of so-called Artificial Intelligence (AI), is largely implemented via machine learning (ML). ML is implemented by artificial neural networks (ANN), and, once initialized as described above, their weights and biases are algorithmically manipulated to inexorably tend towards a configuration that can automatically categorize the syntactical structures that inhere within the massive amount of data such systems are trained on. This just scratches the surface of how these systems work. Nevertheless, the important point for now is that this capacity to automatically categorize structure is a *fixed end*. The ANNs – the core technology powering Large Language Models (LLM) – that are trained to, for example, categorize cat vs. dog pictures, are completely bespoke. In other words, once a given instantiation of an ANN is maximally trained, its internal weights and biases – the trained structure that enables these tools to be contemporary AI – is difficult to improve with more data sets and made to inter-operate with other ANNs trained separately. In essence, these ANNs, once trained, are stuck in a local minimum of all the possible patterns they could have learned. They are an isolated and crystalized mapping of the static structure in the training data to the static structure in the trained neural network. Only a catastrophic resetting of weights and biases – thus loosing most anything learned – in modern AIs can escape this local minimum.[12]

Ashby's homeostat, on the other hand, had a very different relationship between the system and its ends. Because his machine is not so fixed and, to some degree, can adapt, as it reconfigured its internal circuits in response to being pushed out of internal equilibrium, a fact likely not lost on Lotman. Another difference is that the relationship between the system's dynamic and its intended end was *intrinsic*. Its end goals were *multistable*, meaning that it could enact multiple distinct and relatively stable attractor states. This is unlike ANNs, whose structure terminates into one crystalized state, i.e., a fixed output model, after training and remains there to function as a categorizing tool, for example. In these ways, Ashby's homeostat was more like living dynamical systems with multiple

[12] There are techniques, such as convolution, that enable AI algorithms to discern sub-features of an image before the model coheres too quickly on high-level features of the input data. This partly solves the problem of getting stuck in non-optimal local minima, but the output model still results in a fixed solution that is only an approximation of the data it is trained on.

intrinsic stable attractors. Salupere suggests that the “reason why Ashby appealed to Lotman may have been that Ashby, who was a biologist, showed greater interest for ‘living’ systems” (2018: 72).

Since then, we can observe that modern cybernetics in the form of AI are *not* multistable – let alone *metastable*, an even more complex living dynamic discussed in sections 2.3 and 4.1 – in the way that Ashby’s homeostat seems to be. In the interest of a truly biological semiotics, however, one could argue that multistable setpoints within the homeostat are only internally determined. In other words, they are not sensitive – and therefore not relevant – to their surroundings. And, subsequently, these solipsistic set points are not semiosic in the sense of being about what it is not. In a sense, modern ML is more about its environment, insofar as its internal structure is determined by so-called external factors. Notably, however, ML is only about itself in that all its weights and biases have been randomized. Similarly, the homeostat only finds a novel stable equilibrium because its resistor settings were chosen randomly by the engineer *a priori*. And so, in either approach, we find ourselves back at Peirce’s degenerate modes of evolution: law-like or randomized. It will be argued that, unlike fixed or solipsistic ends, semiosic setpoints, or *habits* as in living systems, must be about both these modes and a third thing, *simultaneously*.

What this “third thing” has been historically for biosemiotics has already been alluded to: Peirce’s *agapasm* and Uexküll’s *plan*, for example. To this can be added Lotman’s *metastructure* (Salupere 2018: 77) (first emphasis added):

> “[...] the minimum structure of the text is the presence of two semiotically autonomous subtextual formations and *a semiotic metastructure connecting them*. A fundamental feature of this structure is the trinity of this mechanism, the fact that each of its parts can, to a certain extent, function completely independently of the others while at the same time, in another aspect, they form an indivisible functional whole. This *ustrojstvo* [a design organization in this context] is what enables the text to become a meaning generator in place of a passive transmitter of enclosed meanings. (1982 : 4)”

A common theme for these thinkers is that each of the higher-order concepts cannot be reduced to their simpler components, but nor can they be understood without them. The degenerate modes of evolution for Peirce – his chance *tychasm* and law-like *anancasm* – are inextricable attributes of his concept of *agapasm*, which adds a novel capacity – a *positive sympathy* – able to interrelate the degenerate modes so as to be veritable semiosic evolution, or *semiogenesis* (CP 6.304):

> “In genuine agapasm, on the other hand, advance takes place by virtue of a positive sympathy among the created springing from continuity of mind. This is the idea which tychasticism knows not how to manage.”

Similarly, for Lotman, it can be argued that generative meaning-making in culture requires a *metastructure*, which is not merely a sequential concatenation of subtextual formations; there are aspects of each that constitute the other's distinct nature via some higher-order attribute intrinsic to this "trinity of mechanism". More will be said about the *positive sympathy* of *agapasm*. But first, to ground more generally the biosemiotic inheritance of these higher-order conceptions, and to deepen our understanding of contemporary cybernetics' inability to explain biological processes, Uexküll's function-circle will be employed.

This thesis will extend Jakob von Uexküll's concept to render it part of an overall lineage of semiogenesis. This section will highlight three such extended aspects that may stretch more orthodox interpretations of Uexküll's function-circle: 1) they are generative, 2) this generativity creates "implements", or novel functions, and 3) the novel functionality emerges from resolving *disparation, sensu* Simondon[13]. Echoing the informal hypothesis at the end of section 0.3, generativity increases the living system's own internal capacity; functionality means that these capacities can do more semiosic work; and disparation is a means to resolve the internal disorder. And, for Uexküll in the chordates, this involves self-direction (Uexküll 1926: 157). Illustrated in Figure 2, Uexküll explains this process as such (1926: 157):

> "A new circle is introduced within the animal's own central organ, for the support of the external function-circle, and this connects the action-organ with the mark-organ. In this way, the animal's own action-rule fits in with the indications stimulated from without, and now serves the mark-rule as a skeleton to which it may attach the external indications.
>
> Now for the first time there appear in the world-as-sensed actual implements, possessing a function-rule. […] When the movements of the animal's own limbs enter the mark-organ, it becomes possible for it to control its own actions."

On the surface, the idea that sensory reception of its own actions allows the animal to control those organs seems like a typical negative feedback loop. However, Uexküll claimed that the sensation of one's own actions juxtaposed against their outcome in the outer world, i.e., the "indicator", could be continuously resolved, because "protoplasm has [the] power to go on creating the mechanical apparatus anew and to break it up the again" (1926: 123). Perhaps the outcome of an action was anticipated, but perhaps it was not. In the latter case, a correction must be made. But, in the animal's unique set of circumstances, there is no external programmer to write that code, or "action-rule". And the only "data" available to characterize the aberration, let alone its solution, are within the animal itself,

[13] Simondon discusses how *novel dimensions*, or constraints, emerge via *disparation* (2020: 711), which he exemplifies via binocular rivalry: the retina of each eye sends two distinct two-dimensional images to the visual cortex, simultaneously; each is of the same exact scene, except that they are slightly disparate due to the different vantage point of each eye; and, it is the superposition of these very similar, while disparate, images that a novel third dimension is made available to aid in discerning depth. The connection to generative functionality can be seen in this example.

again, not data sets fed by external agents. A preliminary solution is to add a new functional circle, as illustrated by "New circle" in Figure 2. The principal aim of this thesis is to explain how this generative functionality is possible in living organisms. And Uexküll's work will continue to be part of this explication, as suggested on the page previous to Figure 2 (1926: 156) (emphasis added): "We know a number of cases that are explicable only by *super-mechanical regulation*, and so prove the *intervention of protoplasm*. In contradistinction to these, reflex actions, which are usually of a simple kind, unfold, as it were, automatically."

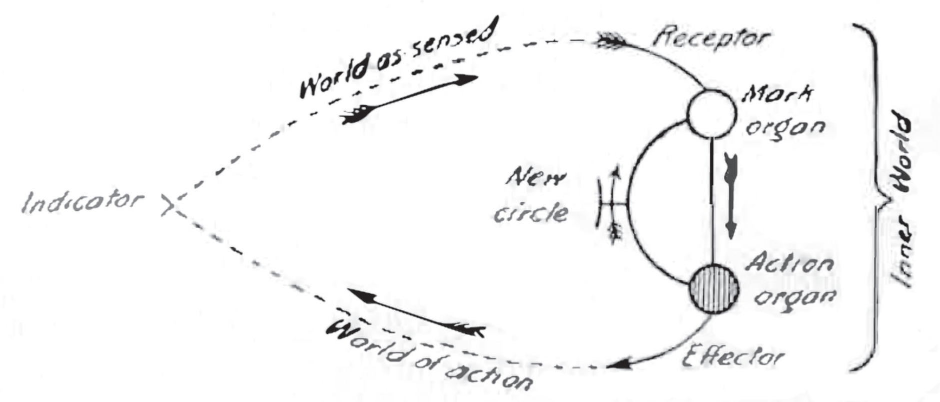


Figure 2 – Jakob von Uexküll's function-circle from Theoretical Biology (1926).

Here, Uexküll very clearly attributes agential and subjective powers to the organism, *per se*, in contradistinction to automatic reflex actions alone. Building on Uexküll's work, or perhaps rediscovering an idea that has been forgotten many times (Grüsser 1995: 47), Erich von Holst empirically demonstrates Uexküll's claim that automated reflex alone cannot account for the ability of animals to distinguish between movement in the world from their own movement (1954: 89), a capacity explored since as the Reafference Principle, i.e., the *efference copy*. This biological phenomenon, and its empirical investigation, undergird a largely invariant thread through the history of biosemiotics – an idea that Peirce, Lotman and Uexküll along with contemporary biosemioticians can agree upon: "Semiosis is the process that is responsible for the existence of sign relations" (Kull and Favareau 2022: 20). It is not certain that Holst, as a more traditional ethologist, would understand this semiotic claim, let alone agree with it. Nevertheless, Holst and Uexküll are both asserting that relations among disparate sensory stimuli must be made and, often novel, actions performed in response. They are both also clearly pushing back, each in their own time, against the perennial claim that animal behavior can be explained by isolated and *a priori* fixed reflexes.

The idea that these mechanical relations exist *all the way down* to explain animal behavior, along with its implications, is explored in Chapter Four of Hoffmeyer's *Biosemiotics* (2008) and his *Signs of Meaning in the Universe*

(1996). In the section entitled *The Epistemic Cut* of the former, Hoffmeyer quotes Howard Pattee (2008: 93):

> "We must define an *epistemic cut* separating the world from the organism or observer. In other words, wherever it is applied, the concept of semantic information requires the separation of the knower and the known. Semantic information, by definition, is about something."

Earlier, in the same publication, Pattee quotes (2008: 17) John von Neumann:

> "We must always divide the world into two parts, the one being the observed system, the other the observer […]. That this boundary can be pushed arbitrarily deeply into the interior of the body of the actual observer is the content of the principle of the psycho-physical parallelism – but this does not change the fact that in each method of description the boundary must be put somewhere, if the method is not to proceed vacuously."

Hoffmeyer then quotes Pattee at length interpreting von Neumann's insistence that the observer be split from the observed "arbitrarily deeply". In brief, Pattee's interpretation is characterized by a system, S, which conducts measurements, M. Given this, as S observes itself and its environment, we have S'=(S+M), which is reminiscent of an animal observing itself in the world, as discussed above. However, Pattee observes that, if both S and M are governed by discernable physical laws and they are considered divided, S' results in an infinite regress. This is because S+M, each term being exclusive of the other, is a concatenation. In other words, like a list of discrete tokens, they can only be related by a system *external* to itself; the system, S, does not *intrinsically* resolve the disparation between its initial self, S, and its sensory "measurements", M, to become its subsequent self, S'. Choices must be made about what is relevant or else the sensory stimuli stack up indefinitely.

To stem this regress, the system, or observer, "must in effect choose what aspects of the physical system to ignore and invent those aspects that must be heeded. This selection process is a decision of the observer or organism, and cannot be derived from the [external] laws (Pattee 1997)" (Hoffmeyer 2008). Uexküll understood this dilemma, which is why he discusses the intrinsic creation of ever-novel rules and function-circles to implement those emergent constraints on irrelevant sensory input.

The direction of Pattee's solution to this regress is captured in his *epistemic cut*: "separating the world from the organism or observer." Hoffmeyer is rightly skeptical of Pattee's solution (2008: 93):

> "In the perspective of this book it remains, however, a big question, as to whether or not Pattee is right in this – for central to the current investigation is the question: Through what processes exactly could a dynamic functional mode possibly become a semiotic functional mode? Pattee is not very specific when it comes to this question."

This is not only the central question of this section, but also the central question of semiotics as it emerges as a discipline from the utilitarian successes of logical positivism, industrial revolution and legacy cybernetics, each harboring their own implicit *epistemic cut*. In chapter four of *Biosemiotics* (2008), Hoffmeyer discusses this *cut* in different disciplines: Weismannism, whereby somatic cell lines are separated from germ lines; Gene Selectionism, whereby the "genetic" actors dictate behaviors onto a passive cytoplasm, as Dawkins argues in his popular book *The Selfish Gene*; and, Digitalism, whereby DNA are claimed to be a literal digital code (Hood and Galas 2003).

Of concern for Hoffmeyer is that all these *cuts* reflect "yet another example of the well-known tendency of science to transform the dominating structures of social reality into natural reality." And since this social reality is historically contingent on what in our time is an industrial society, Hoffmeyer suggests that (2008: 79):

> "[…] a digitalist reading of genetic expression follows naturally. For just as the overwhelming productivity of industrial society was obtained through a separation of planning from execution in a master-servant relation, evolutionary theorists have argued that evolutionary creativity should be explained by a separation of the genetic master plan (the DNA) from the mundane operations of the cytoplasm – with the cytoplasmic processes themselves, of course, obeying the dictums of the genome."

Setting aside Hoffmeyer's social analysis for the moment, Pattee understands both the danger of infinite regress and how a physical description of the system is incomplete, needing a semiotic solution. Ironically – perhaps because of the historical milieu Hoffmeyer summarized – his *epistemic cut* between the world and observer only seems to maintain the regress he diagnosed via his S'=(S+M) analysis. As such, a semiotic understanding is not brought to bear on our physical understanding, as observers are isolated from what it is they observe.

Hoffmeyer explains how he and Emmeche endeavored to narrow the gap maintained by Pattee's *epistemic cut* via their *code-duality*: "a recursive and unending exchange of messages between analog and digital coding surfaces (Hoffmeyer and Emmeche 1991; 2005)" (2008: 80). In this model, DNA is still a *digital code*, but it is not the master plan that actively imposes itself on the cell's cytoplasm. In fact, Hoffmeyer inverts this logic to largely conceive of the DNA as a relatively passive, and therefore stable, symbolic code, which is acted upon by a much more dynamic cytoplasm, the *analog code*. Similarly, instead of a fixed set of reflexes, Uexküll turns to the "super-mechanical" powers of the "protoplasm" discussed throughout his *Theoretical Biology* (1926).

Building off studies in epigenetics, the Weissmann barrier is also broken down so that Dawkins' notion of the genetic germ line is no longer conceived as merely using the soma, whereby the living body is conceived as a "dead end" (Hoffmeyer 2008: 72). Instead, the lives of extant bodies affect germ lines, and cytoplasm in the cells that compose those bodies affect when and how the genome is expressed. *It is a two-way process.*

But Hoffmeyer's claim is deeper than a mere trade or stepwise exchange between two different phenomena, one so-called "digital" and the other "analog"; this would only land us back in a regress. Hoffmeyer goes further to suggest how digital can become analog and analog can become digital. For example, on pages 91–92, Hoffmeyer describes how analog codes reach a threshold to become digital, as in quorum sensing, and digital codes can also sum to be analog codes, as in neuronal integration. Earlier he argues that his conception of digital and analog are "twins in the individuation process that gave rise to life's internal logic" (2008: 88). This suggests that such phenomena, although distinct, are ontologically ***of*** each other.

These subtleties reframe the question from an epistemological problem struggling to use physical language to describe semiosic phenomena to an ontological question of how semiosic phenomena can emerge out of physical phenomena. Hoffmeyer moves this conversation forward by positing the complementary relationship between dynamic, synchronic, time dependent and active phenomena – like cytoplasm – and relatively stable, diachronic, time *in*dependent and passive phenomena – like DNA. For Hoffmeyer, the former is "analog", and the latter is "digital". And he suggests that each phenomenon may transform into the other.

Nevertheless, this transformation – the ability for semiotic systems to in-form themselves by re-forming themselves in a non-stochastic and non-algorithmic degenerate manner – remains largely unexplained. This is because the analog phenomenon for Hoffmeyer remains wholly synchronic; Hoffmeyer conceives of his analog as "mime" (2008: 86), which imprisons his analog code in an efficient causal mode, something akin to Ashby's homeostat. Cleary Hoffmeyer, just like Pattee, intended to escape the infinite regress of their predecessors. Nevertheless, explaining how semiosic systems develop remains unanswered.

Stepping back a bit further, the semiosic problem can be understood as a series of paradoxes, viz. the *extreme terms* listed earlier. In the spirit of S'=(S+M), life must constantly adapt to remain itself. Organisms perceive themselves and their environments to simultaneously recreate themselves accordingly. But this means that living systems must be about what they are not, as introduced in the previous section and Kull and Favareau remind us. The deterministic solution is to try to describe every possible dynamic inside and out, which assumes that each aspect, or *cut*, of the system can be stepwise assessed. But, again, who/what is doing the describing and, with every cut and every measure, did they not just alter the very system they are measuring? Herein lies the infinite regress; it is an exercise in combinatorial explosion, assuming such a task is possible at all. As both Pattee and Hoffmeyer note, choices must be made of what to measure and, based upon that, how to act efficaciously. But, again, these choices must collapse innumerable sensory inputs and remembered relevant experiences into compact acts in real-time with existential stakes. This is a very significant problem life has figured out given its nearly four billion years of continuous operation.

If this question cannot be answered deterministically, perhaps it's statistical inference? No. On the contrary, this thesis will offer yet another path. Both of these oft tread tactics of determinism and chance are Peirce's degenerate cases of evolution: *anacastic* and *tychastic evolution*, respectively (CP 6.302). What is missing is *agapastic evolution* and Peirce's Firstness, without which veritable Thirdness does not exist. Peirce's metaphysics are not the focus of this thesis, but it does help frame the proposed theory of semiogenesis through a semiotic lens. Therefore, briefly, Peirce's Firstness, Secondness and Thirdness can be characterized with respect to tychasm, anancasm and agapasm, as follows (Lacková 2025: 39):

> "Agapasm corresponds to Thirdness as a category representing mediation; as the mediation between Secondness and Firstness, it has a relational character, but the relation is a triadic one which cannot be reduced to dyadic relations of anancasm. Thus, laws and randomness in nature are derivatives of agapasm […]"

As will be discussed in section 4, Self-regulation is a mediating capacity, just as agapasm described above. And just as Thirdness mediates Firstness (chance) and Secondness (brute reaction) (CP 6.202), agapasm mediates tychasm (chance) and anancasm (law). Similarly, as will be argued throughout, some kind of self-regulation must mediate between disorder and order; flux and fixity; under and over-coherence. Most models of semiosic systems to date, however, including Hoffmeyer's, are bound in degenerate Secondness, devoid of veritable Firstness. As suggested above, this is because Hoffmeyer conceives of his "analog" as "mime", which is well within the reactionism of degenerate Secondness. This conception of analog is strictly synchronic.

Nevertheless – as introduced above and explored in Bacigalupi (2026; 2013; 2022; 2023a; 2023b; 2024; 2025) [Articles I, II, III] – there are expanded notions of analog phenomena that are potentially diachronic, or time *independent*. For example, the unbounded electromagnetic signals superposed in the noise of a system are a font of linear *potential* relations, as with both constructive and deconstructive interference. So, not only can this expanding conception of Hoffmeyer's analog code provide a transformational bridge between his now deterministic analog and digital codes, the superposed aspect of this expanded analog phenomenon can also facilitate how a semiosic system can be about many things at once that are both present (signal/figure) and absent (noise/ground), a very important distinction in semiotics that will be revisited in section 4. Before then, however, sections 2 and 3 will render in greater detail both the hypothesis of this research and the methodology for testing it.

2.0 RESEARCH TASK: PRELIMINARY HYPOTHESIS

2.1 Model Overview

The intent of the model in this section – in addition to resolving the questions in the previous section – is to provide a heuristic lens through which complex generative agential phenomena, such as a termite mound (Bacigalupi 2022) [Article II], physiological coordination (Bacigalupi and Favareau 2023) [Article IV] or creative sentience (Bacigalupi 2023a) [Article III] more generally, might be more rigorously understood. Towards this end, this section will characterize a theory of semiogenesis, and section 3 will outline a novel technology able to emulate this theory. The principal conclusions of this section were largely completed by the end of 2011 and build on Bacigalupi (2013) [Article I]. Moreover, these conclusions will be reached in two steps. The first step is to more rigorously and completely characterize some of the dynamics introduced above: Relevant Complexity (Č), Adaptive Work (∑W) and Semiogenesis (Š). Normative Self-regulation (Ř) will be explored further in section 4.1. The second step is to present a schematic design for a non-exotic novel technology able to emulate some observable degree of Synthetic Cognition and semiogenesis, more generally. The degree to which semiogenesis is successfully implemented by the eventual instantiation of this technology will be measured by Š. Any repeatable non-zero measure of Š will justify the acceptance of the Alternative Hypothesis of Semiogenesis.

As discussed above, this model does not duplicate semiosis in living systems. Nevertheless, it intends to move our understanding forward by being grounded in both information theory and thermodynamics, while simultaneously incorporating the paradoxical aspects of semiosic agency summarized above. This physically grounded system is able to not only tolerate but thrive off these paradoxes.

A principal question at the very beginning of this research is how it is possible for neurons to wire themselves to be about complex patterns in their environment without an external programmer. Studies by Christophe Koch (Anastassiou et al. 2011), and others (C. Hales and Pockett 2014), on non-synaptic causes for neuronal potentiation and connection, such as ephaptic coupling and Local Field Potential (LFP), suggest that the interstitial milieu among neurons may help explain learning. Intuitively, it was unsatisfying to imagine how existing neurons could rewire themselves non-stochastically without a more distributed global phenomenon. Empirically, LFP, a more distributed interstitial phenomenon among neurons, has been shown for decades to both mold and be molded by neuronal behavior; empirical studies continue to corroborate the causal efficacy of these more distributed and linear phenomena (Anastassiou et al. 2010; Buzsáki, Anastassiou, and Koch 2012; C. G. Hales 2014; C. Hales and Pockett 2014; Herreras 2016; Weiss 2010). In any case, this was not the only problem with existing orthodoxy; as described at length above, there remains the core issues for sentient beings having to resolve the existential paradoxes they regularly face, whether at the neuronal or organismic scales.

Early on in this investigation, the most persistent intuition able to address both the empirical and the philosophical questions was the analogy of an interference pattern, which can be visualized as drops on a pond and the superposed ripples they create. Embodied in this interference pattern are both the distinct events, the drops, and their spatial and temporal summations. Additionally, as discussed in previous sections, the physical common medium – whether water or LFP – is able to embody, in principle, an infinite number of patterns in a finite extent. And, again, these innumerable undulations superpose such that the immense dimensional potential[14] of this medium can entail both the individual distinct patterns and their inter-relations, simultaneously. Of course, each of these undulations are transparent to each other, in the sense that waves will pass through each other summing for just an instant, while otherwise not leaving a lasting impact on each other. This independence is a principal feature of noise. This analogy illustrates linearity, continuity and decoherence.

