The Engine of Engines – Toward a Computational Ecology

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Abstract

Our knowledge related to the entailments of functionalities of different biological processes as they enable sentience to arise in the human is still limited due to the biological complexity of the body. There are two interrelated research paradigms that can be developed to approach this problem– one paradigm seeks to study the body and articulate its entailments (intra-functionalities) at multiple scales over time; the second paradigm seeks to glean knowledge from this study of biological processes and create new forms of computation to enable us to transcend the limitations of current computational modes. The nature and scope of the question necessitates an interdisciplinary approach to research through the development of a multi-perspective approach to knowledge production. Here, key solutions can in part arise at the interstices between disciplines, and potentially enable us to define and 'chip away' at the problem set. Central is observing the body as a distributed network of computational processes that function at different physical scales as well as across time-dependent, process-oriented accretive frames. We can articulate the study of the body by calling it an electrochemical computer— a computer whose deep functionality is not yet fully entailed. Historically the nature of the problem has been to isolate a biological system and study its entailments to ascertain its functionality. Yet, the nature of sentience asks us as researchers to take a more holistic approach, despite the complexity at play. These two paradigms then become a long-term problem set that a network of high-end researchers can collaborate on, by bringing different areas of expertise to the table. The notion of developing a biomimetic/bio-relational *Engine of Engines— A Computational Ecology* (Stengers 2005) derives from observing computational systems at work in the body and approaching them through observation— through technological, mathematical and/or computational abstraction. Where the body has been described as functioning as a computational system that transcends the Turing limit (Siegelmann 1999)(Maclennan 2003)(Penrose 1989) new approaches to computation need to be undertaken to reflect this deep complexity.

The Engine of Engines – Toward a Computational Ecology

In the words of von Neumann from The General Theory of Automata: "[…] it is a fundamental requirement of the scientific viewpoint – the so-called principle of the psycho-physical parallelism – that it must be possible so to describe the extra-physical process of the subjective perception as if it were in reality in the physical world – i.e., to assign to its parts equivalent physical processes in the objective environment, in ordinary space." (von Neumann 1995)

Introduction

When we study the body we can consider it to function incorporating the architecture of different computational processes that are currently not fully understood, especially in terms of the interrelation of those processes over time functioning in concert with other biological functionalities. From this overarching perspective we can study the body as an ultra-complex time-dependent computational ecology. We ask, what are all of the salient computational processes on multiple scales that contribute to our sentience over the course of our lives that become operative within this biological network? It is imperative to develop new computational methodologies to approach this problem set. MacLennan, in his paper *Transcending Turing Computability* discusses "Hypercomputation" — "The Turing-machine model makes assumptions about information representation and processing that are badly matched to the realities of natural computation (information representation and processing in or inspired by natural systems)." (MacLennan, 2003). Research into the *The Engine of Engines* seeks to entertain such new methodologies by exploring the two paradigms in an interoperative manner — 1) seeking to define the entailment structures of the body at different scales, at operation over time and 2) to explore new forms and approaches to computation, informed by paradigm 1, forming a biomimetic and/or bio-relational *Engine of Engines*. Exploration of these new forms should fold back in an ongoing expanding manner and further inform both paradigms. Seaman's concept of an "Insight Engine," a system to house related data and enable such a complex undertaking (Seaman 2009), embodies a multi-perspective approach that intermingles databases and discourse processes from the sciences, the humanities and the arts—potentially enabling a Koestler-like space for bisociation (Koestler 1964). In discussions with researcher Olivier Perriquet, it has become clear that such a multi-perspective approach enables one to understand any object of study in a multivalent manner resulting in different discourses on the same object or experience (Perriquet & Seaman 2011). This approach enables new ideas to arise at the intersection/juxtaposition of disciplines.

Seaman and Rössler in *Neosentience / The Benevolence Engine* (Seaman & Rössler, 2011) have been exploring the potentials for a related AI/Robotic branch of research. Many references from there book inform the writing of this paper. Seaman and Rössler's paper entitled *Toward the creation of an intelligent situated computer and related robotic system: An intra-functional network of living analogies* (Seaman & Rössler, 2006) discusses the notion of articulating physical processes in the body and making analogical and/or digital abstractions of them in the service of this new AI/Robotic paradigm. *Endophysics and the Thoughtbody Environment: an Outline for a Neo-computational Paradigm* (Seaman, 2005) also frames some of the initial parameters of this discussion. Seeing the mind/brain/body/environment set of relations as being both analogue and digital, this research falls in relation to, yet differentiates itself from entirely discrete models of computation. (Zuse, 1969)(Wolfram, 2002)(Fredkin, 2005). One can see the value in the "discrete" approach and von Neumann pushed for this to get beyond problems of noise in early computation. Alternately, von Neumann discussed the mixed character of living organisms as being both digital and analogue, recognizing the potential of shifting the efficacy of neural processes via "humoral" media (von Neumann, 1995). Central to the research is seeing the body as an ultra-complex electrochemical computer that has mixed distributed analogue and digital computational qualities (Seaman & Rössler, 2011) that contribute to the arising of sentience.