However, habits in nature from self-organization to more complex life are not just linear, continuous and decoherent; they are also non-linear, distinct and coherent to some degree. Persistent far-from-equilibrium dynamics are some balance of these ostensibly dichotomous attributes; they are both coherent and decoherent, simultaneously. In semiotic terms, this is extending Juri Lotman's argument that "[t]he combination of translatability-untranslatability (each to different degrees) is what determines the creative function" (1990: 15) down to the cellular scale. Put in information-theoretic terms, Cecile Malaspina (2018: 16) nicely frames a similar dichotomy: "the same mathematical method nevertheless justifies two diametrically opposed definitions of information: one of information as 'information entropy' and the other, on the contrary, of information as the 'negation of entropy'." This tension between surprisal and what is anticipated can be generalized as life's complementary tendencies to both *explore* – expanding *breadth* of opportunity – and *exploit* – homing in on *depth* of opportunity, respectively.

It became quite clear, early on in this investigation, that a principal achievement of semiosis, viz. living organisms, is the capacity to navigate this paradox, not as a dichotomy, but as a yin/yang co-constitution: in their embodiment, decoherence is of the coherence and coherence is of the decoherence; each is of the other as the balance between them adaptively ebbs and flows.

A consequence of this ebb and flow is that life is radically creative. Discussed in detail below, as emergent structures are habituated out of the relevant noise,

---

[14] This potential can be illustrated by comparing a still flat surface of water that can be defined by just two dimensions with an interference pattern in that surface perturbed by one, two, three or an arbitrary number of contemporaneous drops; with each drop the surface generates an interference pattern of arbitrarily large complexity. With an increase in physical complexity, an increasing number of dimensions are needed to characterize this pattern. For example, a Fourier transform that characterizes the frequency spectrum of a given snapshot of an interference pattern would require increasing numbers of sinusoidal terms to characterize ever more complex patterns.

new constraints are necessarily captured that fundamentally alter and complexify the initial and boundary conditions for subsequent dynamics (Longo, Montévil, and Kauffman 2012); this is fundamental to sense making, as Peirce's semiosis, Simondon's Individuation (2020) and Hoffmeyer's *semiogenic capacity* (2008: 188) suggest. This section will render more rigorously the intuitions and the informal definition of semiogenesis in the introduction above.

A major piece missing from the interference pattern analogy above is some kind of non-linear element to balance the purely linear nature of superposed wave forms in a continuous physical medium; being a purely linear phenomenon, there is no memory in superposed patterns. Non-linear elements are needed to both generate and, in a sense, *interpret* these linear patterns and their inter-relations. In biological neural networks, these non-linear elements are neurons. But, unlike contemporary models of neural networks that conceive of abstract neurons as identical nodes with fixed rules exchanging symbols, this project chooses to imbue individual nodes with diverse analog sympathies. These diverse sympathies overlap while being differentially sensitive to sensible energetic patterns in their shared surroundings, or associated milieu, which in this model is an interference pattern or "sea of noise".

But it is critical to note that this interference pattern is not only perturbed by energies from the "outside"; it is also populated by patterns produced by the non-linear nodes on the "inside". This common medium of the interference pattern, via its diverse sympathies, is simultaneously of an arbitrary "inside" and "outside", while it also molds and is molded by the behavior of diverse non-linear nodes, again, *simultaneously*. As will be illustrated below, this associated milieu of superposed energy exchange – that is both linear and non-linear, distributed and localized, continuous and distinct – is how the paradoxes above are faced and also why trying to localize agency within an arbitrary boundary is problematic.

2.2 Adaptive Work

The proposed non-linear nodes are arranged in an array of diversely tuned oscillators in a common medium, which for our purposes, can be free space through which electromagnetic waves permeate, what this project calls the continuous common medium or milieu. Embedded in this medium are distinctly tuned oscillators within Primary Nodes – the darker dots in Figure 3 – that have circuits, which exhibit three main behaviors: 1) they are sensitive to frequencies in their environment that are at or near their respective resonant frequency[15], 2) they can transmit an electromagnetic pulse, like a ripple, into their shared milieu when triggered, and 3) they have potentially hard wired connections with other Primary Nodes, a process I call *armoniataxis* (Bacigalupi 2025).

[15] These are physical analogs for Peirce's *positive sympathies* introduced in section 1.2 and, arguably, a precondition for his Agapastic Evolution (CP 6.304).

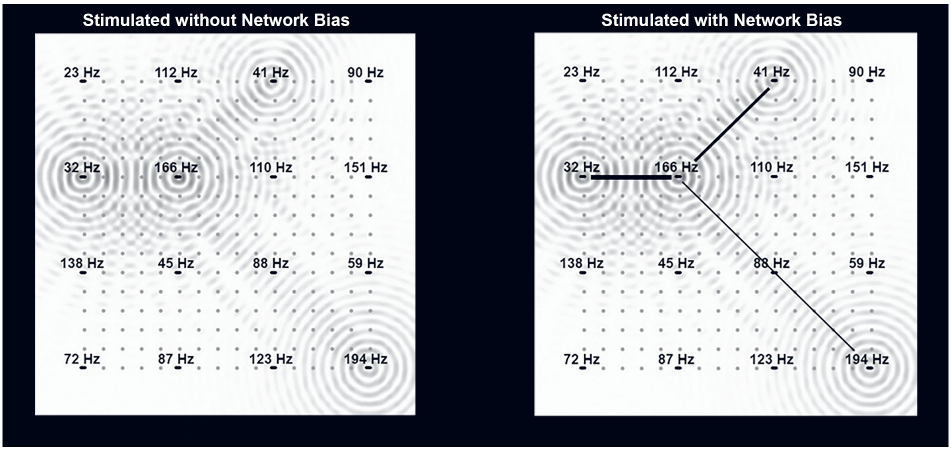


Figure 3 – Adaptive Work. On the left, particular Primary Nodes – the darker dots with resonant frequencies above – are stimulated by arbitrary frequencies from the environment between times a and b, on the left side of Equation 1. As these frequencies persist, stimulation in the sympathetic Primary Nodes will be triggered, which results in pulses. These pulses interfere in the array's shared common medium creating an ephemeral interference pattern with emergent asymmetry as constructive interference. This constructive interference can be sensed by the more numerous grey Secondary Nodes. This is the basis upon which biases, or "hard connections", accrue in the network, diagrammatically illustrated at right. These accrued biases render the network responsive to this more complex pattern. These biases, i.e., emergent ephemeral structure, facilitate a more robust response when these learned patterns recur in the environment, which results in more Adaptive Work, as denoted between times x and y in Equation 1 on the right. Adapted from Bacigalupi (2013).

Each Primary Node has a frequency posted above it that indicates its resonant frequency. This is the frequency that, if it occurs in the array's surroundings, the node will be most strongly stimulated. Primary Nodes, whose resonant frequency is at or near these external frequencies, will be stimulated; once this stimulation reaches an empirically derived threshold, the node will be triggered and send a pulse, like ripples, into its shared interstitial milieu. These ripples then interfere with each other analogous to ripples on the water. And this interference pattern is *relevant noise*. This noise is relevant because it is cultivated by the particular pulses, or "voices", of stimulated Primary Nodes, nodes that have been stimulated exactly because they have an intrinsic sympathy for distributed energy patterns in their surrounding milieu. There is a kind of selection. Each Primary Node has unique tunings so they will respond only to particular aspects of their milieu; when stimulated they will contribute back to that distributed noise, like a member of a choir contributes to the choir's song. As will be demonstrated in subsequent sections, this "song" is always different, yet similar, to past patterns. This is arguably Lotman's *(un)translatability*. From moment to moment, the system translates itself, based both on its own state and that of the indeterminate milieu the system is embedded. This is the relevant nature of – not purely stochastic – relevant noise, which harbors *potential structure*.

One way that *potential structure*, having emerged from the *relevant noise*, becomes *actual structure* (Bacigalupi 2022) [Article II] is that the initial constructive interference illustrated in Figure 3 exhibits greater potential energy than the areas of greater deconstructive interference. The Secondary Nodes – the more numerous grey nodes amongst the Primary Nodes – can sense this differential order in the interference pattern, which then serves as a *virtual map* based upon which novel wired connections can non-stochastically and non-algorithmically connect and strengthen, thereby re-wiring the network. This accrued network bias then predisposes this array to become preferentially sensitive to not only individual frequencies, but also groups of similar co-occurrent frequencies that may happen again in the future.

$$Work[a,b] = \sum_{i}^{16} \int_{a}^{b} I_i \, V_i \, \cos\theta_i \, d\tau \; < \; Work[x,y] = \sum_{i}^{16} \int_{x}^{y} I_i \, V_i \, \cos\theta_i \, d\tau \quad \text{Equation 1}$$

The Adaptive Work inequality in Equation 1 reflects how re-wiring has altered the relationship between alternating current and voltage in the emergent circuits. Prior to biasing, noise dominates, which leads to a less coherent behavior among Primary Nodes. Initially, the system during time interval [a,b] can be exposed to a pattern, like a musical chord discussed below. The system is then hypothesized to re-wire itself, as outlined above and further in section 3. The system will have been physically organized to be preferentially sensitive to more complex patterns like the ones experienced previously by the system. This can be tested empirically by exposing the biased network to the same musical chord at the same intensity during time interval [x,y], which will be equal in duration to interval [a,b]. Accepting the Alternative Hypothesis, H_1, will require, at a minimum, that more work is done during [x,y] than [a,b], as stipulated in Equation 1.

Technically, this is because the wired biases, or *actual structure*, will have slightly aligned the phasic relations between current (I) and voltage (V) among the sparse subset of Primary Nodes; this results in increased *real power* for this particular sparse higher-order pattern, which means that when this pattern recurs in the system's surroundings, this biased network will be able to more effectively draw on available energy and increase the chances of rising above the noise floor, thereby becoming salient *potential structure* able to either create novel or strengthen existing *actual structure*; the cycle continues. These emergent circuits will instantiate a dynamic *attractor*. And, since the time integral of real power is work and this particular work is the result of underlying *relevant noise*, it will be called Adaptive Work ($\sum$W).

Here we have a somewhat rigorous illustration of how actual structure can emerge from the infinity of possible interference patterns in this finite matrix of nodes, whereby the slightest change in which nodes are stimulated, when and by how much can significantly change the resultant interference pattern. In practice, each Primary Node that is triggered will compete with other coincident patterns and tend not to generate a new structural habit, because living agents face all manner of competing *possible* patterns. This will likely contribute to noise insofar as their signals lack the salience to accrete structure. Nevertheless, a sparse number of nodal firings will constitute a salient dynamic attractor that can remain salient above the noise floor long enough to do efficacious work. See section 3 for a more detailed description of these dynamics. For clarity, the deconstructive, or "noisy", regions in Figure 14 are shown as "flat" white. However, these regions would typically be abuzz with *relevant noise*.

Because noise is always intrinsic to the system, its tendency to cohere on just one pattern is mitigated. Even as biases accrue, noise is in tension with the tendency for any one dynamic attractor to dominate. This begins to technically implement the discussion above regarding under-coherence being in tension with over-coherence; they co-constitute each other by, ironically, mitigating each other's more pernicious tendencies. As such, *the viability of the system requires that this edge-of-criticality between noise and any one attractor is maintained*. Coherent tendencies must necessarily undermine themselves just as purely decoherent, or noisy, tendencies must be undermined; it is by each dynamic being in tension with the other that complexity may accrue. This leads to a rigorous understanding of Relevant Complexity.

2.3 Relevant Complexity

For the purposes of this model, Relevant Complexity (Č) is defined as the capacity to bias, or re-wire, circuit connections among a matrix of Primary Nodes such that the system accrues *metastability*[16] in three ways: 1) more attractors – such as stable habits, like simple musical chords – at a given level of Complexity, 2) increased bias of those attractors, meaning more coherent activity among nodes for a given attractor, and 3) inter-relations among these distinct attractors such that higher-order levels of sympathetic behaviors can accrue, like a more complex compound chord, discussed further below. In Figure 4, operating beyond points a and c outside of the parabola are death-states: under-coherent "noise" and over-coherent fixed structure, respectively. Living systems and semiogenesis must be in the non-zero Complexity space, e.g., points b_1, b_2 or b_3. Inside of the parabola is the operational space within which semiogenesis is viable.

The initial level, as a Zeroth Level, has zero Complexity. Non-zero Complexity, on the other hand, requires that distinct, often dissimilar, sensitivities be associated. As discussed above, this is implemented by sensing asymmetries, such as sparse

---

16 This project builds off of three types of stability: fixed stability, multistability and metastability. Fixed stability describes a system with one state. A multistable system can have many states, but transforming among them is not well-defined; it can be catastrophic for the system to switch among states. A metastable system also has many states that can be visited in relatively well-defined ways; living systems are largely metastable as, for example, an organism reforms themselves to switch from exploitation of a resource to exploring for resources. Bacigalupi and Favareau (2023) [Article IV] discuss the difference between multi and metastability in greater detail.

constructive interference, in the interference pattern of superposed ripples emanating from stimulated nodes, i.e., *relevant noise*. This "sensing" happens as the sparse pattern persists long enough above the noise floor such that *potential structure* among co-active nodes can be instantiated into *actual structure*: novel circuit connections, biasing subsequent system behavior. These biases will then instantiate a 1st Level Attractor, meaning that the individual sensitivities of diverse Primary Nodes, in combination with their accrued biases, will realize a higher-order sensitivity towards groups of co-active Primary Nodes.

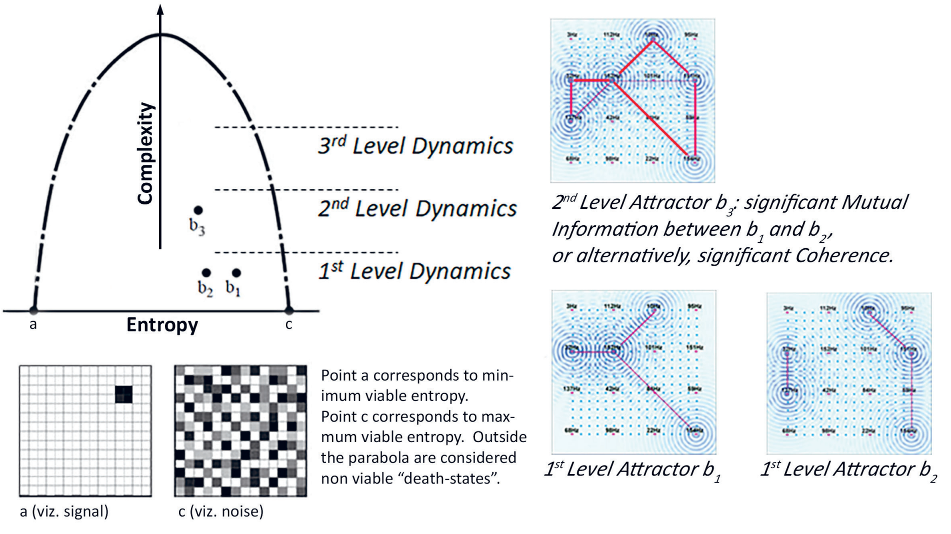


Figure 4 – Relevant Complexity. The parabola at left figuratively represents a balance between order, at point a, and disorder, at point c. There are ordinal, i.e., countable, levels of order. For example, a 1st level attractor is a distinct set of single nodes that tend to be co-stimulated by a particular pattern in their environment; there can be an arbitrary number of distinct 1st level attractors. A 2nd level attractor is a dynamic that becomes possible upon the scaffolding of two or more 1st level attractors, which have become associated over time. The three matrices on the right are all the same physical matrix as in Figure 3 and are intended to illustrate novel connectivity. Adapted from Bacigalupi (2013).

This same circuit matrix can also become sensitive to other groups of nodes. For example, the nodes of the 1st Level Attractor b_1 – e.g., a C Major chord – are different from that of 1st Level Attractor b_2 – e.g., an E minor chord. Complexity has increased insofar as now there are two distinct attractors at the 1st Level; we can imagine that Complexity can accrue as an arbitrary number of distinct 1st Level Attractors are accrued – e.g., arbitrarily many simple chords. This is the first attribute of Complexity listed above and illustrated diagrammatically on the right of Figure 4 (note that all the matrices illustrated between Figures 3 and 4 are the same physical matrix).

The second attribute is the degree to which each distinct attractor is instantiated in the self-biased wiring of the circuit matrix. It is important to emphasize that this circuit matrix – as it will be built in actuality, described further shortly – is analog to a large extent. This means that self-biasing circuit attributes – such as resistance, capacitance and inductance – can take on a continuous, and therefore infinite, number of possible values. Subsequently, such a system's sympathy for a pattern like C Major can also take on an infinite number of values. In other words, the proposed circuit matrix can exhibit attractor dynamics that more or less continuously exhibit "C Major-ness" as an embodied object. The more sensitive the accrued circuit biases are to this particular energy pattern, the more strongly and tightly the attractor will behave. This is the level of saliency of the "C Major" attractor that can rise above the default noise floor of this circuit matrix. Notably, the increased saliency of any given attractor will compete against, i.e., be in tension with, the third and final attribute of Complexity.

This third attribute of Relevant Complexity is when two or more 1st Level Attractors are co-stimulated such that these distinct sympathies become associated at a higher level of Complexity, a 2nd Level Attractor b_3, e.g., C Major 7th, which is the combination of the simpler chords suggested above. Attractors b_1 and b_2 can co-exist in the system's environment, which creates an even more complex interference pattern; this pattern physically entails both the original two patterns, but now this even more complex pattern is the basis by which novel higher-dimensional biases are instantiated. Complexity can now be populated by arbitrary numbers of 2nd to nth Level Attractors. But any accrued higher-dimensionality will have been because of the noisy continuous medium among the co-extant 1st level attractors. This so-called "noise" is an infinite well of possible degrees of freedom that the two, at first, competing patterns can draw from in order to manifest a more complex and integrated attractor. If, however, any one attractor is too salient, as alluded to above, this path to integration via the noise is not possible. As will be a central theme throughout this dissertation, there exists a sweet zone of operation that oscillates between coherence and decoherence of multiple simultaneous attractors.

To sustain this dynamic balance, the system must be able to build Complexity by increasing the number of distinct attractors at a given level of Complexity and increasing the number of levels by harnessing dynamical constraints from the noise among interfering distinct attractors, associating them into higher level attractors. Note that these more complex dynamical constraints are *ontic* phenomena, whereas the ability to measure these actual dynamics requires novel dimensions in our empirical and *epistemic* model. This is a model by which we might more rigorously understand how an Umwelt accrues attractors in a process of semiogenesis to arbitrary levels of Complexity.

The original research proposal mathematically expressed the above intuitions regarding Relevant Complexity as follows (Bacigalupi 2013) [Article I]:

$$\check{C} \equiv \Sigma(\sigma_i) + \Sigma(\sigma_{ij}) + \Sigma(\sigma_{ijk}) + \ldots + \Sigma(\sigma_{ijk\ldots n}) \qquad \text{Equation 2}$$

This equation uses the standard deviation (σ_i) of each distinct and emergent i^{th} attractor and the correlation among attractors. This was a more intuitive way to express the three attributes of Complexity above. Just the fact that there is an i^{th} and/or j^{th} distribution with a non-zero standard deviation is the first attribute above; there can be arbitrarily many emergent attractors that are measurable via these statistical distributions. These distributions measure the presence of learned patterns, like the C Major and E minor attractors. The standard deviation measures the shape of a distribution: the tighter the distribution around the mean attractor value, the more certain the response, which is the second attribute of Complexity. The third attribute is when the i^{th} and j^{th} attractor – having already been learned – begin to co-occur above chance; this is the example of C Major 7^{th} and is represented by the second term in equation 2: $\Sigma_{ij}(\sigma)$.

Information entropy was, and still is, a guiding inspiration for Complexity. Information entropy and the standard deviation, in equation 2, are similar approaches but not mathematically identical. There are different reasons for each. The eventual experimental setup for testing the schematic circuits in section 3 will determine the most convenient mathematical tools for measurement. For now, the units of Complexity can be considered in bits, given Complexity's information theoretic inspiration. Below, information entropy is reviewed in order to highlight some of these more important inspirations for Complexity.

Relevant Complexity is a state variable like information entropy, *H(x)*, which can be represented mathematically in a number of different ways. This mathematical expression as a ratio is particularly illustrative:

$$H(x) = log\ \frac{N!}{x_1\ !x_2\ !x_3\ ! \dots x_n\ !} \qquad \text{Equation 3}$$

The numerator, N, is the total number of events, whereas x_i are the distinct possible outcomes. For example, a single die has six sides that it can land on. As such, we have possible outcomes of x_1 through x_6. Now imagine that the die is rolled 18 times; this means that N = 18. We can think of each x_i as a tally of all the times that possible outcome occurred. For a fair die, the probability that each distinct tally will receive an event is equal; for our example, this means that, ideally, x_1 through x_6 will all take the value of 3. The denominator in this case will be 3! x 3! x 3! x 3! x 3! x 3! = 6^6 = 46,656. Now imagine that we have an unfair die that has been structurally altered to roll a six more often than a fair die. Again, with a total of 18 events, our distribution might be 0! x 2! x 2! x 3! x 2! x 9! = 17,418,240. The biased die has a more structured distribution of outcomes, which results in a more expected outcome: the roll of the number 6, in our example. Because the numerator stays the same in each case and our calculated denominator is much larger for the unfair die, it will result in a *decrease* in information entropy. This means that the biased die communicates more about the structure of the die.

This is directly analogous, but not equivalent, to both Adaptive Work and Relevant Complexity. The unbiased circuit matrix in the left panel of Figure 3 will have a less distinct response than the biased circuit depicted in the right panel. Given the nature of this circuit design, which will be further described below, less power is generated by the less structured circuit. Like the die example, the unbiased die tells us that there is nothing distinct about its structure and that tumbling on the table will result in any side just as likely as another. The biased die, however, tells us that the die is more likely to land on one particular side. Similarly, the biased circuit matrix tells us something distinct about the system's sympathies.

There are, however, at least two big differences between the die example and the proposed circuit model: the first is that the biased die is indifferent to its environment, whereas the circuit matrix is biased exactly because of its resonant sympathy to a particular pattern in its environment; the second is that the die can only instantiate the simple bias of which side(s) it tends to land on, whereas the circuit matrix can embody arbitrarily many structural biases. This is well characterized by Relevant Complexity. For example, our circuit matrix can entail sympathies for not only multiple distinct chords, but also chords of chords, such as C Major 7^{th}. It could also be biased for different modalities, like vision or touch. As listed above, the three attributes of increased Complexity can now be put in information theoretic terms: 1) more attractors accrete, measured as novel distributions in the denominator, 2) increase the probability, i.e., structural bias, of one or more attractors, measured as more distinct distributions and 3) distinct attractors that are integrated into a higher-order attractor, measured as mutual information (I), whereby previously learned discernable attractors tend to co-occur above chance.

But what exactly is an "attractor", in terms of the discussion above, and how will it be measured?

The proposed matrix in Figures 3 and 4 is a 4 × 4 configuration of Primary Nodes. This gives a total of 16 nodes. Analogically, imagine that each node is one side of a sixteen-sided die. This means that the denominator in Equation 3 would have sixteen possible states, instead of 6 for a six-sided die. This sixteen-sided die can be rolled many times, and, if it is a fair die, all the possible states in the denominator will tend to be filled evenly; this generates what is called a *uniform distribution*. But now imagine that, instead of there being one die that is rolled sequentially, there are innumerable dice, in our extended analogy, that represent all the possible patterns from the environment that can stimulate the 16 nodes into firing. If these innumerable dice are a random distribution of signals, then it is as though the proposed matrix will merely be exposed to noise. Given such noise, no biases will tend to form because – even if all the nodes are stimulated to fire repeatedly – no sparse order will emerge above the ground of noise in the interference pattern. This is because random noise, which leads to random firings of all the nodes, will only lead to an interference pattern of pure noise. With respect to measurement, again, the denominator in Equation 3 would be a uniform distribution, which would minimize its denominator, resulting in maximum information entropy, i.e., no meaning-making.

If, however, there is a repeated signal, like a C Major chord, then the nodes whose resonant frequency is near the notes c, e and g will be preferentially stimulated, thereby competing against the noise. Assuming the circuit can then bias itself so that these particular Primary Nodes develop hard connections, as described above, they will become sympathetic to future occurrences of C Major, or a pattern similar to it. When, in fact, a C Major pattern reoccurs – or a pattern similar to it – in the environment, nodal dynamics will tend to exhibit a pattern typical for "C Major-ness"; this is the C major attractor. Having measured the Primary Nodes most active during this particular dynamical attractor, the distribution of the denominator will *not* be uniform, because – of all the instances of Primary Nodes firing – a select few of the total 16 nodes will tend to fire more than the others. This is an *attractor* in the sense that the distribution of firings will have cohered or emerged like an island above the surrounding sea of noise.

This attractor can be considered a "sign". And, as discussed above, it is in quotes to indicate that, like the ephemeral attractor, so-called "signs" in semiosis are *distinct* dynamics necessarily interrelated with other dynamical attractors, or "signs". Ontologically, in practice, *these attractors are never discrete*.

Nevertheless, this emergent distribution now has a non-zero standard deviation that can become more or less distinct and can do work as a "sign" while always being related to other "signs". Empirically, this is the phenomena that has led me to Equation 2: a novel attractor – e.g., an emergent bias in the circuitry for the relatively more complex pattern of C Major – will have come into existence that can be measured and represented by its own unique standard deviation, e.g., σ_i in Equation 2. Other attractors, like E minor, have their own distinct distributions: σ_j. These are the first two attributes of Complexity: 1) novel attractors and 2) the distinctness of the distribution of those attractors. Then there is the third attribute: 3) attractors of attractors, like C Major 7th. This is represented by the terms $\Sigma(\sigma_{ij}) + \Sigma(\sigma_{ijk}) + \ldots + \Sigma(\sigma_{ijk\ldots n})$ in Equation 2. All these terms are a bit confusing. Generally, what they communicate is that there can be sympathies for patterns, like C Major; sympathies for patterns of patterns, like C Major 7th, which is composed of both C Major and E minor; and sympathies for patterns of patterns of patterns; etc. This is the heart of a measure of Complexity that can account for innumerable emergent patterns of patterns of patterns of patterns, etc. in a finite matrix.

Information theory, as expressed in Equation 3 and given the 16 proposed Primary Nodes able to fire or not, accounts for the different probabilities for a given configuration of firings. There are many more ways that the 16 nodes can fire randomly than the number of firings realized in a sparse subset of those nodes, as is the case for an attractor. What information theory cannot account for is *how* the proposed matrix can go from random to sparse – and therefore more "ordered" or coherent – firing patterns. It just identifies that, in a communication system with a given set of possible messages, only some tend to occur, which is "information" in the technical sense of Equation 3, or similar. Nevertheless, *information*, as a more general concept, entails semantics and meaning. Shannon understood this distinction, as he states at the very beginning of his *Communication Theory* (1948: 1) (emphasis in original):

> "The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have *meaning*; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem."

On the contrary, the model proposed herein moves well beyond the scope of Shannon's project to, in fact, engage and realize the "semantic aspects of communication". This is not against Shannon's Communication Theory; it leverages that tool for all it is worth in this context *but not more*.

A first step in this expanded scope is to understand how living systems expand not only the messages that are possible to receive within a given communication system but also messages that were previously not possible to receive, because the communication system has re-wired itself to be sensitive to new signals. For example, the 16 nodes of the proposed circuit matrix can be considered a kind of "alphabet", just as the six sides of a die are an alphabet or the 26 letters in the English language are an alphabet. Each of these alphabets is constituted by a finite number of signals that can be received. And, reconfiguring these discernable signals, there are a maximum number of messages that can be communicated. In a very Lotmanian turn, von Foerster points out how Shannon discovered that the English language in practice cannot effectively communicate at this maximum threshold. In fact, communication cannot happen at the minimum either; the former maximum entropy would be complete *untranslatability*, whereas the latter minimum entropy would be complete *translatability*. As Lotman asserts: "The combination of translatability-untranslatability (each to different degrees) is what determines the creative function." And this "each to different degrees" in spoken English ends up being about an even 50/50 split. In Shannon's words: "redundancy of ordinary English […] is roughly 50%. This means that when we write English half of what we write is determined by the structure of the language and half is chosen freely" (1948: 14). Information theory is well suited to measuring this empirical reality: measuring what messages are probable, and even possible, given the structural configuration, or "alphabet", of a communication system. Nevertheless, it is not well suited to measuring, let alone explaining, how such meaning-bearing constraints dynamically emerge: explaining how entirely new alphabets emerge via a *self*-restructured communication system.

To understand how such meaningful constraints can emerge, consider the circuit matrix above as it is trained on particular patterns, like C Major. As such, exposure to C Major biases the circuity, Equation 3 can measure this bias. There will be a discernable threshold whereby an observer of this system can be confident that a certain reduction in entropy – while being repeatedly exposed to this particular pattern – indicates that this pattern has been internalized or embodied by the system as an attractor. Now this distinct attractor can be input into Equation 2, whereby the waxing and waning of its standard deviation, σ_i, can be tracked. Most significantly, arbitrarily many such distinct attractors – e.g., the time-invariant firing configurations[17] of the 16 nodes – can emerge. Technically, these time-invariant configurations result in at least 16! configurations, which are more than 20×10^{12} configurations. Given this, we have the paradoxical capacity to have a larger alphabet than what was originally available with 16 Primary Nodes. From the perspective of information theory, there can be arbitrarily many distinct alphabets: the 16 physical resonant nodes and all the possible distinct firing configurations that can emerge in this finite technology, e.g., all possible musical chords or all the letters of the English language. With these multiple alphabets, the possible messages explode into unimaginable – arguably infinite – possibilities.[18] Information theory is not suited to explain how this is possible or how these emergent attractors are diverse sympathies that are about themselves and their surroundings, simultaneously. As argued throughout this dissertation, this will be the basis for "the semantic aspects of communication" considered "irrelevant" by our extant technologies and theories.

In trying to communicate this theory over the years, it is always tempting for people to try to reduce the higher-order "alphabets" to the base layer of sixteen nodes. Even if the configuration space is huge, in principle, twenty billion configurations seem deterministically tractable. But this is not the case, because the behavior of each node in a given attractor is, at a minimum, constrained in a continuous spatiotemporal manner, as introduced above and explained further in section 3. For now, however, the principle point is that two attractors may be seen as identical from an information theoretical perspective, as measured in isolation. But the system itself operating over the medium to long-term will enact these two attractors as wholly distinct, even if similar in the near-term. This is a fundamental aspect of individuation as explored by Simondon (2020) and this project: each distinct layer of "alphabets" cannot be reduced to or accurately translated by lower-dimensional alphabets. In other words, the physical reality of C Major or E minor attractors cannot be reduced to the information theoretic assessment of the 16 physical nodes, and nor can the C Major 7th attractor – building on the lower order chords – be reduced to those attractors alone. There are always novel constraints that distinguish these emergent levels of alphabets, which cannot be reduced to the alphabets themselves in any countable or tractable manner. It is in these interstitial novel constraints that relevance and meaning are manifest. Complexity alone – with its information theoretic dimensionality – is not enough to characterize semiogenesis; Work, as defined in the previous section, also needs to be assessed.

---

[17] Allowing for some non-zero time interval further expands the possible patterns, since the interval can exhibit more complex temporal patterns of these time-invariant 16! configurations.

[18] This point warrants emphasis, because we can have arbitrary numbers of alphabets that will have emerged. It is infinitely arbitrary because of the infinite degrees of freedom available to create ever novel higher-order attractors, as described above. Arbitrarily many alphabets can emerge to communicate astronomically many messages, all within a finite matrix (cf. Kauffman's adjacent possible explored by Favareau (2015)).

2.4 Semiogenesis, a preliminary hypothesis

Again, Complexity, as defined above, is a state variable. As such, this measure says nothing about how (or why) a system moved from one state to another. Such trajectories, in both mathematical and physical terms, require a path function. Work is a path function. And both the different states of Complexity and the Work done along the way are empirically observable measures that indicate the presence of semiogenesis, in general, and measurable Semiogenesis, in particular. This section outlines the relationship between these three quantities – Č, ∑W and Š – and why they are relevant for this thesis on biosemiotics.

Semiogenesis, as introduced in section 0.1, is a result of Relevance, which will be defined in terms of Adaptive Work and Complexity below. Relevance will need to be empirically observed by a physically implemented technical object, which is schematically specified in section 3.1. Informally, *semiogenesis* (formerly **"**Refinement**"** in Bacigalupi (2013) [Article I]) is described as follows:

> A process whereby a system increases its average Relevance (viz., engagement, sensitivity, or "awareness") to its surroundings by increasing its own internal capacity to resolve the increase in internal disorder, which is the result of increased Relevance, into a higher-order internal structure able to increase capacity to do useful work.

More formally, as illustrated in Figure 5, Semiogenesis (Š) is hypothesized to be the polynomial regression of this empirically observed Relevance. This semiogenic capacity increases as an agent learns, which is illustrated by the successively larger overlapping parabolae. And these parabolae – analogous to an extended interpretation of Umwelten[19] – grow because they are more Complex and thus able to do more Adaptive Work.

This increased Complexity (Č) and Adaptive Work (∑W) capacity is the result of two distinct behaviors: the tendency to accrue biases, as introduced above, and the capacity to drive the system dynamics away from the death-states at the edge of each parabola at a given stage of development. This drive forestalls an inescapable tendency towards either over or under-coherence.

One of the indicators that the system is moving too close to either of these death-states is that the measure of Adaptive Work begins to diminish. This indicator in our heuristic model relates to the fact that work done by the Primary Nodes cannot exceed the total energy consumed by the system, because this would violate the 2nd Law of Thermodynamics. As such, Relevance is proportional to and always less than the measure for Complexity with the same units. This is because Complexity is always reduced by the ratio of total work done –

---

[19] The argument for this extended understanding of Umewelten, which can grow within an agent's lifetime, builds off of the emergent "alphabet" – perhaps novel "sign" repertoires – discussion in section 2.3. Novel alphabets are analogous – if not equivalent – to novel senses. Just as novel sensory organs afford new sensitivities to energy patterns in an agent's milieu, so too do novel alphabets afford new sensitivities to energy patterns in an agent's milieu.

the collective work of all the active Primary Nodes – and the total energy consumed during measured time intervals; this ratio is always between zero and one.

$$\text{Relevance} \equiv \check{C} \times (\Sigma W/E_{input}) \qquad \text{Equation 4}$$

$$\check{S} \equiv \text{curved regression of Relevance} \qquad \text{Equation 5}$$

This Work/Energy ratio – which is unitless, because work and energy have the same units – is defined as the Cost, which when multiplied by Complexity is Relevance; see Equation 4 above. As the Cost ratio falls close to zero, all the Complexity in the world will not exhibit Relevance in this model, because the system is struggling to convert *relevant noise* into *potential* and *actual structures* that contribute to and sustain Complexity. As illustrated in Figure 5, however, Relevance does in fact regularly drop. This is a necessary attribute of this hypothetical model for two related reasons: learning higher orders of Complexity often necessitate some unlearning of past patterns, and, in order to avoid over and under-coherence, progress towards Complexity must intermittently be sacrificed. Nevertheless, within the parabola, there is no *a priori* "right" or deterministic place to be as long as the process stays within it, balancing coherent and decoherent behaviors on the edge-of-critical tension.

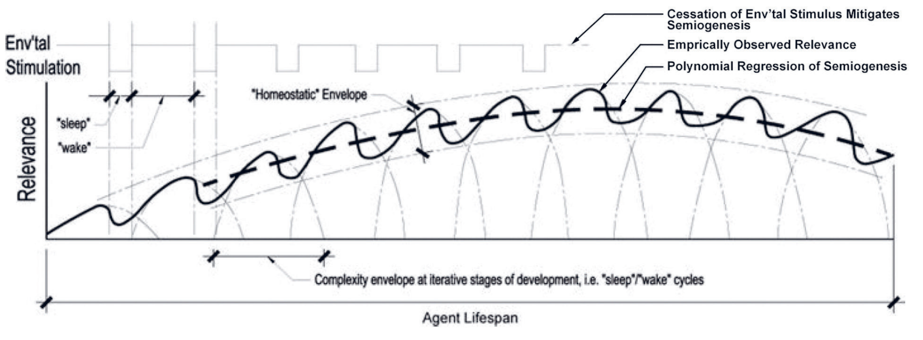


Figure 5 – Preliminary Hypothesis. Parabolae of Complexity from Figure 4 grow as a result of diverse environmental stimulation. In this hypothesized idealization, each cycle is one step in a ratchet whereby Relevance – the product of Adaptive Work/Energy and Complexity – momentarily descends to set the stage for its subsequent ascension. It is hypothesized that such a cycle may be the reason for sleep, which intermittently insulates the semiosic agent from external stimulation so that sparse order can be harvested from the day's "noise". The polynomial regression of this ratchet is Semiogenesis. Env'tal means Environmental. Adapted from Bacigalupi (2013).

There are complimentary tensions in Adaptive Work and Complexity. And semiogenesis is always caught between *exploring*, even expanding, the possibility space and *exploiting* sparse regions within that space. Agency can explore different possible work pathways – which are synonymous with attractors or *habits* in Hoffmeyer's terminology (2008: 189) – and even expand the space of possible pathways as it faces novel stimulation in the world. It might also cohere on a particular pathway, increasing real power to maximize work potential, thereby exploiting a given habit. However, adaptively navigating the complimentary tensions between the distinct strategies of exploring, expanding and exploiting is a non-trivial attribute of semiogenesis, as will be discussed in detail in section 4.1 with respect to self-regulation in semiosis and the ultimate Alt. Hypothesis of Semiogenesis for this thesis.

For now, however, this processual trade-off in this preliminary hypothesis is idealized in Figure 5. It is perhaps a means to explain how Hoffmeyer's *semetic interaction* (2001: 391) – variously called *semethic interaction* in (2008: 189) – is implemented by nature. While exposed to stimuli from the environment – e.g., the sun, heat, wind for plants and animals or chords for humans, etc. – all these modes superpose and interfere, cultivating relevant noise; differentially sympathetic nodes compete to echo their preferred signals, but they can only out-compete most nodes by cooperating with a sparse group, which is, again, an intrinsic tension. As some assemblies are successful in converting salient potential structure into actual structure, attractors emerge as habits. However, at some point, given the inherited capacity of the organism, it will reach diminishing returns, and its capacity to convert the environmentally perturbed noise into coherent structure will wane giving way to runaway decoherence, or fatigue. As indicated in Figure 5, this may be the need for some type of "sleep" – i.e., insulation of the organism from continuous stimulation – despite sleep's obvious existential risks. This insulation permits the system to recohere by processing the day's noise and integrating it with past experience: a "sandboxed" rhythm between decoherence and coherence able to elevate Complexity, perhaps via dreaming. At the risk of then over-cohering, or risking predation, the organism "wakes" to novel stimulation able to elicit higher-dimensional connections among the patterns of the day before, which is now scaffolding for new experiences.

This cyclical theory, if remotely accurate, is a rhythmic balance between over and under-coherence that is robust in the face of paradoxes faced daily by populations of coupled agents. And, in so doing, these agents simultaneously mold and are molded by their shared associated milieu collectively generating novel attractors, necessarily expanding and individuating their Umwelten, with each overlapping cycle. This is the preliminary hypothesis for semiogenesis, as quantitatively indicated by Š, defined in Equation 5 above.

3.0 METHODOLOGY: TESTING THE HYPOTHESIS

3.1 Schematic Circuit Design

The above preliminary hypothesis is not semiogenesis, per se, but a measurable index for it. Nevertheless, over the years, this hypothesis has served two interrelated aims: 1) to provide design guidelines for a novel analog/digital hybrid technology able to emulate some aspect of veritable semiogenesis, and 2) to provide a formal theory to empirically test the technology for the hypothesized behavior. The resultant schematic design for this technology then served as a heuristic, by which the missing piece of efficacious self-regulation could be investigated. The results of this investigation and the Hypothesis of Semiogenesis are in section 4.1. The schematic design for this novel technology is as follows.

Imagine a novel machine as an array of Primary Nodes (the dark nodes in Figure 3 above). Each Primary Node has its own sympathies implemented in this model by different resonant frequencies. On the left panel in Figure 3, some of these nodes are stimulated by perturbations from their environment. In response, they emit ripples into their shared milieu, i.e., common interstitial medium, generating an interference pattern. As discussed above, this interference pattern embodies a lot more information than might be immediately obvious. For example, not only does this pattern physically manifest each distinct behavior of these particularly tuned nodes, but it also captures the spatio-temporal relationship between these nodes' stimulation and emission. As the illustrated constructive interference rises above the surrounding noise floor, it can be harnessed by the system itself. This is abstractly represented in the right panel of Figure 3 by lines, which indicate that these nodes have become connected based on this emergent interference pattern. These self-made connections bias the future behavior of the machine: in the future it will not only be sensitive to signals that have stimulated individual nodes but also be sensitive to more complex patterns. But how does the proposed machine instantiate what are merely abstract connections in Figure 3 above?

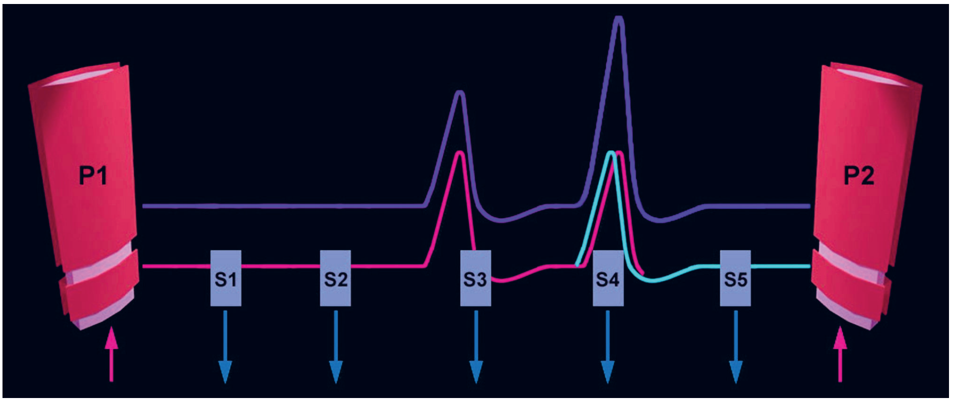


Figure 6 – Primary and Secondary Nodes with constructive interference. Image by author

The emergent constructive interference pattern – in Figures 3 and 4 above and in Figure 7 below – is a *virtual map* for this machine to bias itself; in this way, it re-*forms* itself to in-*form* itself. How living systems can harness this sparse higher-order pattern to create more complex future behaviors remains an active area of research. As an initial step towards empirically justifying this research, the schematic design below proposes the light blue nodes in Figure 7 – the same as the lighter grey and more numerous Secondary Nodes in Figure 3 – which are able to discern the regions of greater power afforded by the sparse constructive interference in Figures 3, 4 and 7. The illustrated ripples represent the constructive interference that can generate differentially more power in the Secondary Nodes compared with the surrounding noise, which is represented as the white region without ripples in Figure 3.

This is illustrated as a cross-section in Figure 6. As two Primary Nodes are stimulated, having reached a threshold for emitting a signal, their respective emissions ripple through their shared continuous medium (the blue and red pulses in Figure 6). The constructive interference is the superposition, or summation, of each individual pulse; this is the purple pulse illustrated in Figure 6. The light blue Secondary Nodes can indicate not only that some pulses exist, but that some are bigger than others. Secondary Node S4, for example, translates this ephemeral event into a digital record of when and where this heightened pulse occurred. This indicates that Primary Nodes P1 and P2 are active. It also indicates that P1 fired first, because S4 is closer to P2, meaning that the pulse from P1 will have been propagating before P2 fired. Information like this is continuously stored about the overall interference pattern. Figure 7 illustrates this more complete analog/digital hybrid schematic.

In general, the areas of greater constructive interference are recorded by Secondary Nodes. In this current implementation, a digital algorithm then calculates which Primary nodes could have fired to generate this pattern. This information is then used to create connections between Primary Nodes that will bias their future behavior in the presence of similar environmental stimulations. This describes how the weighted lines in the right panel of Figure 3 will have accrued with stimulation over time. This process operates continuously and can generate arbitrarily complex circuit patterns as illustrated in Figure 8.

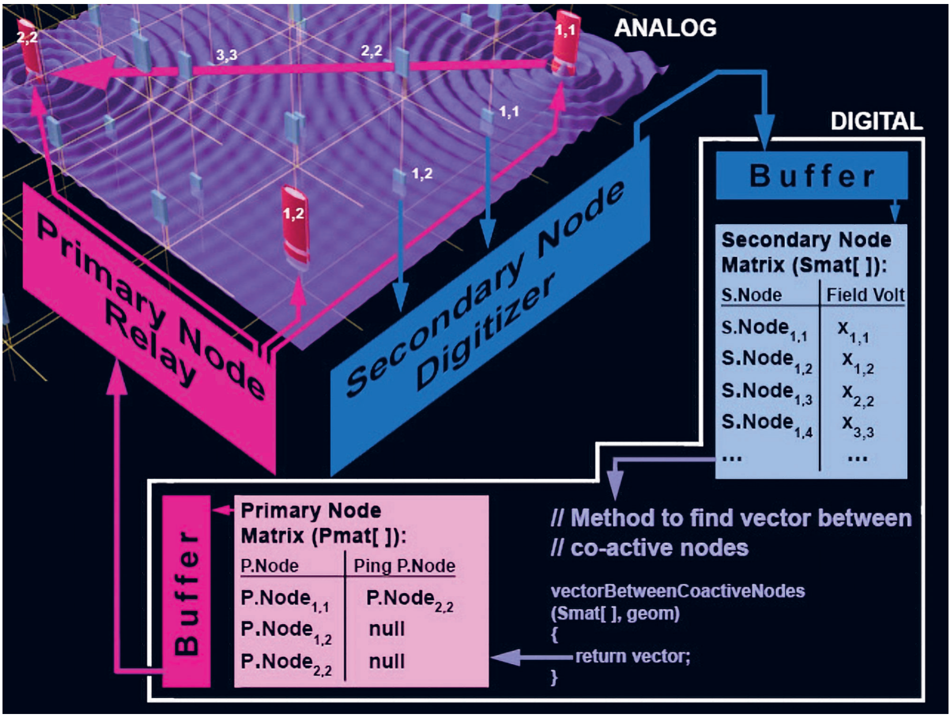


Figure 7 – Schematic design for an analog and digital hybrid emulation of semiogenesis. Image by author.