This new research starts with the body as being conceived (bringing together different code potentials); growing up— nested in the environment over time, unfolding biological potentials via the code-based processes enabled through DNA; building up knowledge of environment via the senses and through coupled interaction with environment— the embodied/embedded paradigm (Clancey, 1992) (Froese, 2002), as well as through introspection; the acquisition of natural language; moving in space; having a deep multi-modal understanding of changing context; learning; being creative; and interacting with others as part of a larger intellectual, social and cultural ecology. Froese in his paper *On the role of AI in the ongoing paradigm shift within the cognitive sciences* discusses related embodied/embedded approaches under the rubric of "enactivism"…which "radicalizes the embodied-embedded approach by placing autonomous agency and lived subjectivity at the heart of cognitive science." (Froese, 2002) How do the low level systems enable the high level processes of being sentient to arise? Undertaking a multidisciplinary, multi-perspective approach to knowledge production is here essential. The central concept is to create and study analogous computational systems and interfacing methodologies to those at operation in body, and to explore bio-relational approaches to further illuminate aspects of human computation.

The Body and Computation

It was Descartes who first understood the body to be a special variety of machine. Rashevsky pointed to early ideas surrounding analogue two step neural processes of excitation and inhibition (Rashevsky, 1940); McCulloch and Pitts (Rashevsky's student), shortly after the publication of Rashevsky's seminal book, *Advances and Applications of Mathematical Biology*, began to articulate computational potentials based on their notion of the Neural Net (McCulloch and Pitts, 1943). Rashevsky's critique of the neural net was essential as well as his approach to articulating logical processes (Rashevsky, 1948). Von Foerster early on talked about cognition as computation (von Foerster, 1973). Turing discussed notions of "input" and "output" organs. (Turing, 1986) Elsewhere Seaman has discussed the notion that we learn and accretively gain our intelligence via experience in the world in part through a series of sense-based pattern flows (Seaman, 2005) Hebb's law (Hebb, 1949) (Wiles et.al., 2010) here is central. Yet, what different computational processes in the body contribute to the ability to register these patterns flows of sense perturbations? What computational processes enable the building of the biological systems in themselves? Von Neumann's notion of the self-replicating machine from the *Theory of Self-reproducing Automata* here comes to the fore. (von Neumann 1966) (Stevens [no date given])

Popp et al. in the book “Biophotons” discuss the release of low-level coherent light as a means to communicate between cells. They articulate the notion that very weak coherent light plays a central role in cellular communication, where photons set in motion the activation energy to promote biochemical reactions which take place in a cell.(Chang et.al., 1998) Thus, biophotons need to be folded into our new model for distributed computational processes as they fall in relation to other bodily processes as a means of biological communication. Entailment of the body as an ultra-complex system, seeks to map and understand the role of all of the contributory processes to sentience production as a long-term goal. Another “fine grained” approach includes the research of Penrose and Hameroff (Penrose & Hameroff, 1998) and in particular Hameroff’s discussion of microtubules and quantum level processes in the brain. (Hameroff, 1987) The central hypothesis in our research is that there is a machine-like biophysics behind all processes in the body relevant to sentience production. This can be seen as a different attitude to that of Rosen as discussed in *Life Itself* (Rosen, 1991), who did not want to see the body as a machine. One goal of the research seeks to more fully entail distributed aspects of the body’s functionality. Seaman sees the body as a *not yet fully entailed biomachine* of ultra-complexity — an electrochemical computer with related sensing/volition mechanisms (Seaman and Rössler, 2011). It is interesting to also note that Rosen, like Pitts studied under Rashevsky and is perhaps best known for his work related to category theory, (Rosen, 1958) another approach relevant to our research.