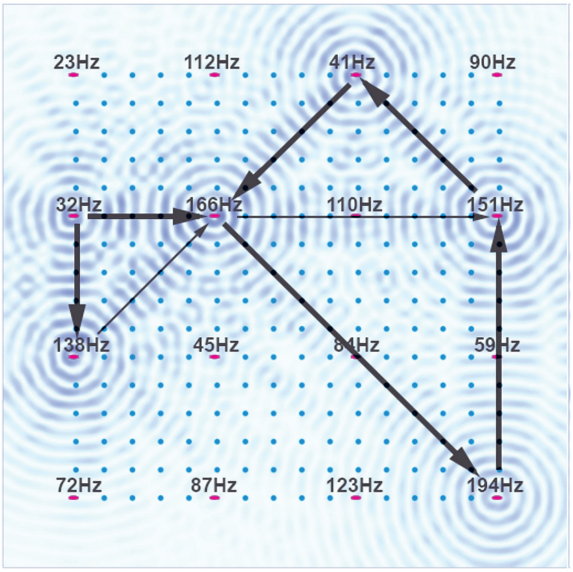


Figure 8 – Arbitrarily complex self-wired circuit. The arrows in this diagram reflect the directional information gained by the proposed technology, as illustrated in Figure 7. This reflects the capacity for Spike Timing Dependent Plasticity (STDP) in biological neurons to develop similarly directional connections based on precise firing timing. Image by author.

Similar abstract implementations exist, such as reservoir computing (Nakajima and Fischer 2021; Tanaka et al. 2019; Yan et al. 2024), liquid state machines (Maass 2010) and echo state networks (Lukoševičius 2012; Sun et al. 2024). Also, neuromorphic strategies involving analog components and simulation of noise from Hynna and Boahen (2007)[20] to Huang and Gunji (2026)[21] have existed for decades trying to emulate neurons. However, it seems that no such analog/digital hybrid exists that employs the interstitial common medium and resonant nodes proposed in this section. The distinction between all the referenced research above and the project herein is that the former can be characterized by solely mechanistic and *pseudo*-stochastic phenomena, and the latter implements a third attribute: *habituality*, specifically implemented as diverse resonant sympathies – Peirce's Thirdness – implemented in a *veritably* continuous and physical medium – Peirce's Firstness.

Contemporary artificial neural networks (ANNs) responsible for so-called "artificial intelligence" do update their networks. However, these updates are predicated completely on fixed algorithms and *pseudo*-randomization alone, which are both relegated to Peirce's Secondness. The proposed novel technology, on the other hand, evolves based on intrinsic sympathies and the transfinite potential of the *virtual* interference pattern. This novel process is not reducible to its numerical representation or functional machines, as in legacy approaches, because the evolving analog circuits generate ever-novel patterns that are highly sensitive to initial and boundary conditions, which themselves are continuously evolving. This *meta*-evolution entails a radical form of creativity that this project argues is a necessary precondition for veritable semiosis in living adaptive agents.

This novel technology does employ both algorithms and chance (approximated in extant machines and computer simulations via pseudo-random algorithms), *but it does more than this*. It also embodies *positive sympathies* (Peirce 1893: 189) – agapasm more generally – and their shared continuum – Peirce's Synechism. These are the preconditions for *virtuality*, loosely imagined in Figure 9, which enables this novel machine to transcend its initial form.

20 It is notable that, since the mid-2000s, I have followed Kwabena Boahen's lab, *Brains in Silicon* at Stanford University. His team there is not alone in designing, implementing and testing analog devices meant to emulate neural behavior. However, such approaches are still committed, like Ashby's homeostat, to the degenerate modes of a priori mechanism and stochastic chance.

21 These researchers' focus on *recurrent resonance* and the maintenance of a tense balance between coherence and decoherence of structure at the "edge of chaos", likely contributing to this project. But, as in the previous footnote, it ultimately appears to be committed to the degenerate modes of mechanism and chance alone.

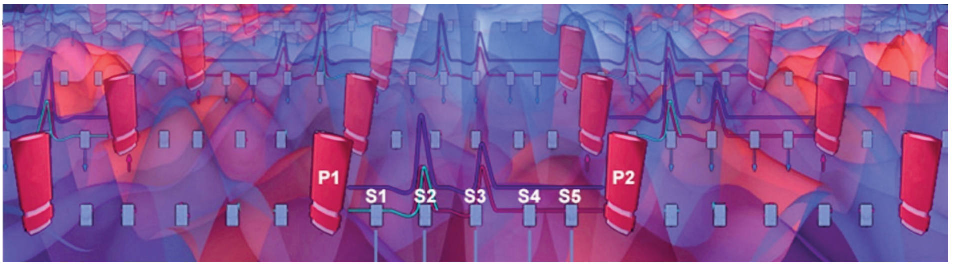


Figure 9 – Primary and Secondary Nodes in their shared (imagined) interstitial continuous medium. Image by author.

Digging into the details of this schematic design another level, the ongoing behavior of each Primary Node is simultaneously a result of its shared continuum and the "hard" circuit interconnections that have been accrued due to its exposure to patterns in its environment, as outlined above. The Primary Node's sensitivity to its shared milieu is illustrated by the receiver at g) in Figure 10; its accrued connections to other Primary nodes is indicated by inputs x_i at b) and outputs y_i at j).

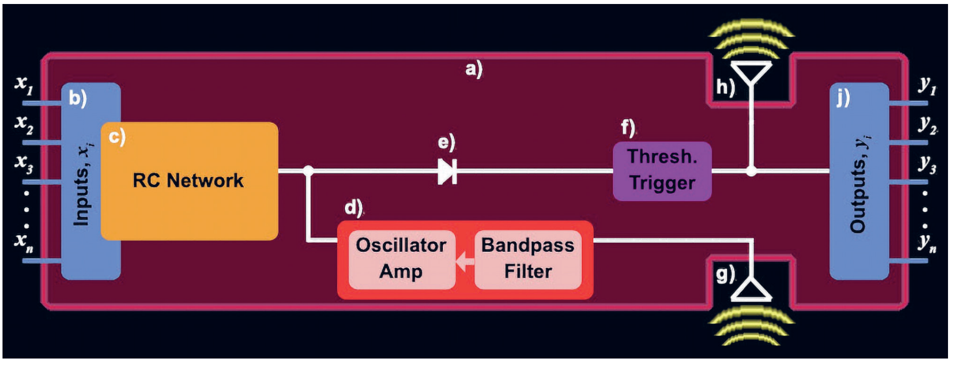


Figure 10 – Schematic circuit design of a Primary Node. Image by author.

Simultaneously stimulated by inputs – x_i at b) – and the portion of the interstitial noise filtered by its own sympathies – via the bandpass filter and amplifier at d) – this particular node may reach its threshold for stimulation – via the diode at e) and threshold trigger at f). When this threshold is reached this node will fire, which means that it will do three possible things: emit a pulse back into its shared common medium via the transmitter at h); send excitatory output pulses y_i at j) to formerly connected downstream nodes; or send inhibitory pulses at j). What a given Primary Node decides to do is of critical importance to Self-regulation discussed in sections 4.1 and 4.2.

The above schematic circuit design describes how Adaptive Work and Relevant Complexity will be instantiated in a buildable and testable technology meant to emulate veritable semiogenesis; this implementation is not intended to duplicate biology. Nevertheless, what remains conspicuously missing from this schematic for emulation is a rigorous treatment of Self-regulation, which cannot be formalized like the preliminary hypothesis in section 2. So far, the tension between coherence and decoherence, physically implemented by Work and Complexity, is relatively well characterized. Moreover, these two physical attributes will be further developed in the next section. Nevertheless, Normative Self-regulation, the intrinsic capacity for a semiosic system to self-maintain this intrinsic tension while non-stochastically avoiding systemic death-states, will be explored in section 4.

3.2 Testing Circuit Behavior

In this model, the amount of work any *one* Primary Node can do is a result of both stimulation from the ambient EM field and from inter-connections with other nodes. This means that the Primary Node most able to do useful work will have connected to other nodes over time based on their co-activity, and it will have a resonant distribution that is responsive to a signal that occurs regularly in its local ambient environment, like the C Major example above. The amount of work any *assembly* of inter-connected nodes can do is a result of the Relevance of the inter-connections and the overlapping sympathies of individual nodes; these overlapping sympathies are a necessary attribute of the diverse distribution of resonant frequencies among Primary Nodes. The Relevance of each Primary Node or assembly of nodes is in direct proportion to their response-ability to specific signals in their shared physical milieu and previously made "hard" connections. Empirically, this activity will be measured by Complexity, Work, Relevance, and Semiogenesis, which are all defined quantities that are an index for a synthetic system's capacity to accrue potential to do semiosic work over time.

Maximum possible work occurs per Primary Node if a signal present in the EM field is exactly at a given node's resonant frequency and if the timing of incoming stimulation from other nodes is synchronous with each other incoming signal, which are also coincident with resonant stimulation via the ambient field. It is unlikely that all these dynamic behaviors will align perfectly, but as discussed before, perfect order, i.e., over-coherence, is not conducive to the self-adaptive system; maximizing order is not viable. This is because a perfect one-to-one mapping between input and output, though maximizing order, significantly mitigates the capacity to create higher-order assemblies able to assimilate and do more complex work through adaptation. Overlapping sympathies, as specified by the diverse resonant frequencies in Figure 3, are attributes of self-adaptive systems necessary for this higher-order assimilation. It is also notable that Lotman's (un)translation – a precondition for meaning-making and his *creative function* (1990: 15) – also necessitates this diversity, as the system only ever partially translates itself. And, this necessity ensures that maximum work will not be realized by any one node, because adaptation is not about a one-to-one synchronization of a signal to a node at the lowest order of Complexity. A self-adaptive system may refine its capacity to do increasing amounts of higher-order

Complex Work over time exactly because "imperfect" inter-dependencies are intrinsic to the system.

It is the capacity to intrinsically self-generate novel relationships between distinct physical patterns that distinguishes this project from the vast majority of efforts to date. As illustrated by the parabola in Figure 4, any one-to-one functional system, such as digital computation, exists at the lowest order of Complexity. This is deceiving because our digital machines seem quite complicated. But in reality, they are only lists of discrete states mapping to other discrete states in a one-to-one manner. As such, they can certainly become very long lists. However, they are not Complex in the same useful way that semiosic systems are because discrete lists will always just be that: *tokenized lists*. It is the map vs. territory argument, which argues that the map is an abstract representation of physical reality, not reality itself (Korzybski 1948). Cognition, it can be argued, is also a representation of its wider surroundings. However, it is a very special representation that is distinct from any Turing-equivalent implementation, exactly because Turing-equivalency is first and foremost a list of mutually exclusive discrete states and the fixed rules to change those states based on other discrete states. Cognition, on the contrary, is a physically continuous territory in the same sense that the world outside is a continuous territory. Turing-equivalent machines, however, will always be at the lowest order of Complexity, essentially along the x-axis in Figures 4. Arbitrarily many discrete states in digital machines may be fantastically ordered, but this order comes at the cost of interrelated higher-orders of Complexity, which are available to semiosic cognitive systems.

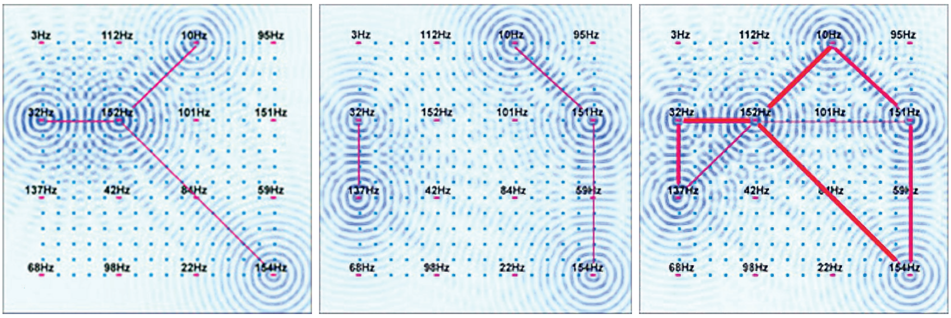
To assess this adaptation numerically, Complexity and Work exhibited by the proposed analog/digital hybrid technology must be measured as it assimilates distinct patterns from its environment. Work and Complexity, although inter-dependent in practice, will be assessed empirically as separate quantities. The measurement of Work is relatively straight forward. Both current and voltage will be measured directly at the diode at point e) in Figure 10 above, for each Primary Node.

These values multiplied together are equal to *real power*[22]. This real power integrated over time is the work that is done by the Primary Node being measured. The work from each individual node within a nodal assembly in response to a distinct environmental stimulus is summed to provide Adaptive Work, $\sum W$. As a system increasingly learns some patterned stimulus, the response of some nodes within the system is expected to become more distinct and coherent. This was described mathematically in section 2, whereby the Work done by the system in

[22] In the context of analog circuits with alternating current, real power is a function of the phasic relationship between alternating current, I, and alternating voltage, V. If current and voltage are completely out of phase, the energy expended results in zero real power. If, on the other hand, current and voltage are completely in phase, 100% of the energy input is converted to real power. And, between these extremes, there is a continuous range of real power as current and voltage drift in and out of phase with one another.

response to some external stimulus will be expected to change from equal time intervals [a,b] to [x,y], as in Equation 1 in section 2.2.

Complexity at separate time intervals will also be assessed with the aid of the digital portion of the proposed technology. A digital data structure will record connections that accrue among Primary Nodes in response to environmental patterns. Figure 11 enlarges the 1st and 2nd level attractors illustrated in Figure 4 to illustrate how distinct patterns will accrue to contribute to Complexity, but also how patterns of patterns will accrue to further increase Complexity in the vertical y-axis dimension of the parabola in Figure 4. Importantly, the actual physical implementation of the novel technology of Synthetic Cognition contains Primary Nodes that are physically sensitive to a bounded, yet continuous, distribution of physical phenomena, such as a distinct range of frequencies. The abstract data structure, however, cannot assimilate such relationships because its internal states are discrete and insensitive to the environment by design. This is not a problem if seen for what it is and can be used to keep track of inter-connections between Primary Nodes that have accrued as described in sections 2 and 3.1. With this discrete information from the data structure, Complexity can be numerically assessed over time.



a) b) c)

Figure 11 – Complexity Implemented. Patterns of patterns and distributions of overlapping distributions. Each panel a), b) and c) are the same matrix as illustrated in Figures 3, 4 and 8. Panels a) and b) represent the assimilated 1st level attractors of C Major and E minor, respectively. Panel c) represents the 2nd level attractor of C Major 7th, which entails both the attractors in panels a) and b), along with further novel structural constraints. Image by author.

For example, Figure 11 a) shows the hypothesized co-activity of distinct nodes responding to notes in the chord C Major: continued exposure of the Primary Nodes that resonate with actual frequencies within C Major will cause the proposed system to accrue the interstitial sparse order within the interference pattern between them. As discussed earlier, these inter-connections are stored in the abstract data structure, constituting "hard" connections among Primary Nodes. And if, in response to the C Major pattern perturbing the system again, the response of these particular nodes occurs more than surrounding nodes significantly greater than chance (e.g., $p < 0.05$)[23] in response to a previously taught pattern, Complexity will be determined to increase and learning exhibited. Figure 11 b) shows the same for learned inter-connections for E minor. C Major and E minor are two distinct assimilations of two distinct environmental stimulations at the 1st level of Complexity. Figure 11 c) illustrates inter-connections between Primary Nodes that will have responded to the co-occurrence of 1st level patterns C Major and E minor. This is the higher-order chord of C Major 7th at the 2nd level of Complexity. Again, the assessment of this higher-order pattern of response to C Major 7th as a contribution to Complexity is based on standard statistical thresholds for significance (e.g., $p < 0.05$). These two empirical measures – the accretion of novel 1st level attractors and the accretion of 2nd level attractors – exemplify the first and third attributes, respectively, of Complexity, as introduce in section 2.3.

As the statistical improbability, or increased coherence, of any one nodal assembly in response to a given stimulus increases with increased "learning", its contribution to Complexity also increases. This is visually represented in Figures 8 and 11 c) as heavier inter-connection lines among specific nodes. This empirical measurement is the second attribute of Complexity defined in section 2.3.

Figure 12 is a description of the above hypothesized behavior for the successful self-adaptive and semiosic system. *It is not actual data.* It imagines how a synthetic self-adaptive system can be measured to discern whether the Null, H_0, or the Alternative Hypothesis, H_1, is accepted by comparing the Relevance of the system before and after learning specific stimuli. For example, Test 1 during time interval [a,b][24], in Figure 12, stimulates the proposed systems with two distinct patterns: the notes e, c and the notes e, c, g. This example is intended to exemplify how the C Major chord in Figure 11 can itself be composed of two distinct attractors with different stimulations. This is in contrast to the example above where the C Major assembly of nodal behavior was a 1st level attractor, as illustrated in Figure 4. In the series of tests outlined in Figure 12, C Major can actually be a 2nd level attractor. In this different setup, notes e and c can be "learned" by the imaginary experimental setup in Figure 12 via Primary Nodes 5, 6 and 16. This means that those physical nodes will have been triggered to fire more often than surrounding nodes by the stimulation of the notes e and c. As these two notes persist, in this example, Primary Nodes 5, 6 and 16 will self-bias themselves into an inter-connected circuit attractor.

23 Methodologically, the experiment may track Work every time interval [x,y] rises above its baseline stimulation, prior to interconnections, during time interval [a,b]. If, this measurement outcome succeeds 50 times, statistical significance will have been achieved and all the Work done during those intervals can be summed and count towards Refinement. If, on the other hand, statistical significance is not achieved, the failed attractor will not count towards Complexity, and its previously measured Work can be "forgotten". Attractors may, in fact, be "forgotten" due to intermittent cycles of decoherence. As such, formerly learned attractors will have to be retested and re-established if they have faded.

24 Note that intervals [a,b] and [x,y] correspond to the integration bounds in Equation 1.

We can then suppose that a subsequent external stimulation occurs during Test 1 in Figure 12; this stimulation is the coincident occurrence of notes e, c and g. These notes happen to be what Western music considers a C Major chord, but they could be any possible coincident frequencies. This particular system, having already learned the “5,6,16” attractor will be stimulated additionally by the frequency of note g, which for this experimental setup will instantiate the “3,5,6,16” attractor, or what is called C Major in the previous example.

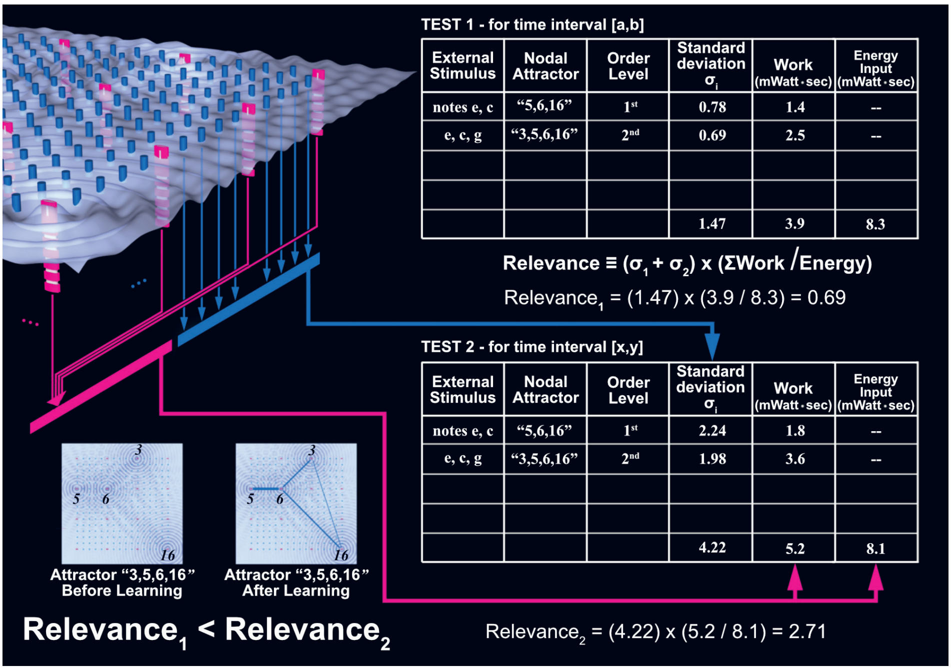


Figure 12 – Measuring Work and Complexity to Derive Relevance. Based on Figures 3 and 7, a numerical example assessing Complexity, Work, and energy input for the successfully self-adaptive, or “learning”, system is hypothesized. The single stimulus pattern, stimulus I, is proposed, and the successful system is shown to have increased its Relevance from Test 1 to Test 2 due to learning between the two tests. As in Figures 3 and 7, the response of individual and assemblies of nodes will have become more salient, thereby increasing Complexity. And, due to higher-orders of activity having emerged from more coordinated lower-order activity, more Work is done per unit energy input, thereby decreasing the Cost activity. As such, Relevance, as defined, is increased. Image by author.

What justifies the designation of “attractor”, given a particular external stimulation, is that sparse order in the interstitial interference pattern will be enough to afford self-biasing in the proposed technological implementation. This is represented in Test 1 in the Standard Deviation column. This non-zero standard deviation is because some of the Primary Nodes, more than others, are intrinsically sympathetic to these particular frequencies. These nodes with increased sensitivity to these particular stimulations will therefore respond more strongly than nodes whose resonant frequencies are not sensitive to these frequencies. The interference pattern that results – as discussed in sections 0.3, 2 and 3.1 – is the physical affordance that facilitates circuit re-wiring able to become even more sensitive to the higher-order patterns when they occur in the future. This is the point of the second time interval [x,y], Test 2, in Figure 12. Assuming the Alt. Hypothesis of Semiogensis can be accepted, "learning" will have occurred via the self-biasing circuits. In practice, actual values will be measured from Primary and Secondary Nodes, as illustrated by the blue and red arrows in Figure 12. Given H_1, the standard deviation for these distinct attractors and the work they are able to do will increase, as illustrated in the Standard Deviation and Work columns of Test 2. This will result in an increase in Relevance per Equation 4.

$$\text{Relevance} \equiv \check{C} \text{ x } (\Sigma W_i/E_{input}) \qquad \text{Equation 4}$$

$$\check{S} \equiv \text{curved regression of Relevance} \qquad \text{Equation 5}$$

Again, assuming H_1, Equation 5 will result in Semiogenesis, as hypothesized in Figure 5. Nevertheless, it is also hypothesized, as discussed in section 2.4, that this increase in Relevance is not and cannot be a steady monotonic increase. It is not the nature of self-adaption, semiosis or cognition in general. The self-acquisition of higher-order internal patterns is predicated on a system's capacity to be open to re-configuration. Lower-orders can only cohere into higher-orders if those lower-orders can be re-ordered, or physically in-*formed,* based on continuous input from the physical world. This necessitates distinct periods of disorder for the self-adaptive system. Life it seems is intrinsically a "two steps forward, and one step backward" process. In essence, this is the reason for death in all its forms: death of the organism, death of the idea, death of the sub-optimal pattern so that it can continually be reborn as an increasingly adaptive and relevant pattern. Matter and energy are not destroyed in any absolute sense. In the evolving Universe, they are merely reformed into other forms. And the degree to which any one pattern remains vital is directly related to two factors: 1) its own dynamical distinctness (what Simondon calls a singularity), and 2) the degree to which that distinctness is physically engaged with its surroundings, including other distinctnesses. These are often competing tendencies, and it is in the tense balance between them that ever more vital and complex forms emerge.

As introduced in sections 0.3 and 2.4, this tense balance of semiogenesis, generally, is a cyclical process whereby the physical interaction between the distinct nature of the internal system and perceivable events outside the system physically re-form the system so that the capacity to do useful Work is increased. Each successive restructuring becomes the foundation upon which more of the agent's surroundings can be perceived, or "understood". These new perceptions will often challenge existing internal configurations, disorganizing them, so that they can be re-organized into more Complex and more Relevant configurations. Again, the agent's new internal foundation supports an even greater capacity to conceive of even wider and deeper aspects of its world. Nevertheless, the capacity to navigate the tense ratio of all these paradoxes must somehow be "decided" by the living system *intrinsically*. This is Normative Self-regulation.

4.0 RESEARCH TASK RESOLUTION: NORMATIVE SELF-REGULATION

4.1 Self-Regulation in Principle

The goal of section 4 is to frame this question of Self-regulation in section 4.1 and then offer a preliminary answer to it in section 4.2. Both sections extend the provisional hypothesis in sections 2 and 3 into a future research agenda in section 4.3. This future research will have the task of explaining why self-regulation – from the smallest cell to the biosphere, including human institutions – is a necessary attribute of vital semiogenesis. This dissertation, however, has the more modest task of physically grounding the core hypothesis of semiogenesis. I have developed Relevant Complexity and Adaptive Work reasonably well over the years; sections 2 and 3 reflect this. The principle purpose of this section, however, is to more rigorously characterize Normative Self-regulation and how it supports the case for realizing the Semiogenesis Hypothesis, H_1, proposed herein.

It is important to re-emphasize – as is the case for Peirce's triadic semiosis – that H_1 can only be realized insofar as all three ontic dynamics – Complexity, Work and Self-regulation – continuously co-constitute each other. As illustrated in section 3.2, it may be possible to empirically justify the Semiogenesis Hypothesis by measuring just two of these: Complexity and Work. Even though Self-regulation will need to be implemented in the proposed technology of Synthetic Cognition, it cannot be formalized a priori; it must be implemented in either living beings or some novel technology, as proposed in section 3. While aspects of the process of semiosis may be observed, this project claims that actually embodying this process is fundamentally indeterminate and therefore intractable. In other words, *simulation* of semiosis is not *duplication* of it. The goal of this project is somewhere in between: *emulation*.[25] And to move in this direction is to reserve at least one portion of our analysis for this intractability. This section will explore Self-regulation as that portion. Methodologically, this likely means that H_1 is not proof of semiogenesis in living systems, per se, but an indication of progress towards implementing it more veritably than mere simulation in digital computers.

As was introduced in section 0.3, structure both generates and constrains noise, while noise both enriches and dissolves structure. Each tendency waxes and wanes in a continual dance with the other, as long as life persists. Both Relevant Complexity and Adaptive Work entail this tension in their observable operations. In order for these physical attributes to persist, the tension between

---

25 This proposed model is not claiming to be living or even conscious as in living creatures. Nevertheless, it does claim to implement a preliminary instance of *virtuality*, which, as Simondon asserts (2017: 156), does not exist in any extant machine. The proposed technical object does claim, in principle, to embody – or emulate – virtuality to some degree, setting the stage for future phases of increased synthetic virtuality. See Bacigalupi (2025) for the complete (meta)physical case for semiogenesis.

order/disorder, coherence/decoherence and noise/structure must be intrinsically managed. This requires Self-regulation.

Putting the above tension in the terminology of Bacigalupi (2022) [Article II], there exists an exchange between the more inertial nodal network, i.e. *actual structure*, and the more ephemeral interstitial milieu, i.e. *virtual structure*. In the termite example of Bacigalupi (2022), actual structure were the termite mounds, whereas the virtual structure is the stigmergic distribution of their ephemeral pheromonal topographies; each is of the other. In sections 2 and 3, *actual* structure is the circuit that builds itself, based on the *virtual* structure of the constructive interference pattern that the circuits both mold and are molded by, simultaneously. This exchange is the transduction of patterned energies, which, in principle, has the potential to generate ever novel relevant structures from the continual tension between metastable structure and *relevant noise*. This intrinsic and generative creativity is certainly influenced by an agent's environment, but the capacity to generate internal adaptive forms is predicated on life's continuous tendency to sustain this intrinsic tension between *relevant noise*, *virtual* and *actual structures* (Bacigalupi 2022) [Article II] – each of which simultaneously mold and are molded by each other.

This adaptive generativity exists in a poised critical balance between over-coherence on a few pathways – to the exclusion of all others – and the under-coherence of *irrelevant* noise – to the exclusion of any Complex structures. Recalling the parabola from Figures 4 in section 2.3, Figure 13 refers to either of these extreme states as death-states, whereby a system is operating outside the hypothesized parabola of sustainable operation (Bacigalupi 2023a) [Article III]. These death-states are states in which either actual structure, i.e., *fixity*, or virtual structure, i.e., *flux*, will have become too dominant, such that its co-constitutive dynamic will collapse.

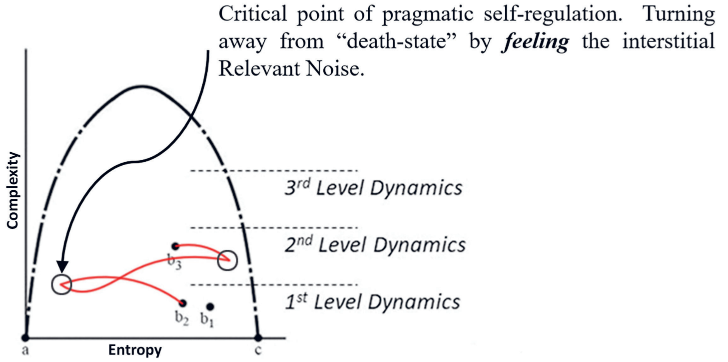


Figure 13 – Self-regulation. The vital system must explore its operational space between over and under-coherence. Nevertheless, it must avoid the liminal state, past which the system will cease to be viable. This model proposes that the quality of relevant noise, or affective field, can be an index, by which the system is able to autonomously explore its intrinsic operational space while avoiding existential operational boundaries, i.e., death-states. Adaptive from Bacigalupi (2023).

The vital operating regime within the parabola, on the other hand, represents a balance between coherent stabilized attractors, like the C Major chord example, and decoherent metastability among many possible attractors, like the interference pattern of C Major and E minor co-occurring, generating *relevant noise*, which is a precondition for discerning network biases indicative of C Major 7th: "harvesting the sparse order from the noise" (Bacigalupi 2013) [Article I]. Each tendency must coexist simultaneously in a dynamic ratio, which depends on many factors including the history and context of the system from moment to moment. This operating ratio between coherence and decoherence is both the substrate from which sparse order is harvested and an indicator, by which the system avoids death-states. This ability for relevant noise – i.e., the interference pattern distributed throughout the shared interstitial common medium – to serve as an ever-changing index for proximity of the system to the edge of its operational regime is the initial intuition for an *intrinsic* self-regulatory power.

This proposed intuition is itself a very general kind of cybernetics insofar as it embodies feedback. Nevertheless, this extended hypothesis, which can efficaciously leverage this index to enact a vital balance between over and under-coherence, is very different from legacy approaches to cybernetics, from Ashby's homeostat to modern Machine Learning. This is because the feedback of legacy cybernetics is not *about* the dynamics of the world, in the philosophical sense of intentionality or in the biosemiotic sense of meaning-making; there is no living autonomy. The proposed model, however, does have this capacity for aboutness, because it embodies diverse *positive sympathies*, as described in section 2. Extant state-based machines, on the other hand, have no such sympathies, because their operating states are perfectly exclusive of each other, by design; their intent is accuracy and control. This is their strength insofar as their state, at any given moment, will have been the result of rules set by the designer beforehand. As such, there are no sympathies by which these machines can be either efficaciously or deleteriously surprised by their environment.

On the contrary, the proposed system adaptively "feels" the aforementioned interference among all these non-predetermined sympathetic echoes: an *affective field* that is of the continuous interstitial medium. This affective field in the vital being will remain in tension, sometimes veering towards abyssal chaos, i.e., under-coherence, and other times veering towards deterministic and ridged cosmos, i.e., over-coherence. Edgar Morin's *chaosmos* (2007) echoes this tension between order and disorder (1983). The tendency to manage this chaosmos via the affective field is Normative Self-regulation.

In implementing these ideas, the proposed technology in section 3 begins by sensing whether or not the grey Secondary Nodes in Figure 12 are able to discern any sparse order in the *relevant noise*, a result of intrinsic sympathies. If not, one strategy hinted at in Figure 5 is "sleep". The system will need to reduce environmental stimulation in order to reduce the level of noise. This reduced noise will, in effect, render more legible any inherent potential order that may be lurking under the noise floor. Alternatively, when operating too close to over-coherence, Secondary Nodes will become oversaturated as patterns in the interstitial, or *affective*, field repeat, indicating no new information. In response, a salutary drive for more stimulation can ameliorate the tendency towards over-coherence. Translated into Gestalt terminology, the *ground* will have dominated in the former case as the system's operations move too close to the left side of the parabola in Figure 13, whereas the *figure* will have dominated in the latter case as the system's operation moves too close to the right side of the parabola. The former threatens under-coherence, whereas the latter threatens over-coherence.[26] An ongoing dynamic balance is sustained while in vital operation, which does not presuppose random attractors within this ever expanding and vital operational space.

Structuration and relevant noise both contribute to adaptive creativity by providing the boundary conditions for the other, holding each other in a tense balance with each other. They co-exist and exchange dominance on an annealing schedule that will have evolved different rhythms in diverse species. The co-existence and continual exchange of energy between relatively more and less inertial asymmetries is the fecund tension of Virtuality and Affinity, which are (meta)physical attributes beyond the scope of this dissertation discussed in Bacigalupi (2023a; 2025) [Article III]. These two dynamics frame the liminal overlap both between coherent/decoherent tendencies and actual/potential phenomena immanently throughout the system, providing both the wellspring for higher-dimensional dynamics from the "sea" of relevant noise and the index by which a viable tension between coherent and decoherent tendencies is intrinsically sustained.

Emergent attractors mitigate the more pathological extremes of the interference patterns in the interstitial continuous medium, while the relevant noise of this continuous interstitial medium mitigates the more pathological extremes of emergent attractors; fixity mitigates flux, just as flux mitigates fixity. Attractor dynamics tend to cohere into ever tighter and myopic attractors, whereas the continuous medium tends to decohere into the abyss of endless possibilities. Over-expression of either of these dynamical attributes will tend toward death-states. There is always a ratio between the co-existence of the actual structures of attractors and the virtual structure of the continuous medium in tension with each other that is well suited to the indeterminate set of contingencies that a sentient system finds itself to sustain vital operation. Maintaining this balance in-*tension* between coherent fixity and decoherent flux cannot be entailed in these two dynamics, let alone being reducible to either one of these general tendencies alone. A third dynamic attribute is necessary. This is Self-regulation.

Self-regulation is the capacity for a vital system to literally *feel* this tension between fixity and flux in real-time. What is felt is the *affective field* of the shared interference pattern discussed above. Self-regulation in semiogenesis must be normative because there are "good" and "bad" patterns; a choice, with existential

---

[26] In this model, a novel understanding of homeostasis, or heterostasis, and the many rhythms of rhythms – such as interrelated sleep-wake cycles, body temperature, hormones and circadian rhythms – of living systems can be articulated.

stakes, must be made by the system itself, as will be discussed below. But this choice is based on the ability to discriminate between different kinds of patterns in the continuous interstitial medium. What are the characteristics of these kinds of patterns that are being chosen between?

Patterns that either move precariously close to pure decoherent noise or too close to a single, tyrannical and coherent signal are considered "bad". Too much decoherence, or under-coherence, can be understood in terms of the second law of thermodynamics: the tendency towards increased entropy and dissipation in closed systems. Alternately, over-coherence can be understood as a positive feedback loop that amplifies one pattern to the exclusion of all others. Either way, the number of so-called "bad" patterns is infinite and a highly probably state of any non-living dynamical system; to avoid these death-states, living systems, on the other hand, must maintain a very rare dynamic that can be characterized mathematically, for example, by a power law. This law characterizes patterns that entail a range of dynamics from a very few high-energy dominant attractors to an order of magnitude more medium-energy attractors to several orders of magnitude more numerous low-energy, subtle attractors. The vital system – in the tension between fixity and flux, over and under-coherence – maintains the existence of this diverse range of patterns superposed in any given vital system, simultaneously.

Using our music analogy, this normatively "good" power-law-like dynamic can be illustrated as a symphonic fugue or an improv jazz session. There is a transfinite quantity of these possible patterns, meaning infinite yet bounded. Inside this bounded region of vital operation, these "good" patterns of music instantiate a particular kind of organization. It is a complex nested structure that has overarching themes and dynamics that characterize the movement as a whole, which are themselves constituted by an order of magnitude more medium sized attractors, which are the chords and phrases, which are themselves constituted by another order of magnitude more small sized attractors: the notes.

In dynamical systems, this power-law character can be further illustrated by a pile of sand in the bottom half of an hourglass. As sand trickles from above on top of the pile, small avalanches happen very often, medium avalanches happen at a medium rate and large avalanches happen rarely. In network theory, which is also closely related to our neuromorphic networks, *small-world networks* can sometimes exhibit a power-law (Perera, Bell, and Bliemer 2017). Small-world networks exhibit a range of community types, which are hubs of network connections. Large communities have many connections and are relatively rare; medium communities have a medium number of connections and occur a medium number of times; and small communities have a small number of connections and are quite frequent throughout the network.

It is this type of behavior and structure that characterizes an aesthetically satisfying and resilient affective field. Given access to transfinite degrees of freedom, sensitivity to initial conditions of chaotic attractors, non-linear behavior of network dynamics and indeterminate contingencies in the living being's environment, any extant affective field cannot be preconceived, has never occurred before and will never occur again (Bacigalupi 2024). Nevertheless, this irreversible and wholly unique dynamic has a particular character that, when it begins to dissipate or over-cohere, the sentient being must feel and correct to maintain this vital dynamic. But how do individual nodes in this proposed model behave to enact this vital balancing, if the aesthetic field is forever unique and no a priori law or algorithm can anticipate what to do when?

In this model, the answer to this question is *drive*, in the sense of the "death [or life] drive", which are enacted by individual nodes and the network, as a whole, in response to the particular quality of the affective field. If the field's dynamic tends to over-cohere, more and more nodes will exhibit one set of behaviors. Or, if the field tends to under-cohere, more and more nodes will exhibit an opposite set of behaviors. The field itself is distributed, but individual nodes will have their own interpretation of the aesthetic quality of that field and judge accordingly, as discussed below. When there exists a balance between these two regimes, the system is held in a productive tension, *tendency* or "sweet zone", which is typified by the power-law characteristics described above; this is also a very fecund phase of operation where chaotic attractors are near criticality (Longo and Montévil 2019) and highly *metastable*, a mode of operation where the vital system can transition from one efficaciously relevant habit to another with relative ease (Bacigalupi and Favareau 2023) [Article IV]. This may be considered a "flow state". Nevertheless, when this adaptively flexible flow state begins to veer towards over or under-coherence, more and more nodes must "vote" by exhibiting a *drive* intended to forestall an irreversible slide into one or the other death-states.

To give a general sense for how this behavior exists in practice, this model specifies how nodes must behave, in principle, to implement the two distinct modes of *drive*: away from either over or under-coherence. When nodes sense a slide into over-coherence, they need to become more sensitive to the field. They will need to be more likely to fire in the presence of sympathetic stimulation to amplify diverse attractors that can compete with the dominant attractor causing over-coherence. Also, for similar reasons, their tendency to inhibit other nodes in the network, which will be discussed in the next section, needs to be reduced. On the other hand, when nodes sense a slide into under-coherence, they need to be less sensitive to the field. They need to be less likely to fire in the presence of sympathetic stimulation to allow more attractors to rise above the decoherent sea of noise. Also, their tendency to inhibit other nodes in the network needs to be increased to similarly reduce noise. As more and more nodes "vote" in one direction or another, there will also need to be network-wide level drives that increase overall exposure to external stimulation upon over-coherence and reduce overall exposure to external stimulation upon under-coherence; the former is analogous to being "awake", whereas the latter is analogous to being "asleep".

More about these self-regulatory behaviors will be discussed in the next section. But first, a matrix of these specified behaviors are listed in Table 1. This table is expressed in terms of information entropy as defined in Equation 3 in section 2.3. The three rows are the three different attributes of Complexity, while the two columns are under and over-coherence. As the proposed system approaches either of these extremes, its viability decreases. The implemented technology must be designed such that $\boldsymbol{n}$ (the number of possible states, like the sides of a die), $\boldsymbol{\sigma_i}$ (the standard deviation of the distribution, like the distribution of either a fair or unfair die over numerous rolls) and **I**(X|Y) (the mutual information) must self-regulate both locally, at each node, and globally, viz. "sleep/ wake" cycles, in order to mitigate the death-states of dissipating flux or paralytic fixity, respectively.

Table 1 – Specified Self-regulation behaviors

	upon approaching **under-coherence**	upon approaching **over-coherence**
n, the number of possible states, e.g., # of states *x* or *y*	decrease ***n***	increase ***n***
H(X), the entropy of a random variable, e.g., X or Y	decrease **H**	increase **H**
Mutual Information, **I**(X|Y)	increase **I**	decrease **I**

$$H(X) = log \frac{N!}{x_1 !x_2 !x_3 ! \dots x_n !} \qquad \text{Equation 6}$$

$$H(Y) = log \frac{N!}{y_1 !y_2 !y_3 ! \dots y_n !} \qquad \text{Equation 7}$$

Table 1 specifies what needs to happen when a system veers too close to either of its death-states. For the purposes of formal explanation, it is put in information theoretic terms. In this way, Self-regulation can be empirically measured similar to Work and Complexity, assuming the Alt. Hypothesis, H_1, is realized in the proposed model of Synthetic Cognition. Of course, H_1 cannot be assumed a priori, exactly because the above information theoretic description *does not explain how to actually implement Self-regulation* in the proposed circuit schematic in section 3.1. It therefore does not explain semiogenesis; it can only measure an aspect of it. There remains a normative capacity inherent to Self-regulation that also remains unexplained; to explain this is to explain the Normative aspect of semiogenesis. And, as the section below will introduce, this normative aspect of semiogenesis hinges exactly on the uncanny aspect of semiosis introduced initially: "A principal feature of the sign relation is *aboutness* – the property of a sign being about something *other than itself*" (Kull and Favareau 2022: 21).

4.2 Self-regulation in Practice

Central to semiosis, as alluded to in the quote just above, is its *absential* aspect. This essential aspect of semiosis has not been discussed in detail up until now, because to characterize it first requires the explanation of all the sections above. Nevertheless, it is difficult, if not impossible, to imagine any living system that *does not miss something*. On the contrary, nutrients, water, shelter, rest, mates, etc. are all things that at some moment or another all living beings will miss. But how exactly does a being, able to self-maintain itself, miss that which is needed to do just that: maintain itself? The being has to first know that something is missing; then it has to know how to acquire it; and then it has to know how to assimilate it. These are all non-trivial capacities that we all do countless times a day. Every decision one has ever made is, at least in part, about something missing.

The entailed paper by Bacigalupi and Favareau (2023) [Article IV] discusses the physiology of how a body maps itself spatiotemporally and how it can use these maps to coordinate the acquisition of that which it does not have but wants, like water. And the above section has introduced the concepts of self-regulatory *tendencies* and *drives*. All of these capacities of what is *present* must entail something that is missing: something *absential*.

Semiosic beings must simultaneously be about what they are and they are not. This section explores the pragmatic means by which such a paradox can be realized. This can start with the affective field. This normative phenomenon has a "sweet zone", which must be composed of distinct salient aspects in tension with more distributed interrelating aspects. As discussed throughout, these dynamical attributes must co-constitute each other. Each must provide the boundary conditions for the other. This section will dig more deeply into the Primary and Secondary Nodes introduced above to better understand how this tense balance within the aesthetic affective field can be positively cultivated and negatively thwarted from the operational death-states.

To better explain this more positive capacity, the absential aspect of Primary Nodes will be explored. Nevertheless, as has occurred multiple times in this dissertation, this exploration will, again, "kick the can down the road", because the resulting tension between present and absential aspects of Primary Node dynamics will still need self-regulation. This "can", although "further down the road" of explanation, will still require a third mode of mitigation. This will be addressed by the Self-regulatory capacity of Secondary Nodes' sensing of the affective field cultivated by the Primary Nodes. The Secondary Nodes will provide the boundary constraints of negative feedback as the affective field degenerates into either over or under-coherence, both tending to mitigate the normative quality, or *aesthetics*, of this affective field.

The capacity to cultivate an aesthetic, or viable, affective field hinges on both the present generative and absential degenerative aspect of Complex affinities that have been embodied through learning. This dissertation, so far, has focused mainly on the present generative aspect of these affinities. For example, Figure 3 in section 2.2 illustrates what has been acquired: novel constraints that facilitate Adaptive Work when some learned stimulus is re-experienced. But this positive aspect of the learned dynamical attractor is fundamentally solipsistic, if that were all there was. For example, C Major is just about C Major, and E minor is just about E minor. It is easy for the Western intellect to focus on the positive thing that is added. When C Major and E minor are in disparation, novel dimensions from the transfinite continuous medium among them can be, again, added to a higher-order attractor: C Major 7th. However, these so-called *added* dimensions were also something *missing* from C Major 7th. For example, we could also imagine that someone learns C Major 7th *before* the other chords, in which case C Major 7th is a 1st level attractor based on the foundational 16 Primary Nodes, not on other learned chords. But then C Major 7th can individuate into C Major and E minor by *losing* constraints; individuation works both ways. What is added and what is missing depends on which way the process of individuation is going and cannot be presupposed. This is one of the principle reasons that transfinite degrees of freedom in the affective field are needed: they do not presuppose what is added or what is missing. Self-regulation requires an intimate connection with the semiosic milieu, which is, again like the "sign", about both itself and not itself, simultaneously.

To demonstrate this in practice, assume that the proposed technology above has become sympathetic to C Major via rewiring of the 16 Primary Nodes. The experimenters could then stimulate the system with the notes c and g, just two of the notes out of the three that constitute the chord. Nevertheless, as is the case with pattern completion, these two notes may be enough to put the system into the C Major attractor state. Now – and only now – can we define what is meant by *missing*. For something to be missing, it must have already been an aspect of a larger entity or process. The missing note e was an integrated part of the originally learned attractor. The two remaining notes were enough to trigger this attractor, but this absential C Major attractor, although a veritable recognition of that formerly learned pattern, is not exactly the same dynamic as the C Major attractor having been stimulated by all three notes; this is the absential aspect of semiosis. But what is the difference at the circuit scale?

The Primary Nodes that were triggered by the active notes c and g, will charge up, i.e., they will be potentiated by drawing available current from the system as a whole. The circuits will be designed such that attractors will have some momentum or inertia – perhaps akin to persistence of vision in humans – meaning that they will stimulate each other via the hard connections that they acquired via the process of learning the C Major pattern in the first place. This stimulation will have been initially triggered by the resonance each Primary Node has for the notes in the C Major chord. Nevertheless, this creates an intrinsic tension or a heightened sensitivity for the nodes that would have been resonant with the note e, because they are being stimulated by the hard connections from the other nodes, *but they do not detect the actual presence of the note in the affective field* via the receiver at g) in Figure 10, as is the case with the other two notes. Herein lies an opportunity to more rigorously understand Gregery Bateson's definition for information: "a difference which makes a difference" (1987: 321).