Rössler’s approach, *Endophysics* is central to the study of these processes from the perspective of a “physics from within” (Rössler, 1998). His concept is to use simulation strategies such that one can become a superobserver of the system, although his study focuses on a more “point” like interface (Seaman in discussion with Rössler). The *Engine of Engines* research seeks to enable embodied study of differing biocomputational modalities through the generation of analogous computational processes, as well as via high-level computational modeling operating in concert with advanced scanning methodologies, functioning in the service of entailment. Cognitive science works with “a complex 3-way analogy among the mind, the brain, and computers. Mind, brain, and computation can each be used to suggest new ideas about the others.”(Thagard, 2011) Expanding on this notion points to the potential of exploring biomimetic and bio-relational systems to better come to understand the distributed computational inter/intra functionalities that are at operation in the body and how they become relevant to brain/mind functionality. Thom’s early approach to emergence via catastrophe theory and topological theory (Thom, 1975) also plays into our discussion, where thought can be seen to be an emergent property arising out of this mixed computational nature. Certainly the writings of Conrad (Conrad, 1992) Zauner (Zauner, 1998) and Adleman (Adleman, 1994), related to molecular and DNA computing, as well as the writings of Patee (Patee, 1969) related to molecular messaging, become important pre-cursors to our research, as does the seminal discussion of analogue processes by Smale— exploring functionality through the rubric of dynamical systems (Smale, 1963; 1967) e.g. if we think of neural transmitters, manufactured in different parts of the body, and their contribution to thought processes, we can discuss a protein shape code and how this code, when in operation, shifts the efficacy of the firing of the synapse.

Divide and Concur— breaking down problem sets and having differing kinds of computers, both analogue and digital, work on them in cooperation

One seeks to define a network of processes mathematically that can reflect specific biological qualities as they are mapped to different mathematical problem sets. In terms of non-conventional computers one could point to different focused qualities relevant to each computer as they are applied to different kinds of problem solving. This is very different in approach to the ideas surrounding the “universal” Turing machine. Siegemann’s has discussed the potential of analogue computation. In her book *Neural Networks and Analog Computation: Beyond the Turing Limit* she discusses the notion of a Church-Turing-like thesis which might be applied to analogue computation, featuring the neural network instead of the Turing machine. In particular she feels that on a mathematical level the exploration of analogue neural networks “enriches” the theory of computation. She feels that the potential for the development of supra-Turing computational theories can arise from the scope of this analogue perspective, (Siegelmann, 1998) and that such an approach “explicates the computational complexity associated with biological networks, adaptive engineering tools, and related models from the fields of control theory and nonlinear dynamics.” (Siegelmann, 1998) She states that “when analog networks assume real weights, their power encompasses and transcends that of digital computers… our model captures nature’s manifest ‘computation’ of the future physical world from the present, in which constants that are not known to us, or cannot even [currently emphasis Seaman] be measured, do affect the evolution of the system." (Siegelmann, 1998) Given this discussion it follows that the focused exploration of analogue systems may help contribute to a more full understanding of how the body functions in terms of the emergent nature of biological computations that contribute to sentience production. It follows that the specific interfacing of differing computational systems, based on biomimetic and bio-relational approaches, may provide new knowledge about sentience production.

Drawing on these distributed processes in the body in terms of their contribution to Natural Computing

Entailment processes must be articulated across different scales found at operation in the body. It is interesting to note that as we fully articulate entailment (biofunctionality), we shift a process from the designation of being "emergent" to that of being entailed (understood)[discussion with Perriquet]. As a research strategy we can seek to map a series of mixed analogue and digital processes that contribute to the arising of sentience over time as well as to define their intrafunctionality. This in part relates to the notion of *Natural Computing* articulated by Rozenberg: "Natural Computing is the field of research that investigates both human-designed computing inspired by nature and computing that takes place in nature, in terms of information processing…(including, emphasis Seaman) neural computation inspired by the functioning of the brain. (Rozenberg, 2012: forthcoming) A number of new definitions for computation in this area seem to be under construction, as they pertain to information change over time. (Fredkin, 2005) (Wolfram, 2002) There is certainly a debate surrounding the discrete vs. continuum-based "understanding" of the world. I see computational processes in the body as being of a mixed analogue/digital nature as discussed by von Neumann above (von Neumann, 1995), functioning across a continuum. I can also understand that this continuum can be successfully parsed at different scales to contribute to differing discrete computational 'articulations' of biological mechanisms. There is still debate concerning the actual lowest level of this discrete parsing as it pertains to the physics underlying biological functionality. Negotiating/debating this potential definition of a new constant also folds into this research. Alternately, in terms of entailment mapping it also makes sense to have different scale discrete parsings that are 'set' [articulated by researchers] which are highly focused to particular regions in the body, and are observed/compared in a time-based manner as they relate to the unfolding of particular biological processes functioning at different scales.