The c and g sensitive Primary Nodes will feel *both* the resonant stimulation of their respective frequencies in the affective field *and* the stimulation from each other via formerly accrued hard wire connections. The e sympathetic nodes, however, will only feel perturbed by the hard connections, not the presence of the actual frequency that once constituted the whole pattern; this absential state is an opportunity fundamental to semiosis. But how does the semiosic system take advantage of this opportunity?

The extended hypothesis of this project is that the absential nodes will attempt to complete the pattern, but they will not do it via the local present attractor – C Major in this example. In this way, there is a tension between the active aspect of the attractor using its available current to reinforce itself, i.e., the emergent actual attractor, whereas the absential aspect of the attractor will use its available current to "call out" beyond the local attractor to the system more broadly trying to find the missing frequency. This calling out will be an EM emission at h) in Figure 10, in the proposed instantiation, sent into the void of the distributed affective field of that which it is missing. This absential state illustrates one of the many paradoxical aspects of semiosis: it is both local and global, distinct and distributed, simultaneously.

Each emergent dynamical attractor will tend to have some ratio between present and absential aspects. This is largely because – as Heraclitus foretold[27] – a semiosic system will neither be in the exact same context as before and nor will it be the same system. Semiosis is an irreversible process (Bacigalupi 2024). Also, in order for patterns like C Major to have any meaning, their pattern will be learned in a unique context, and its embodied sympathetic constraints will be updated when it is either re-experienced or even just remembered. But, again, these subsequent absences – or differences more generally – are the necessary scaffold by which meaning is woven. This can be likened to Lotman's assertion that meaning-making requires (un)translatability (1990: 15). It can also be likened to the observation by Claude Shannon that the English language is about 50% determined by the grammatical structure of the learned language and 50% free choice of the speaker (1948: 14). In this way, the absential aspect of semiosis is a kind of freedom: the main aspect of semiosis open to interpretation and the weaving of novel meanings.

However, this weaving of novel meaning requires some time. It needs a minimum moment or *duration* (Bergson 1999). This is achieved, at least in part, in biology by inhibition. And herein lies another productive tension: the tension between *excitation* and *inhibition*. This proposal hypothesizes that the absential nodes of a given attractor will tend to inhibit locally and excite globally, whereas the present nodes of the attractor will tend to inhibit more globally and excite locally. In terms of nodal behavior, this means that the Primary Nodes that are absential – e.g., the nodes missing the note e in the example above – will tend to *inhibit* the nodes that are not missing c and g and are currently stimulating the absential nodes via hard connections; these same absential nodes, however, will *excite* the surrounding affective field with their own "call". In contrast, the Primary Nodes that are present – e.g., the nodes not missing the notes c and g – will tend to *inhibit* the surrounding nodes whether or not they are connected via hard connections; this is analogous to center-surround phenomena in the neurobiological literature (Steinman, Steinman, and Lehmkuhle 1995; Kiyonaga and

[27] See, for example, the entry on Heraclitus in the Stanford Encyclopedia of Philosophy (Graham 2020), specifically section 3.1 on *flux*: https://plato.stanford.edu/archives/sum2020/entries/heraclitus/#Flu

Egner 2016), as it helps to maintain the emergent attractor above the noise floor; this dynamic and others in this discussion will also be applied to social scale phenomena, as outlined in Lotman's center-periphery dynamics (Gherlone 2022).

These dynamics explain further how more general tendencies of self-focused salient fixity mitigate the more pernicious aspects of the general tendency to interrelate via more distributed flux. And vice versa, the flux of interconnective potential mitigates the more solipsistic and fixed tendencies of salient attractors. The inhibitory dynamics of both tendencies create a *duration*: a reprieve from direct dissipation via the second law of thermodynamics. In the tension between these two tendencies, there is the positive capacity for Primary Nodes to cultivate an affective field by instantiating a population of diverse affinities that has a small-world-like aesthetic distribution of small, medium and large attractors, the so-called "sweet zone" described above. This is the positive generative aspect of Self-regulation. Nevertheless, there is another more negative degenerate constraint – an injunctive boundary condition or drive away from the death-states – possible via Secondary Nodes.

All the above operations create a set of conditions, by which the Secondary Nodes can sense the aesthetic state of the affective field. For example, if Secondary Nodes cannot harness any sparse order – meaning there is little to no asymmetry in the affective field – then this is an indicator for either over or under-coherence. Overcoherence will permeate the whole system with one repeated pattern, whereas under-coherence will permeate the whole system with noise. However, as introduced in Table 1 above, different strategies are needed to mitigate either over or under-coherence. How can the system sense the difference?

Answering this question requires recourse to another attribute of neuro-biology: frequency regimes like alpha, beta, delta and theta waves in the chordates (Jasek, Strmiska, and Koudelková 2018). This extended hypothesis will propose just two: high and low frequencies regimes. The present nodes within the dynamical attractors of Primary Nodes will tend to exhibit low frequencies as they reinforce each other via hard connections. The absential nodes, on the other hand, will tend to exhibit high frequencies as they emit their signals into the interstitial field. There is much more to say about the inter-dynamics among these frequency regimes that are instrumental in how both sets of Primary Nodes compete/collaborate with each other to cultivate an aesthetic affective field. These details will be the subject of future research. The important aspect they serve for the purposes of Self-regulation is to aid Secondary Nodes in answering the question above: how can they sense the difference between an affective field tending towards over versus under-coherence?

Generally, the aesthetic affective field will be physically composed of a super-posed balance of high and low frequencies. The dominance of low frequencies will be indicative of more singular and dominating attractors to the exclusion of medium to small attractors needed for interrelation. The dominance of high frequencies will be indicative of more noise that competes against any attractors at all. The former is over-coherence, whereas the latter is under-coherence. Secondary Nodes can sense the difference. Even though, in either case, there is a tendency for homogeneity and no asymmetries to harness for Complexification, there will be a qualitative difference between these extreme states of homogeneity. In the former case of a dominant system-wide attractor, Secondary Nodes will entrain to that one pattern. Given the comparative capacity of Secondary Nodes, as a collective system-wide network, they will be able to sense their shared dominance. In the latter case of noise, Secondary Nodes will not be able to sense anything discernable at all. As outlined in Table 1, Secondary Nodes can now be conceived to provide the appropriate injunction, or *drive*, against further decent into either death-state. Secondary Nodes can be designed to regulate the excitatory and inhibitory behaviors of Primary Nodes, introduced above, in order to implement the proscriptions listed in Table 1.

This will facilitate Self-regulation. And it can be argued that this Self-regulation, having made aesthetic choices based on the distinct qualitative attributes of the affective field, is a normative tendency: i.e., a continual tendency for present and absential nodes to drive away from under or over-coherence based on sensing the affective field cultivated by said nodes. This is the recursive nature of Relevance in the informal definition of semiogenesis in section 0.1: Relevance – as more rigorously defined in section 2.4 – continually resolves the tensions that Relevance creates in an irreversible and irreducible process of affinity, i.e., "sign", generation. This is the basis for a Normative Self-regulation in semiogenesis, generally speaking.

Self-regulation must facilitate the self-maintenance of a normative tension, a tension able to sustain semiogenesis in the sentient being. Primary nodes must maintain a normative tension between absential and present firing; attractors must maintain a normative tension between saliency and networks of attractors; and Secondary Nodes, while facilitating the latter, must also maintain a normative tension between over and under-coherence. And, arguably, these capacities exist at multiple scales: the single cell, multicellular organisms and societies. The next section will use the model proposed above to discern the state of Normative Self-regulation at the scale of human societies.

4.3 Self-regulation, Future Research

As clever as all of the systems outlined above may be, it is important to note that they are all only *emulation*, not *duplication* of living semiosic beings embodying semiogenesis. The Alternative Hypothesis of Semiogenesis can indicate attributes of veritable living semiogenesis that are categorically missing from our current machines that can only ever *simulate* semiogenesis. Nevertheless, the proposal in this dissertation and the entailed publications must still be specified by their designers at some level of abstraction. The previous section, for example, explains how Primary and Secondary Nodes can be organized to exhibit aspects of semiogenesis that have never before been implemented in a human-made machine. However, the nodes themselves must be presupposed at some level of abstraction, whether analog or digital in its instantiation. Having reflected on the gap between emulation and duplication of semiogenesis, three areas of future research present themselves: the theoretical biology of abiogenesis at the microscale; mathematically characterizing the distinction between strategies of simulation, emulation and duplication of living systems at the mesoscale; and extending these triadic dynamics of semiogenesis to human social phenomena at the macroscale.

A good deal of research has already been done on the subject of abiogenesis both with others in past projects (Deacon, Srivastava, and Bacigalupi 2014; Alexander, Bacigalupi, and Garcia 2021) and the current project (Bacigalupi 2023a; Bacigalupi and Favareau 2023; Bacigalupi 2022) [Article II, III, IV]. The common thread through all of them – except the work with Terrence Deacon – is the application of semiogenesis to biological systems via the work of Kuramoto's model (Saigusa et al. 2008; Kuramoto 1984; Strogatz 2000). At its center, this model proposes a large population of weakly coupled chemical oscillators. In addition to the model of semiogenesis proposed herein, future research at the liminal edge of abiogenesis will synthesize the work of Kauffman and others (Kauffman 1993; Longo, Montévil, and Kauffman 2012) regarding how these chemical oscillators can be diversely tuned autocatalytic networks (Hordijk 2019). And it will also incorporate the work of Longo and others on the capacity for semiogenesis to instantiate and sustain *extended criticality* (Longo and Montévil 2019).

At the very inception of the original efforts above, a central question is the distinction between living systems and our cybernetic machines. This question is intrinsic to semiogenesis, as outlined in section 1.2 above. This question is also quite relevant for today's policy-makers in deciding whether or not to cover the Earth with data centers in the hopes of realizing human-level AI. This effort is like trying to reach the moon by climbing a tree (Dreyfus 1964). A more rigorous characterization between these distinct modes of information processing will certainly aid in dispelling the myths that motivate the waste of hundreds of millions of dollars and resources on such a Sisyphean task. Moreover, this more accurate characterization will open entirely new avenues of technology that do, in fact, better emulate living processes. Fruitful research in making this distinction and empirically exploring how semiogenesis actually works will set the stage for a more grounded and ecosemiotic ethics at the socio-cultural scale. A potential partner in building the proposed experiment in section 3 and to make the case for a truly novel form of non-Turing-equivalent information processing is Jaan Aru at the University of Tartu (2025). Another potential partner for rendering the case for this distinction more mathematically rigorous is Alessandro Sarti, currently at the École des Hautes Études en Sciences Sociales (Sarti and Piotrowski 2015) and Xin Wei Sha, currently at Arizona State University, both of whom have independently arrived at very similar hypotheses.

The inception of this larger project of Synthetic Sentience, back in 2003, was an ethical question: how does living creativity sustain itself in the face of humans' self-destructive tendencies? A preliminary answer to this question certainly includes the preliminary and extended hypotheses described in this dissertation. Building upon this, I have done preliminary research in Bacigalupi (2023a; 2025;

2022) [Article II, III]. These efforts have led me to a distinction between our inherited Cybernetic Technics and a future vision of a human Sentient Technics. Intrinsic to the former is our species' unique relationship with semiosis, given our hyper-symbolic nature (Deacon 1997). This capacity for abstraction embodies a cybernetic mode of being that is arguably both our species' strength and weakness (Mumford 1967). To mitigate the pernicious aspects of this inherited mode, Sentient Technics will be a project that conceives of and advocates for novel modes of technology production and self-governance that entail Self-regulation that emulates such regulation in living systems, as outlined in the previous two sections. The intent of this more ethical advocacy is to increase the alignment between human modes of operation and the only known biosphere, within which such human operations are embedded. In addition to semiotics colleagues – such as, Kalevi Kull, Donald Favareau, Timo Miran, Nelly Mäekivi, Jana Švorcová, Ludmila Lackova, Nicola Zengiaro, etc. – and Simondonian colleagues – such as, Cecile Malaspina, Xin Wei Sha, etc. – other potential partners focused on technics, including Yuk Hui (2021) and Asimina Kouvara (2025) could help to advance the overarching project of Sentient Technics.

5.0 CONCLUSION

Central to the thesis of semiogenesis is how living systems can self-sustain a productive tension between fixity and flux, which both self-problematizes and can resolve the semiosic agent via radical generativity, continuously and simultaneously. This generativity is novel dynamical constraints observed as new dimensions, which are generated from the continuous interstitial medium within the semiosic agent. These constraints must also be accrued into more inertial structures, able to bias future responses to similar future perturbations to pragmatic ends. This is ontic semiogenesis as it exists in living systems.

These proposed emergent and adaptive affinities of semiogenesis are similar to some legacy lines of thought, such as the Scholastics, Peirce, Lotman, Simondon, Hoffmeyer, Sarti, etc. Section 1 also outlines some approaches and thinkers whose projects diverge from the hypothesized dynamics of semiogenesis. To argue for this thesis of semiogenesis, section 2 forwards a preliminary hypothesis that entails the tension between the tendencies towards fixity and flux, along with a means to harness the sparse order that emerges in this tension, which becomes the basis for future adaptive behaviors; the physically observable aspects of this theory are Relevant Complexity and Adaptive Work, which – along with total energy – constitute the definition of Relevance, the polynomial regression of which is the empirically measurable Semiogenesis: an index for really existing semiogenesis. To empirically test this hypothesis of Semiogenesis, a novel technology is proposed in section 3 that is both buildable and testable via the theory in section 2. An extended hypothesis is then explored in section 4 that answers the question of Normative Self-regulation, which was left unanswered by the preliminary hypothesis. It is argued that this third observable is the source of intrinsic normative choice for the semiosic living system and must be considered when building the proposed novel technology in order to achieve the Alternative Hypothesis of Semiogenesis, the epistemic index for ontic semiogenesis.

Future research, in addition to actual implementation and experimentation, will extend the hypothesis above to questions of abiogenesis; the distinction between living and non-living information processing; and how humans can realize a less alienating form of self-governance by employing the proposed technology to implement a Sentient Technics, which can transcend the arguably unsustainable Cybernetic Technics humanity has inherited. Building upon the work both in the dissertation and planned for the near future, this project intends to lay the foundation for a veritable science of semiotics: a biosemiotic theory of semiogenesis.

REFERENCES

Alexander, Victoria, J. Augustus Bacigalupi, and Òscar Castro Garcia. 2021. “Living Systems Are Smarter Bots: Slime Mold Semiosis versus AI Symbol Manipulation.” *Biosystems* 206 (August): 104430. https://doi.org/10.1016/j.biosystems.2021.104430.

Anastassiou, Costas A, and Christof Koch. 2015. “Ephaptic Coupling to Endogenous Electric Field Activity: Why Bother?” *Current Opinion in Neurobiology* 31 (April): 95–103. https://doi.org/10.1016/j.conb.2014.09.002.

Anastassiou, Costas A., Sean M. Montgomery, Mauricio Barahona, György Buzsáki, and Christof Koch. 2010. “The Effect of Spatially Inhomogeneous Extracellular Electric Fields on Neurons.” *The Journal of Neuroscience* 30 (5): 1925–36. https://doi.org/10.1523/JNEUROSCI.3635-09.2010.

Anastassiou, Costas A, Rodrigo Perin, Henry Markram, and Christof Koch. 2011. “Ephaptic Coupling of Cortical Neurons.” *Nature Neuroscience* 14 (2): 217–23. https://doi.org/10.1038/nn.2727.

Aru, Jaan. 2025. “Artificial Intelligence and the Internal Processes of Creativity.” *The Journal of Creative Behavior* 59 (2): e1530. https://doi.org/10.1002/jocb.1530.

Ashby, W. Ross. 1966. *Design for a Brain: The Origin of Adaptive Behaviour*. 2nd ed. 1960. Dordrecht: Springer.

Bacigalupi, J. Augustus. 2013. “Refinement: A Rigorous Description of Autonomous Adaptive Agents.” Edited by Prof. Ranulph Glanville and Prof. David Griffiths. *Kybernetes* 42 (9/10): 1313–24. https://doi.org/10.1108/K-10-2012-0065.

———. 2022. “Semiogenesis: A Dynamic System Approach to Agency and Structure.” *Biosemiotics* 15 (2): 261–84. https://doi.org/10.1007/s12304-022-09494-8.

———. 2023a. “Creativity: Transcending the Cybernetic Mode via the Virtuality of Relevant Noise.” Edited by Cecile Malaspina. *Angelaki* 28. https://doi.org/10.1080/0969725X.2023.2216550.

———. 2023b. “Semiogenesis: Emergent Signs in-Tension among Structure and Openness.” In *Open Semiotics*, 4:111–26. Life and Its Extensions. l’Harmattan.

———. 2024. “Semiogenesis: Naturalizing Semiosic Haecceity and Temporal Irreversibility.” In *Explorations in Dynamic Semiosis*, edited by Elli Marie Tragel, 151–68. Theory and History in the Human and Social Sciences. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-47001-1_5.

———. 2025. “Ontic Origins of Creativity: A (Meta)Physics of Aesthetics.” In *Semiosis as Creation: Between Nature, Body, and Art*, 3–32. Universidad del Rosario.

———. 2026. “Understanding Irreducibility in Semiosis via the Image.” *Sign Systems Studies* 54.

Bacigalupi, J. Augustus, and Victoria Alexander. 2021. “Creative Agency Via Higher-Dimensional Constraints.” *Biosemiotics* 14 (1): 87–93. https://doi.org/10.1007/s12304-021-09418-y.

Bacigalupi, J. Augustus, and Donald Favareau. 2023. “The Physiology of Coordination: Self-resolving Diverse Affinities via the Sparse Order in Relevant Noise.” *The Journal of Physiology*, December, JP284418. https://doi.org/10.1113/JP284418.

Bateson, Gregory. 1987. *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*. Northvale, N.J: Aronson.

Bergson, Henri. 1999. *Duration and Simultaneity: Bergson and the Einsteinian Universe*. Translated by Leon Jacobson. Manchester: Clinamen Press Ltd.

———. 2005. *Creative Evolution*. New York: Cosimo Classics.

———. 2010. *The Creative Mind: An Introduction to Metaphysics*. Mineola, N.Y: Dover Publications.
Bertalanffy, Ludwig. 1968. *General System Theory: Foundations, Development, Applications*. New York, NY: George Braziller Inc.
———. 1972. "The History and Status of General Systems Theory." *The Academy of Management Journal* 15 (4): 407–26. https://doi.org/10.2307/255139.
Bundgaard, Peer, and Frederik Stjernfelt. 2010. "René Thom's Semiotics and Its Sources." In *Semiosis and Catastrophes: René Thom's Semiotic Heritage*, edited by Wolfgang Wildgen and Per Aage Brandt. v. 10. Bern ; New York: Peter Lang.
Buonomano, D. V., and T. P. Carvalho. 2009. "Spike-Timing-Dependent Plasticity (STDP)." In *Encyclopedia of Neuroscience*, edited by Larry R. Squire, 265–68. Oxford: Academic Press. https://doi.org/10.1016/B978-008045046-9.00822-6.
Buzsáki, György, Costas A. Anastassiou, and Christof Koch. 2012. "The Origin of Extracellular Fields and Currents – EEG, ECoG, LFP and Spikes." *Nature Reviews Neuroscience* 13 (6): 407–20. https://doi.org/10.1038/nrn3241.
Cariani, Peter, and Janet M. Baker. 2022. "Time Is of the Essence: Neural Codes, Synchronies, Oscillations, Architectures." *Frontiers in Computational Neuroscience* 16: 898829. https://doi.org/10.3389/fncom.2022.898829.
Deacon, Terrence. 1997. *The Symbolic Species: The Co-Evolution of Language and the Brain*. 1st ed. New York: W.W. Norton.
Deacon, Terrence, Alok Srivastava, and J. Augustus Bacigalupi. 2014. "The Transition from Constraint to Regulation at the Origin of Life." *Frontiers in Bioscience (Landmark Edition)* 19 (6): 945–57. https://doi.org/10.2741/4259.
Di Paolo, Ezequiel A. 2018. "The Enactive Conception of Life." *The Oxford Handbook of 4E Cognition*, 71–94. https://books.google.com/books?hl=en&lr=&id=eh1rDwAAQBAJ&oi=fnd&pg=PA71&dq=info:v-oR09xNV5QJ:scholar.google.com&ots=MjX9GlD4xL&sig=Wi7Tc1ffStDl1mNexwmHL9fpknE.
Di Paolo, Ezequiel, Evan Thompson, and Randall Beer. 2022. "Laying down a Forking Path: Tensions between Enaction and the Free Energy Principle." *Philosophy and the Mind Sciences* 3 (January). https://doi.org/10.33735/phimisci.2022.9187.
Dreyfus, Hubert. 1964. "Alchemy and Artificial Intelligence." In . RAND Corporation: RAND Corporation.
Fagundes, Tadeu Mendonca, Juan Carlos Ordonez, and Neda Yaghoobian. 2020. "How the Thermal Environment Shapes the Structure of Termite Mounds." *Royal Society Open Science* 7 (1): 191332. https://doi.org/10.1098/rsos.191332.
Favareau, Donald. 2015. "Creation of the Relevant next: How Living Systems Capture the Power of the Adjacent Possible through Sign Use." *Progress in Biophysics and Molecular Biology* 119 (3): 588–601. https://doi.org/10.1016/j.pbiomolbio.2015.08.010.
Foerster, Heinz Von. 1984. *Observing Systems*. Second. Seaside, Calif: Intersystems Publications.
Foerster, Heinz von. 2003. "Cybernetics of Cybernetics." In *Understanding Understanding: Essays on Cybernetics and Cognition*, 283–86. New York, NY: Springer. https://doi.org/10.1007/0-387-21722-3_13.
Gherlone, Laura. 2022. "The Center-Periphery Dynamics in Juri Lotman's Later Works: A Way Forward for New Epistemological Dialogues." *RUS (São Paulo)* 13 (December). https://doi.org/10.11606/issn.2317-4765.rus.2022.202220.

Graham, Daniel. 2020. “Heraclitus.” In *The Stanford Encyclopedia of Philosophy*, edited by Edward Zalta, Summer. Summer 2020 Edition. https://plato.stanford.edu/archives/sum2020/entries/heraclitus/.

Grassé, Plerre-P. 1959. “La reconstruction du nid et les coordinations interindividuelles chezBellicositermes natalensis etCubitermes sp. la théorie de la stigmergie: Essai d’interprétation du comportement des termites constructeurs.” *Insectes Sociaux* 6 (1): 41–80. https://doi.org/10.1007/BF02223791.

Grüsser, Otto-Joachim. 1995. “On the History of the Ideas of Efference Copy and Reafference.” In *Essays in the History of Physiological Sciences: Proceedings of a Symposium Held at the University Louis Pasteur Strasbourg, on March 26–27th, 1993*, by Claude Debru, 33:35–56. Amsterdam: Rodopi.

Haken, H., J. A. S. Kelso, and H. Bunz. 1985. “A Theoretical Model of Phase Transitions in Human Hand Movements.” *Biological Cybernetics* 51 (5): 347–56. https://doi.org/10.1007/BF00336922.

Hales, C. G. 2014. “The Origins of the Brain’s Endogenous Electromagnetic Field and Its Relationship to Provision of Consciousness.” *Journal of Integrative Neuroscience* 13 (02): 313–61. https://doi.org/10.1142/S0219635214400056.

Hales, Colin, and Susan Pockett. 2014. “The Relationship between Local Field Potentials (LFPs) and the Electromagnetic Fields That Give Rise to Them.” *Frontiers in Systems Neuroscience* 8 (December). https://doi.org/10.3389/fnsys.2014.00233.

Herreras, Oscar. 2016. “Local Field Potentials: Myths and Misunderstandings.” *Frontiers in Neural Circuits* 10 (December). https://doi.org/10.3389/fncir.2016.00101.

Hoffmeyer, Jesper. 1996. *Signs of Meaning in the Universe*. Advances in Semiotics. Bloomington: Indiana University Press.

———, ed. 2001. “Seeing Virtuality in Nature.” *Semi* 2001 (134): 381–98. https://doi.org/10.1515/semi.2001.034.

———. 2008. *Biosemiotics: An Examination into the Signs of Life and the Life of Signs*. Scranton: University of Scranton Press.

Hoffmeyer, Jesper, and Claus Emmeche. 1991. “Code-Duality and the Semiotics of Nature.” In *On Semiotic Modeling:*, edited by Myrdene Anderson and Floyd Merrell, 117–66. DE GRUYTER. https://doi.org/10.1515/9783110849875.

Holst, E. von. 1954. “Relations between the Central Nervous System and the Peripheral Organs.” *The British Journal of Animal Behaviour* 2 (3): 89–94. https://doi.org/10.1016/S0950-5601(54)80044-X.

Hood, Leroy, and David Galas. 2003. “The Digital Code of DNA.” *Nature* 421 (6921): 444–48. https://doi.org/10.1038/nature01410.

Hordijk, Wim. 2019. “A History of Autocatalytic Sets.” *Biological Theory* 14 (4): 224–46. https://doi.org/10.1007/s13752-019-00330-w.

Huang, Yu, and Yukio-Pegio Gunji. 2026. “Enhancing Neuromorphic Robustness via Recurrence Resonance: The Role of Shared Weak Attractors in Quantum Logic Networks.” *Biomimetics* 11 (1): 81. https://doi.org/10.3390/biomimetics11010081.

Hui, Yuk. 2021. *Art and Cosmotechnics*. University of Minnesota Press. https://doi.org/10.5749/j.ctv1qgnq42.

Hunt, Tam, and Jonathan W. Schooler. 2019. “The Easy Part of the Hard Problem: A Resonance Theory of Consciousness.” *Frontiers in Human Neuroscience* 13 (October): 378. https://doi.org/10.3389/fnhum.2019.00378.

Hynna, Kai M., and Kwabena Boahen. 2007. “Thermodynamically Equivalent Silicon Models of Voltage-Dependent Ion Channels.” *Neural Computation* 19 (2): 327–50. https://doi.org/10.1162/neco.2007.19.2.327.

Jasek, Roman, Martin Strmiska, and Zuzana Koudelková. 2018. "Analysis of Brain Waves According to Their Frequency," October.
Juarrero, Alicia. 2002. *Dynamics in Action*. MIT Press. https://cir.nii.ac.jp/crid/1360300774200960256.
Karatay, Vefa, Yagmur Denizhan, and Mehmet Ozansoy. 2016. "Semiosis as Individuation: Integration of Multiple Orders of Magnitude." *Biosemiotics* 9 (December). https://doi.org/10.1007/s12304-016-9273-4.
Kauffman, Stuart A. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. 1st edition. New York: Oxford University Press.
Kelso, J. A. Scott. 2012. "Multistability and Metastability: Understanding Dynamic Coordination in the Brain." *Philosophical Transactions of the Royal Society B: Biological Sciences* 367 (1591): 906–18. https://doi.org/10.1098/rstb.2011.0351.
Kiyonaga, Anastasia, and Tobias Egner. 2016. "Center-Surround Inhibition in Working Memory." *Current Biology* 26 (1): 64–68. https://doi.org/10.1016/j.cub.2015.11.013.
Korzybski, A. 1948. "A Non-Aristotelian System and Its Necessity for Rigour in Mathematics and Physics." In *Science and Sanity*, 3rd ed. Lakeville: The International Non-Aristotelian Library Publishing Company.
Kouvara, Asimina. 2025. "Transition to Where? Exploring the Transformative Potential of 'Cosmolocal Technology' in Quest of Future Coexistence." https://digikogu.taltech.ee/et/item/1449f121-4c8e-4db4-bbad-83558169fe7c.
Krampen, Martin. 1997. "Models of Semiosis." In *Semiotics: A Handbook on the Sign-Theoretic Foundations of Nature and Culture*, 247–87. Berlin: Walter de Gruyter.
Kugler, Peter N., and M. T. Turvey. 1988. "Self-Organization, Flow Fields, and Information." *Human Movement Science* 7 (2): 97–129. https://doi.org/10.1016/0167-9457(88)90009-7.
Kull, Kalevi. 2015. "Evolution, Choice, and Scaffolding: Semiosis Is Changing Its Own Building." *Biosemiotics* 8 (2): 223–34. https://doi.org/10.1007/s12304-015-9243-2.
Kull, Kalevi, and Donald Favareau. 2022. "Neurosemiotics: A Brief History of Its Development and Key Concerns." In *The Routledge Handbook of Semiosis and the Brain*, edited by A.M. Garcia and A. Ibáñez, 13–29. New York: Routledge.
Kuramoto, Yoshiki. 1984. *Chemical Oscillations, Waves, and Turbulence*. Springer Series in Synergetics. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-69689-3.
Lacková, L'udmila. 2025. *Language of Life*. https://www.peterlang.com/document/1490492.
Longo, Giuseppe, and Maël Montévil. 2014. *Perspectives on Organisms*. Lecture Notes in Morphogenesis. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-35938-5.
———. 2019. "From Physics to Biology by Extending Criticality and Symmetry Breakings: An Update." *Acta Europeana Systemica* 9: 77–92. https://doi.org/10.14428/aes.v9i1.56043.
Longo, Giuseppe, Maël Montévil, and Stuart Kauffman. 2012. "No Entailing Laws, but Enablement in the Evolution of the Biosphere." arXiv. http://arxiv.org/abs/1201.2069.
Lotman, Juri. 1990. *Universe of the Mind; A Semiotic Theory of Culture*. Translated by Shukman. London: I.B. Tauris & Co. Ltd.
Lukoševičius, Mantas. 2012. "A Practical Guide to Applying Echo State Networks." In *Neural Networks: Tricks of the Trade: Second Edition*, edited by Grégoire Montavon, Geneviève B. Orr, and Klaus-Robert Müller, 659–86. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-35289-8_36.

Maass, Wolfgang. 2010. "Liquid State Machines: Motivation, Theory, and Applications," January. https://doi.org/10.1142/9781848162778_0008.

Malaspina, Cecile. 2018. *An Epistemology of Noise*. Bloomsbury Publishing.

Mishra, Rajiv K., Sooyun Kim, Segundo J. Guzman, and Peter Jonas. 2016. "Symmetric Spike Timing-Dependent Plasticity at CA3–CA3 Synapses Optimizes Storage and Recall in Autoassociative Networks." *Nature Communications* 7 (1): 11552. https://doi.org/10.1038/ncomms11552.

Morin, Edgar. 2007. "Restricted Complexity, General Complexity." In *Worldviews, Science and Us*, 5–29. https://doi.org/10.1142/9789812707420_0002.

Morin, Edgar, and Frank Coppay. 1983. "Beyond Determinism: The Dialogue of Order and Disorder." *SubStance* 12 (3): 22–35. https://doi.org/10.2307/3684252.

Mumford, Lewis. 1967. *The Myth of the Machine*. San Diego (Calif.) New York London: Harcourt Brace Jovanovich.

Nakajima, Kohei, and Ingo Fischer, eds. 2021. *Reservoir Computing: Theory, Physical Implementations, and Applications*. Natural Computing Series. Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-1687-6.

Noble, Denis. 1920. *Dance to the Tune of Life: Biological Relativity*. 1st ed. Cambridge University Press. https://doi.org/10.1017/9781316771488.

———. 2012. "A Theory of Biological Relativity: No Privileged Level of Causation." *Interface Focus* 2 (1): 55–64. https://doi.org/10.1098/rsfs.2011.0067.

———. 2022. "How the Hodgkin Cycle Became the Principle of Biological Relativity." *The Journal of Physiology* 600 (24): 5171–77. https://doi.org/10.1113/JP283193.

Peirce, Charles S. 1893. "Evolutionary Love." *Monist*, 176–200.

Perera, Supun, Michael Bell, and Michiel Bliemer. 2017. "Network Science Approach to Modelling the Topology and Robustness of Supply Chain Networks: A Review and Perspective." *Applied Network Science* 2 (October): 33. https://doi.org/10.1007/s41109-017-0053-0.

Pickering, Andrew. 2009. "Psychiatry, Synthetic Brains and Cybernetics in the Work of W. Ross Ashby." *International Journal of General Systems* 38 (2): 213–30. https://doi.org/10.1080/03081070802712025.

Prigogine, I., Isabelle Stengers, and I. Prigogine. 1984. *Order out of Chaos: Man's New Dialogue with Nature*. Toronto ; New York, N.Y: Bantam Books.

Radman, Thomas, Yuzhuo Su, Je Hi An, Lucas C. Parra, and Marom Bikson. 2007. "Spike Timing Amplifies the Effect of Electric Fields on Neurons: Implications for Endogenous Field Effects." *The Journal of Neuroscience* 27 (11): 3030–36. https://doi.org/10.1523/JNEUROSCI.0095-07.2007.

Raja, Vicente. 2018. "A Theory of Resonance: Towards an Ecological Cognitive Architecture." *Minds and Machines* 28 (1): 29–51. https://doi.org/10.1007/s11023-017-9431-8.

Saigusa, Tetsu, Atsushi Tero, Toshiyuki Nakagaki, and Yoshiki Kuramoto. 2008. "Amoebae Anticipate Periodic Events." *Physical Review Letters* 100 (1): 018101. https://doi.org/10.1103/PhysRevLett.100.018101.

Salupere, Silvi. 2018. "The Cybernetic Layer of Juri Lotman's Metalanguage." *Recherches Sémiotiques* 35 (1): 63–84. https://doi.org/10.7202/1050987ar.

Sarti, Alessandro, Federico Montanari, and Francesco Galofaro. 2015. *Morphogenesis and Individuation*. https://doi.org/10.1007/978-3-319-05101-7.

Sarti, Alessandro, and David Piotrowski. 2015. "Individuation and Semiogenesis: An Interplay Between Geometric Harmonics and Structural Morphodynamics." In , 49–73. https://doi.org/10.1007/978-3-319-05101-7_3.

Schrodinger, Erwin. 1944. *What Is Life?* http://archive.org/details/WhatIsLife-EdwardSchrodinger.
Scotus, John Duns. 1300. *The Ordinatio of the Blessed John Duns Scotus*. Translated by Peter Simpson. Vol. Book One. www.aristotelophile.com/Books/Translations/Scotus Ordinatio I dd.1-2.pdf.
Shannon, C. E. 1948. "A Mathematical Theory of Communication." *The Bell System Technical Journal* 27.
Sharov, Alexei A., and Tommi Vehkavaara. 2015. "Protosemiosis: Agency with Reduced Representation Capacity." *Biosemiotics* 8 (1): 103–23. https://doi.org/10.1007/s12304-014-9219-7.
Sharov, Alexei, and Morten Tønnessen. 2021. *Semiotic Agency: Science beyond Mechanism*. Vol. 25. Biosemiotics. Dordrecht: Springer International Publishing. https://doi.org/10.1007/978-3-030-89484-9.
Shirakawa, Tomohiro, Yukio-Pegio Gunji, and Yoshihiro Miyake. 2011. "An Associative Learning Experiment Using the Plasmodium of *Physarum Polycephalum*." *Nano Communication Networks*, Biological Information and Communication Technology, 2 (2): 99–105. https://doi.org/10.1016/j.nancom.2011.05.002.
Simondon, Gilbert. 2017. *On the Mode of the Existence of Technical Objects*. Translated by Cecile Malaspina and R. Rogove. Minneapolis: Univocal Publishing.
———. 2020. *Individuation; in Light of Notions of Form and Information*. Translated by T. Adkins. Minnesota: Regents of University of Minnesota.
Steinman, Barbara A., Scott B. Steinman, and Stephen Lehmkuhle. 1995. "Visual Attention Mechanisms Show a Center—Surround Organization." *Vision Research* 35 (13): 1859–69. https://doi.org/10.1016/0042-6989(94)00276-R.
Strogatz, Steven H. 2000. "From Kuramoto to Crawford: Exploring the Onset of Synchronization in Populations of Coupled Oscillators." *Physica D: Nonlinear Phenomena* 143 (1): 1–20. https://doi.org/10.1016/S0167-2789(00)00094-4.
Sun, Chenxi, Moxian Song, Derun Cai, Baofeng Zhang, Shenda Hong, and Hongyan Li. 2024. "A Systematic Review of Echo State Networks From Design to Application." *IEEE Transactions on Artificial Intelligence* 5 (1): 23–37. https://doi.org/10.1109/TAI.2022.3225780.
Švorcová, Jana. 2024. *Organismal Agency: Biological Concepts and Their Philosophical Foundations*. Springer Nature.
Švorcová, Jana, and Anton Markoš. 2018. *Epigenetic Processes and Evolution of Life*. Boca Raton: CRC Press.
———. 2023. "Closures as a Precondition of Life, Agency, and Semiosis." *Biosemiotics* 16 (February): 1–15. https://doi.org/10.1007/s12304-023-09520-3.
Tanaka, Gouhei, Toshiyuki Yamane, Jean Benoit Héroux, Ryosho Nakane, Naoki Kanazawa, Seiji Takeda, Hidetoshi Numata, Daiju Nakano, and Akira Hirose. 2019. "Recent Advances in Physical Reservoir Computing: A Review." *Neural Networks* 115 (July): 100–123. https://doi.org/10.1016/j.neunet.2019.03.005.
Tognoli, Emmanuelle, Mengsen Zhang, Armin Fuchs, Christopher Beetle, and J. A. Scott Kelso. 2020. "Coordination Dynamics: A Foundation for Understanding Social Behavior." *Frontiers in Human Neuroscience* 14 (August): 317. https://doi.org/10.3389/fnhum.2020.00317.
Tononi, Giulio. 2004. "An Information Integration Theory of Consciousness." *BMC Neuroscience* 5 (1): 42. https://doi.org/10.1186/1471-2202-5-42.
Turing, Alan. 1950. "Computing Machinery and Intelligence." *Mind* LIX (236): 433–60. https://doi.org/10.1093/mind/LIX.236.433.

Uexküll, Jakob von. 1926. *Theoretical Biology*. London: K. Paul, Trench, Trubner & co. ltd.

Weiss. 2010. "Field Effects in the CNS Play Functional Roles." *Frontiers in Neural Circuits*. https://doi.org/10.3389/fncir.2010.00015.

Weston, P E, and Heinz Von Foerster. 1973. "Artificial Intelligence and Machines That Understand." *Annual Review of Physical Chemistry* 24 (1): 353–78. https://doi.org/10.1146/annurev.pc.24.100173.002033.

Wiener, Norbert. 2000. *Cybernetics or Control and Communication in the Animal and the Machine*. 2. ed., 10. print. Cambridge, Mass: MIT Press.

Yan, Min, Can Huang, Peter Bienstman, Peter Tino, Wei Lin, and Jie Sun. 2024. "Emerging Opportunities and Challenges for the Future of Reservoir Computing." *Nature Communications* 15 (1): 2056. https://doi.org/10.1038/s41467-024-45187-1.

SUMMARY

My overall research project, which this dissertation and the entailed publications below support, is motivated by a central question: how is creative meaning-making and value generation possible in living systems embedded in a physio-chemical universe? My initial research into this question (Bacigalupi 2013) [Article I] resulted in a schematic for a novel technology designed to emulate aspects of this creative capacity that are not currently realizable by our legacy machines. Contemporaneously, I developed a theory – based on information and thermodynamic theories, as well as neurobiological evidence – to test this novel technology for evidence of emulating generative meaning-making in living systems (*ibid*).

The preliminary hypothesis that resulted from this initial research led to a conclusion that was and remains uncommon: i.e., that creative meaning-making and value generation in living systems requires a third type of dynamic that is simultaneously distinct from, while co-constitutive with, the liminal tension between flux and fixity – and that the three distinct dynamics sustain and delimit each other, simultaneously and continuously (Bacigalupi 2023a) [Article III]. This discovery eventually led to my current investigations into the dynamics of semiosis. In particular, Peirce's Firstness, Secondness and Thirdness comported very well with my project's initial results. Such triadicity, I later discovered, was evident in Uexkull's protoplasmic *plan* (1926: 127), Lotman's *metastructure* (1990: 134; Salupere 2018: 77) and Simondon's *Individuation* (2020). Exploring these thinkers then led me to discover and reinterpret elements of triadicity in the thinking of the Scholastics, and in particular, Duns Scotus (1300). Nevertheless, the goal of my project is not the exegesis of triadicity, *per se*; it is, rather, to substantively move this particular thread of my investigation into the *semiogenesis* in living systems forward.

Detailing the methodology that was necessary in order to accomplish this progress is the purpose of this dissertation. After contextualizing this effort in the biosemiotic and cybernetic traditions in section 1, section 2 describes the preliminary hypothesis. This initial hypothesis is a formal theory developed to account for the uncanny adaptive creativity intrinsic to living systems. It defines two principle measures for what I call the Alternative Hypothesis (H_1) of Semiogenesis: Adaptive Work and Complexity, and these are explored in detail in sections 2.2 and 2.3, respectively. *Relevance* is then defined in section 2.4 as the product of Complexity and Adaptive Work divided by the total energy consumption of the semiogenic system. Semiogensis, as observable evidence for H_1, is defined as the curved regression of Relevance – which is, again, a function of Complexity, Work and total energy consumption. To empirically test this hypothesis, section 3.1 proposes a schematic design for the novel technology introduced above (Bacigalupi 2013) [Article I]. Section 3.2 describes how this technology could be tested for Semiogenesis, as defined in section 2. One of the conclusions of this preliminary hypothesis is that Relevance must oscillate to increase Complexity over time.

This two steps forward and one step back rhythm raised a critical question: how does the tension between order and disorder – i.e., fixity and flux – manage itself intrinsically in a creative living system? My answer is analogous to Lotman's notion of translatability and untranslatability, "each to different degrees" (1990: 15). Each dynamic, Lotman understood, co-constitutes the other's capacity to contribute to meaning-making. But neither translatability nor untranslatability can manage this contextually relevant balance in of themselves. There needs to be a third dynamic that needs to be more deliberately built into the technology proposed in Section 3.0. Perhaps for Lotman, this is his *metastructure*. For my project, this is the self-regulative capacity of the *affective field*.

How this affective field and its self-regulatory capacity is explored as an extended hypothesis is the focus of section 4. Section 4.1 starts by framing the critical importance of self-regulation's ability to maintain a semiogenic system within a "sweet zone" of operation between over and under-coherence – i.e., operationally untenable degrees of fixity or flux, respectively (Bacigalupi 2023a) [Article III]. Section 4.2 then digs deeper into the circuits proposed in section 3, demonstrating how the absential nature of semiosis (Kull and Favareau 2022: 21) is intrinsic to this dissertation's central thesis regarding the nature of adaptive creativity in living systems. Section 4.3 then looks to future research regarding self-regulation as a normative power in of itself: this I characterize as Normative Self-regulation. This adds the third empirical observable to the discussion of Adaptive Work and Complexity, as formally defined throughout the dissertation.

The hypothesis of Semiogenesis summarized above is developed throughout the publications entailed within this dissertation. Bacigalupi (2013) [Article I] first introduces the concept of what I then called Refinement, and which I now call Semiogenesis, and this is the first publication of my previous research into sentient creativity in living systems. Bacigalupi (2022) [Article II] then uses this hypothesis as a semiotic lens to understand living systems, such as termites and human societies. Bacigalupi (2023a) [Article III] focuses directly on the adaptive creativity hypothesized to exist in living systems; it also introduces the concept of the *cybernetic mode*, which will undergird future research that extends the above hypothesis to the social scale. (2023) [Article IV], similarly to Bacigalupi (2022) [Article II], use the hypothesis of Semiogenesis as a heuristic lens to explain how highly complex spatio-temporal coordination in living systems it is at all possible. A brief summary of each of the four articles follows.

Article I – Refinement: A rigorous description of autonomous adaptive agents (Bacigalupi 2013)

The purpose of this paper is to develop a theoretical framework to empirically test for cognitive behaviour in autonomous adaptive agents. The methodological approach of this project proposes a theoretical framework, or set of design parameters, inspired by empirically observed phenomena, cognitive behaviors and thermodynamics. Success of the framework will be measured by its capacity to provide not just a model of select attributes of cognition, but to implement the foundational physical nature of cognition, upon which all observed behaviors are based. The paper's findings result in a rigorous mathematical framework, employing only information theory and conventional physics, which is hypothesized to empirically measure for cognitive behaviors. Such empirical studies can be conducted on synthetic agents using the theoretical framework described herein to demonstrate whether or not cognitive behaviors have been achieved. In sum, this paper proposes an alternative form of information processing inspired by evolved organisms, distinct from Turing-equivalent machines, able to augment existing human and digital systems.

Article II – Semiogenesis: A dynamic system approach to agency and structure (Bacigalupi 2022)

This paper develops the concept of *semiogenesis* – a process of novel sign generation – and how instances of this process, such as agency, relate to their built environment and beyond. Section two of this paper builds on Hoffmeyer's discussion of swarms (1996: 113), specifically the idea of *overlapping swarms* and its manifestation in the creation of termite mounds, in order to introduce three types of structure. Building upon this real-world example explored in section two, the third section presents a heuristic for semiogenesis: a neuromorphic dynamic system model grounded in information and thermodynamic theory. Through the lens of this heuristic model, the penultimate section more rigorously characterizes the similarities and differences between termite and human agency in their respective built milieus.

Article III – Creativity: Transcending the cybernetic mode via the virtuality of relevant noise (Bacigalupi 2023a)

This paper explores how adaptive creativity is continuously generated and sustained in living systems. The philosophical frame and motivations for this investigation is introduced by juxtaposing an actual creative process with current cybernetic efforts to automate creativity. Past and present process philosophers that have critiqued the implicit commitments of these contemporary techniques set the stage for further investigations. The litmus of progress in this investigation is here measured against the extension of two concepts: *virtuality*, as introduced by Gilbert Simondon (2017), and *relevant noise* (Bacigalupi, Semiogenesis: A Dynamic System Approach to Agency, 2022) [Article II]. To refine the concepts of virtuality and relevant noise for the purposes of this project, a rigorous theoretical model is proposed whose intent is to explain veritable unbounded creativity. This model then serves as a heuristic lens to explore additional extant models, such as the Kuramoto model (Strogatz, 2000), that are used to explain empirical observations of adaptive and creative behaviors in a diversity of biological phenomena. Based on these models of biological creativity and the critique of the contemporary cybernetic project, this paper concludes by outlining the ethical implications of our culture's current commitments to a cybernetic world view and how we might develop beyond it.

Article IV – The Physiology of Coordination: Self-resolving diverse affinities via the sparse order in relevant noise (Bacigalupi and Favareau 2023)

Living systems at any given moment enact a very constrained set of end-directed and contextually appropriate actions that are self-initiated from among innumerable possible alternatives. However, these constrained actions are not necessarily because the system has reduced its sensitivities to itself and its surroundings. On the contrary, living systems are continually open to novel and unanticipated stimulations that require a physiology of coordination. To address these competing demands, this paper offers a novel heuristic model informed by neuroscience, systems theory, biology, and sign study to explain how organisms situated in diverse, complex, and ever-changing environments might draw upon the sparse order made available by 'relevant noise'. This emergent order facilitates coordination, habituation and, ultimately, understanding of the world and its relevant affordances. Inspired by the burgeoning field of coordination dynamics and physiologist Denis Noble's concept of 'biological relativity', this model proposes a view of coordination on the neuronal level that is neither sequential nor stochastic, but instead implements a causal logic of phasic alignment, such that an organism's learned and inherited sets of diverse biological affinities and sympathies can be resolved into a continuous and complex range of patterns that will implement the kind of novel orientations and radical generativity required of such organisms to adaptively explore their environments and to learn from their experiences. Authors' contribution: J.A.B. was responsible for the proposed heuristic model and its application to coordinative dynamics in living systems. D.F. contributed expertise in relating the application of this model to the discipline of biosemiotics in the introduction and the section 'Semiotics in coordination'.

SUMMARY IN ESTONIAN

Biosemiootiline semiogeneesi teooria: Testitava hüpoteesi loomine normatiivse iseregulatsiooni jaoks

Minu üldist uurimisprojekti, mille raames valmis käesolev väitekiri ja selle osadeks olevad publikatsioonid, on ajendanud keskne küsimus: kuidas on füsiko-keemilisse universumisse paigutatud elussüsteemides võimalik tähendusloome ja väärtuste teke? Minu esmane uurimus selle küsimuse kohta (Bacigalupi 2013) [artikkel I] viis skeemi väljatöötamiseni uudse tehnoloogia jaoks, mille eesmärk on emuleerida biosemiootilise süsteemi loova võimekuse aspekte, mida masinad praegu ei suuda realiseerida. Samal ajal arendasin välja teooria – tuginedes informatsiooni- ja termodünaamikateooriatele ning neurobioloogilistele tõenditele –, mis võimaldaks testida seda tehnoloogiat elussüsteemides esineva genereeriva tähendusloome emuleerimise tunnuste suhtes.

Sellest esialgsest uurimusest tulenenud hüpotees viis märkimisväärsete järeldusteni: nimelt, et tähendusloome ja väärtuse teke elussüsteemides eeldab kolme eri tüüpi dünaamikat, mis ühtaegu ja pidevalt nii toetavad kui piiritlevad üksteist (Bacigalupi 2023) [artikkel III]. See viis järgmise sammuna minu praeguste uurimusteni semioosi dünaamikast. Niisugune lähenemine sobitus hästi Charles Peirce'i esmasuse, teisasuse ja kolmasuse loogikaga. Näitan oma töös semiogeneesi mudeli seoseid Jakob von Uexkülli (1926: 127), Juri Lotmani (1990: 134; Salupere 2018: 77) ja Gilbert Simondoni individuatsiooniteooria (2020) vastavate mõistetega. Nende mõtlejate uurimine viis mind omakorda triaadilisuse elementide ümbertõlgendamiseni skolastikute mõtlemises, eriti Duns Scotuse (1300) puhul. Siiski ei ole minu projekti eesmärk triaadilisuse eksegees iseeneses; pigem on sihiks edasi arendada seda uurimissuunda, mis käsitleb semiogeneesi elussüsteemides.

Käesoleva väitekirja peatükk 1 paigutab selle projekti biosemiootilisse ja küberneetilisse traditsiooni. Peatükk 2 kirjeldab esialgset hüpoteesi. See esialgne hüpotees on formaalne teooria, mis püüab selgitada elussüsteemidele omast adaptiivset loovust. Määratlen kaks peamist mõõdet semiogeneesi alternatiivse hüpoteesi (H1) jaoks: adaptiivne töö ja komplekssus; neid käsitletakse üksikasjalikult vastavalt alapeatükkides 2.2 ja 2.3. Seejärel määratletakse alapeatükis 2.4 relevantsus komplekssuse ja adaptiivse töö kaudu semiootilise süsteemi kogu energiatarbimise suhtes. Semiogenees kui H1 empiiriline tunnus defineeritakse relevantsuse mittelineaarse regressioonina – mis omakorda on komplekssuse, töö ja kogu energiatarbimise funktsioon.

Selle hüpoteesi empiiriliseks testimiseks esitab alapeatükk 3.1 eespool tutvustatud tehnoloogia skeemilise kavandi (Bacigalupi 2013) [artikkel I]. Alapeatükk 3.2 kirjeldab, kuidas seda tehnoloogiat saaks testida semiogeneesi suhtes, nagu see on määratletud peatükis 2. Üks selle esialgse hüpoteesi järeldusi on, et relevantsus peab ajas komplekssuse suurendamiseks võnkuma.

See „kaks sammu edasi, üks tagasi" rütm on tõstatanud kriitilise küsimuse: kuidas korraldab loov elussüsteem sisemiselt korda ja korratust – s.t püsivust ja voolavust – ühendavat pinget? Minu vastus on analoogne Lotmani (1990: 15) tõlgitavuse ja tõlkimatuse käsitlusega. Kuid ei tõlgitavus ega tõlkimatus üksi suuda seda kontekstuaalselt asjakohast tasakaalu hallata. Vajalik on kolmas dünaamika, afektiivse välja iseregulatiivsus, mida vaadeldakse peatükis 3.

See, kuidas afektiivne väli ja selle iseregulatsioon toimivad laiendatud hüpoteesina, on peatüki 4 keskne teema. Alapeatükk 4.1 alustab iseregulatsiooni kriitilise tähtsuse rõhutamisest: selle võimest hoida semiootiline süsteem toimimise „magusas tsoonis" üle- ja alakoherentsuse vahel – s.t operatiivselt jätkusuutmatute püsivuse või voolavuse äärmuste vahel (Bacigalupi 2023) [artikkel III]. Alapeatükk 4.2 süveneb peatükis 3 pakutud tsüklitesse, näidates, kuidas semioosi absentsiaalne olemus (Kull ja Favareau 2022: 21) on käesoleva väitekirja keskse teesiga adaptiivse loovuse kohta lahutamatult seotud. Alapeatükk 4.3 vaatleb tulevasi uurimissuundasid, käsitledes lähemalt normatiivset iseregulatsiooni. See lisab adaptiivse töö ja komplekssuse kõrvale kolmanda empiiriliselt vaadeldava mõõtme, nagu need on väitekirjas formaalselt määratletud.

Ülal kokku võetud semiogeneesi hüpoteesi arendatakse edasi käesoleva väitekirjaga seotud publikatsioonides. Artikli I (Bacigalupi 2013) eesmärk on arendada teoreetilist raamistikku autonoomsete adaptiivsete agentide kognitiivse käitumise empiiriliseks testimiseks. See tutvustab esmakordselt mõistet, mida nimetan semiogeneesiks (tolles artiklis veel tähistatud terminiga *refinement*); see on minu varasema elussüsteemide tajulise loovuse uuringu esimene publikatsioon. Artikkel II (Bacigalupi 2022) arendab semiogeneesi mõistet – uute märkide tekkimise protsessi, ja esitab neuromorfse dünaamilise süsteemi mudeli. Artikkel III (Bacigalupi 2023) keskendub otseselt elussüsteemidele omistatavale adaptiivsele loovusele ning vaatleb ka küberneetilise režiimi mõistet, laiendades seda sotsiaalsele tasandile. Artikkel IV (Bacigalupi ja Favareau 2023) kasutab sarnaselt artiklile II semoigeneesi hüpoteesi heuristilise vahendina, et selgitada, kuidas elussüsteemides on üldse võimalik äärmiselt keerukas ruumilis-ajaline koordineeritus. Tuuakse esile ka seos Denis Noble'i 'bioloogilise relatiivsuse' käsitlusega.

PUBLICATIONS

CURRICULUM VITAE

Name: James Augustus Bacigalupi
Born: August 25, 1969
E-mail: bacigalupiworks@gmail.com

Education:

2022–2026 University of Tartu, doctoral studies, Semiotics and Culture Studies

2007–2009 City College of San Francisco, associate's studies, Departments of Electronics and Software Programing

1994–1997 University of Colorado at Denver, master's studies, Department of Architecture and Planning

1988–1993 University of California at Santa Barbara, bachelor's studies, Department of Environmental Social and Natural Science, Physical Chemistry

Study visits at other universities:

2024 October Palacký University Olomouc, visiting PhD student

Design and Research Career:

2018–2022 Sentient Societies Research Group, San Francisco, principle investigator

2013–2018 Studio for Public Spaces, Exploratorium Science Museum, San Francisco, studio co-founder and architectural lead

2012–2018 Emergent Dynamics Research Group – principle investigator Terrance Deacon, Berkeley, researcher

2002–2014 BacigalupiWorks, San Francisco, principle of architectural deign practice

Research topics:

Peircean evolution, Simondonian individuation, biosemiotics, theoretical biology, complexity, emergent dynamical systems, semiogenesis

Acknowledgements:

2022 The Fourth Annual Jesper Hoffmeyer Award for Early Career Researcher in Biosemiotics for presentation entitled: "Semiogenesis: Harnessing higher-order dimensions from structured noise"

Publications:

Alexander, Victoria, J. Augustus Bacigalupi, and Òscar Castro Garcia 2021. "Living Systems Are Smarter Bots: Slime Mold Semiosis versus AI Symbol Manipulation." *Biosystems* 206 (August): 104430.

Bacigalupi, J. Augustus 2013. "Refinement: A Rigorous Description of Autonomous Adaptive Agents." Edited by Prof. Ranulph Glanville and Prof. David Griffiths. *Kybernetes* 42 (9/10): 1313–24.

Bacigalupi, J. Augustus 2022. "Semiogenesis: A Dynamic System Approach to Agency and Structure." *Biosemiotics* 15 (2): 261–84.

Bacigalupi, J. Augustus 2023a. "Creativity: Transcending the Cybernetic Mode via the Virtuality of Relevant Noise." Edited by Cecile Malaspina. *Angelaki* 28.

Bacigalupi, J. Augustus 2023b. "Semiogenesis: Emergent Signs in-Tension among Structure and Openness." In *Open Semiotics*, 4:111–26. Life and Its Extensions. l'Harmattan.

Bacigalupi, J. Augustus 2024. "Semiogenesis: Naturalizing Semiosic Haecceity and Temporal Irreversibility." In *Explorations in Dynamic Semiosis*, edited by Elli Marie Tragel, 151–68. Theory and History in the Human and Social Sciences. Cham: Springer Nature Switzerland.

Bacigalupi, J. Augustus 2025. "Ontic Origins of Creativity: A (Meta)Physics of Aesthetics." In *Semiosis as Creation: Between Nature, Body, and Art*, 3–32. Universidad del Rosario.

Bacigalupi, J. Augustus 2026. "Understanding Irreducibility in Semiosis via the Image." *Sign Systems Studies*. Tartu: University of Tartu Press.

Bacigalupi, J. Augustus, and Victoria Alexander 2021. "Creative Agency Via Higher-Dimensional Constraints." *Biosemiotics* 14 (1): 87–93.

Bacigalupi, J. Augustus, and Donald Favareau 2023. "The Physiology of Coordination: Self-resolving Diverse Affinities via the Sparse Order in Relevant Noise." *The Journal of Physiology*, December, JP284418.

Deacon, Terrence, Alok Srivastava, and J. Augustus Bacigalupi 2014. "The Transition from Constraint to Regulation at the Origin of Life." *Frontiers in Bioscience (Landmark Edition)* 19 (6): 945–57.

ELULOOKIRJELDUS

Nimi: James Augustus Bacigalupi
Sünniaeg: 25. august 1969
E-post: bacigalupiworks@gmail.com

Haridus:

2022–2026 Tartu Ülikool, doktoriõpingud

2007–2009 City College of San Francisco, õpingud elektoonika ja tarkvara programmeerimise osakonnas

1994–1997 University of Colorado at Denver, arhitektuuri ja planneerimise osakond, magistriõpingud

1988–1993 University of California at Santa Barbara, füüsikaline keemia, bakalaureuseõpingud

Õpingud teistes ülikoolides:

2024 oktoober Palacký University Olomouc, külalisdoktorant

Teenistuskäik:

2018–2022 Sentient Societies Research Group, San Francisco, vastutav uurija

2013–2018 Studio for Public Spaces, Exploratorium Science Museum, San Francisco, stuudio kaasasutaja ja arhitektuurijuht

2012–2018 Emergent Dynamics Research Group (vastutav uurija Terrence Deacon), Berkeley, teadur

2002–2014 BacigalupiWorks, San Francisco, arhitektuurilise disaini paraktikajuht

Uurimisvaldkonnad:

Charles Peirce'i ja Gilbert Simondoni teooriad, biosemiootika, teoreetiline bioloogia, kompleksuuringud, emergentsed dünaamilised süsteemid, semiogenees

Tunnustused:

2022 Jesper Hoffmeyer'i noore uurija auhind biosemiootika alal ettekande eest: "Semiogenesis: Harnessing higher-order dimensions from structured noise"

Publikatsioonid:

Alexander, Victoria; Bacigalupi, J. Augustus; Castro Garcia, Òscar 2021. "Living Systems Are Smarter Bots: Slime Mold Semiosis versus AI Symbol Manipulation." *Biosystems* 206 (August): 104430.

Bacigalupi, J. Augustus 2013. "Refinement: A Rigorous Description of Autonomous Adaptive Agents." Edited by Prof. Ranulph Glanville and Prof. David Griffiths. *Kybernetes* 42 (9/10): 1313–24.

Bacigalupi, J. Augustus 2022. "Semiogenesis: A Dynamic System Approach to Agency and Structure." *Biosemiotics* 15 (2): 261–84.

Bacigalupi, J. Augustus 2023a. "Creativity: Transcending the Cybernetic Mode via the Virtuality of Relevant Noise." Edited by Cecile Malaspina. *Angelaki* 28.

Bacigalupi, J. Augustus 2023b. "Semiogenesis: Emergent Signs in-Tension among Structure and Openness." In *Open Semiotics*, 4: 111–26. Life and Its Extensions. l'Harmattan.

Bacigalupi, J. Augustus 2024. "Semiogenesis: Naturalizing Semiosic Haecceity and Temporal Irreversibility." In *Explorations in Dynamic Semiosis*, edited by Elli Marie Tragel, 151–68. Theory and History in the Human and Social Sciences. Cham: Springer Nature Switzerland.

Bacigalupi, J. Augustus 2025. "Ontic Origins of Creativity: A (Meta)Physics of Aesthetics." In *Semiosis as Creation: Between Nature, Body, and Art*, 3–32. Universidad del Rosario.

Bacigalupi, J. Augustus 2026. "Understanding Irreducibility in Semiosis via the Image." *Sign Systems Studies* (in press).

Bacigalupi, J. Augustus; Alexander, Victoria 2021. "Creative Agency Via Higher-Dimensional Constraints." *Biosemiotics* 14(1): 87–93.

Bacigalupi, J. Augustus; Favareau, Donald 2023. "The Physiology of Coordination: Self-resolving Diverse Affinities via the Sparse Order in Relevant Noise." *The Journal of Physiology*, December, JP284418.

Deacon, Terrence; Srivastava, Alok; Bacigalupi, J. Augustus 2014. "The Transition from Constraint to Regulation at the Origin of Life." *Frontiers in Bioscience (Landmark Edition)* 19 (6): 945–57.

DISSERTATIONES SEMIOTICAE UNIVERSITATIS TARTUENSIS

1. **Михаил Ю. Лотман.** Структура и типология русского стиха. Тарту, 2000.
2. **Елена Григорьева.** Эмблема: структура и прагматика. Тарту, 2000.
3. **Valdur Mikita.** Kreatiivsuskäsitluste võrdlus semiootikas ja psühholoogias. Tartu, 2000.
4. **Ирина Аврамец.** Поэтика новеллы Достоевского. Тарту, 2001.
5. **Ян Левченко.** История и фикция в текстах В. Шкловского и Б. Эйхенбаума в 1920-е гг. Тарту, 2003.
6. **Anti Randviir.** Mapping the world: towards a sociosemiotic approach to culture. Tartu, 2004.
7. **Timo Maran.** Mimikri kui kommunikatsiooni-semiootiline fenomen. Tartu, 2005.
8. **Элеонора Рудаковская-Борисова.** Семиотика пищи в произведениях Андрея Платонова. Tartu, 2005.
9. **Andres Luure.** Duality and sextets: a new structure of categories. Tartu, 2006.
10. **Peeter Linnap.** Fotoloogia. Tartu, 2006.
11. **Daniele Monticelli.** Wholeness and its remainders: theoretical procedures of totalization and detotalization in semiotics, philosophy and politics. Tartu, 2008.
12. **Andreas Ventsel.** Towards semiotic theory of hegemony. Tartu, 2009.
13. **Elin Sütiste.** Tõlke mõiste dünaamikast tõlketeaduses ja eesti tõlkeloos. Tartu, 2009.
14. **Renata Sõukand.** Herbal landscape. Tartu, 2010.
15. **Kati Lindström.** Delineating Landscape Semiotics: Towards the Semiotic Study of Landscape Processes. Tartu, 2011.
16. **Morten Tønnessen.** Umwelt transition and Uexküllian phenomenology. An ecosemiotic analysis of Norwegian wolf management. Tartu, 2011. 231 p.
17. **Anu Sarv.** Õppejõu eneserefleksioon ja professionaalne identiteet. Tartu, 2013, 141 lk.
18. **Vadim Verenich.** Semiotic models of legel argumentation. Tartu, 2014, 249 lk.
19. **Maarja Ojamaa.** The transmedial aspect of cultural autocommunication. Tartu, 2015, 173 p.
20. **Tiit Remm.** Sociocultural Space: Spatial Modelling and the Sociocultural World. Tartu, 2015, 142 p.
21. **Riin Magnus.** The Semiotic Grounds of Animal Assistance: Sign Use of Guide Dogs and Their Visually Impaired Handlers. Tartu, 2015, 154 p.
22. **Davide Weible.** Exaptation: Towards a Semiotic Account of a Biological Phenomenon. Tartu, 2016, 144 p.

23. **Mari-Liis Madisson.** The Semiotic Construction of Identities in Hypermedia Environments: The Analysis of Online Communication of the Estonian Extreme Right. Tartu, 2016, 195 p.
24. **Claudio Julio Rodríguez Higuera.** The Place of Semantics in Biosemiotics: Conceptualization of a Minimal Model of Semiosic Capabilities. Tartu, 2016, 148 p.
25. **Kadri Tüür.** Semiotics of Nature Representations: on the Example of Nature Writing. Tartu, 2017, 257 p.
26. **Gleb Netchvolodov.** Pictorially simplified images as machine vision design tool: semiotics approach. Tartu, 2017, 143 p.
27. **Сильви Салупере.** О метаязыке Юрия Лотмана: проблемы, контекст, источники. Tartu, 2017, 210 c.
28. **Remo Gramigna.** Augustine and the study of signs and signification. Tartu, 2018, 237 p.
29. **Nelly Mäekivi.** The Zoological Garden as a Hybrid Environment – A (Zoo)semiotic Analysis. Tartu, 2018, 172 p.
30. **Silver Rattasepp.** The Human Mirror. A Critique of the Philosophical Discourse on Animals from the Position of Multispecies Semiotics. Tartu, 2018, 156 p.
31. **Ott Puumeister.** On Biopolitical Subjectivity: Michel Foucault’s perspective on biopolitics and its semiotic aspects. Tartu, 2018, 170 p.
32. **Lyudmyla Zaporozhtseva.** Structural Units of Mass Culture Mythology: A Cultural Semiotic Approach. Tartu, 2019, 193 p.
33. **Tatjana Menise.** Fairy Tales in Transmedia Communication: Fanfiction. Tartu, 2020, 142 p.
34. **Alexandra Milyakina.** Digitalization of Literary Education in the Context of Cultural Autocommunication. Tartu, 2020, 137 p.
35. **Tyler James Bennett.** Detotalization and retroactivity: black pyramid semiotics. Tartu, 2021, 238 p.
36. **Jason Mario Dydynski.** Semiotic Modeling of Cuteness in Cartoon Characters/Mascots. Tartu, 2021, 176 p.
37. **Tiina Hoffmann.** La traduction cinématographique en Estonie soviétique : contextes, pratiques et acteurs. Tartu, 2021, 489 p.
38. **Mirko Cerrone.** Interspecies Relationships: A zoosemiotic Analysis of Human-Ape Communication. Tartu, 2021, 160 p.
39. **Jonathan Grant Griffin.** A Semiotic of Motives: Kenneth Burke and Deely-Tartu Semiotics. Tartu, 2022, 244 p.
40. **Kyle Jonathan Davidson**. Semiotic Modelling of Identity and Communication in Virtual Reality, Augmented Reality, and Mixed Reality. Tartu, 2022, 221 p.
41. **Aleksandr Fadeev.** Lev Vygotsky’s approach in the Contemporary Semiotic Research of Learning, Meaning-Making and Inner Speech. Tartu, 2022, 146 p.
42. **Eugenio Israel Chávez Barreto.** The Semiotic Theory of Luis Jorge Prieto. Tartu, 2022, 236 p.

43. **Katarina Damčević.** Semiotics of Hate Speech and Contested Symbols: The “Za dom spremni” Ustaša Salute in Contemporary Croatia. Tartu, 2023, 166 p.
44. **Merit Rickberg.** Towards Complexity Thinking With Juri Lotman: Modelling Cultural Dynamics in Educational Systems. Tartu, 2023, 233 p.
45. **Tuuli Pern.** Affective-imaginative modelling in semiotic context: A Vichian perspective. Tartu, 2023, 147 p.
46. **Auli Viidalepp.** The Expected AI as a Sociocultural Construct and its Impact on the Discourse on Technology. Tartu, 2023, 149 p.
47. **Lauri Linask.** Autocommunication in the Semiotic Development of the Child. Tartu, 2024, 193 p.
48. **Oscar Salvador Miyamoto Gómez.** The Forms of Memory: Biosemiotic Modelling of Alloanimal Episodic Semiosis. Tartu, 2024, 175 p.
49. **Andrew Mark Creighton.** Wolves as Signs of McDonaldization in Northern Manitoba. Tartu, 2024, 164 p.
50. **Daria Arkhipova.** How Artificial Intelligence recommendation systems impact human decision-making. Tartu, 2024, 327 p.
51. **Martin Oja.** Semiotics of Multimodal Conflict: Modes, Modalities and Audio-Visual Incongruence in Feature Film. Tartu, 2024, 219 p.
52. **Muzayin Nazaruddin.** Semiotics of Natural Disasters: The Entanglements of Environmental and Cultural Transformations. Tartu, 2024, 208 p.
53. **Irmak Mertens.** How Layers of Meaning Affect Museum Translation: Semiotic-Translational Perspectives. Tartu, 2024, 261 p.
54. **Lona Päll.** Bridging the disconnections: an ecosemiotic approach to place-lore in environmental conflict communication. Tartu, 2025, 201 p.
55. **Raili Lass.** Näidendi interlingvistilise tõlke osakaal ja roll lavastuses kui intersemiootilises tõlkes ja polüsemiootilises struktuuris. Tartu, 2025, 119 lk.
56. **Krista Simson.** Visuaalkunsti väljendusvahendid semiootilise analüüsi kontekstis. Tartu, 2025, 176 lk.
57. **Alec Richard Kozicki.** The De-sign Process of Inhabiting Techno-Living Spaces. Tartu, 2026, 178 p.
58. **Michele Cerutti.** On Truth from a Semiotic Point of View. Tartu, 2026, 215 p.