Dodig-Crnkovic has been working to define her own particular approach to computation in relation to information. In her paper entitled *Info-Computationalism and Morphological Computing of Informational Structure* **(**in this volume**)** she points to the fact "that knowledge is generated bi-directionally, through the interaction between computer science and the natural sciences." She aptly points out that "While the natural sciences are rapidly absorbing ideas, tools and methodologies of information processing, computer science is broadening the notion of computation, recognizing information processing found in nature as (natural) computation. (Rozenberg & Kari, 2008); (Stepney et al., 2006)"…"This new concept of computation allows for nondeterministic complex computational systems with self-* properties. Here self-* stands for self-organization, self-configuration, self-optimization, self-healing, self-protection, self-explanation, and self(context)-awareness. Dodig-Crnkovic in (Dodig-Crnkovic & Müller 2009) argues that "natural computation (understood as processes acting on informational structures) provides a basis within info-computational framework for a unified understanding of phenomena of embodied cognition, intelligence and knowledge generation." (Dodig-Crnkovic, 2011) How can we define and articulate a relationality between "processes acting on informational structures" (Dodig-Crnkovic, 2011) and other historical approaches to computation, both analogue and digital? Here we can look at "all" process-change in nature as discrete computation (for the sake of ease of mathematical discernment), as in the thought of Friedkin exemplified in his paper on *A Computing Architecture For Physics* (Fredkin, 2005), yet, I am suggesting that the body achieves focused biological functionality through specific "varieties" of computational processes as they function in conjunction with other biological process distributed across the body, mixing analogue and digital methodologies. These processes are "interfaced" internally or run at a distance (or function on different scales of space and/or time) inside of the body, as well as become interfaced with focused computational processes that run both internal and external to the body, that can be intentionally explored in the service of knowledge production, social interaction, as well as the focused study of biological functionality.

The body functions as an autopoietic unity (Maturana & Varella, 1980), summing these different computational processes. A debate continues concerning the seeing of the body as a hierarchy and/or dynamic heterarchy under particular extreme biological conditions. (McCulloch, 1945)(Pattee 1973)(Seaman and Rössler, 2011) This will be further discussed in a subsequent paper. We must seek to develop new models to reflect the true complexity of our biological systems as they function over time in relation to different environments, as well as in relation to deep structural changes (sometimes catastrophic [pun intended]) (Thom, 1975), that can affect the autopoietic unity. This also includes the implanting of devices that transcend traditional notions of this biological unity e.g. cochlear implants et al.

The focused study of the relationality between different forms of computation is essential to the *Engine of Engines'* two interrelated research paradigms. Here we see an integration of biological processes as they enable distributed computational processes discussed as "natural computing", which can be seen to nest other "concepts" or "varieties" of computation, both analogue and digital. We must also remember any analogue process can be modeled (to a particular degree of accuracy) via a discrete computational system, and also become part of our ecology.

Alternately, the notion that the body functions as a self-observer (as mentioned by Dodig-Crnkovic) becomes important— an observer that can differentiate and frame different notions of computation, and be introspective about this framing. Thus the human computer functions as one of the "computers" in the network ecology. When we draw a distinction between well articulated differences in the (re)definition of computation, we can include notions of "Morphological" computation (Dodig-Crnkovic, 2011) as a *different level of computational functionality* that enfolds and nests other computational functionalities in the body— a pattern of information patterns changing over time. Dodig-Crnkovic discusses a number of issues surrounding information and computation in her paper entitled *Dynamics of Information as Natural Computation*.(Dodig-Crnkovic, 2011b) Here we must seek to negotiate a stable definition of 'information' especially as it subtly migrates across different research domains from physics, to biology, to mathematics, to computation. The notion of sharing careful definitions across interdisciplinary fields is essential. Also the difference between the functionality of physical/analogue codes [e.g. protein shape codes] and how they become operative, versus how digital code functions as a physical system in the light of "Natural Computing", is by no means trivial. One could also research how different varieties of analogue/digital codes could be simultaneously running at different scales and across differing time frames within the body, especially as it falls in relation to the larger environment. (Dodig-Crnkovic, 2011b)

Computational processes at operation in the body

Seeing these biologically networked computational processes as relevant to human biocomputation, one thus seeks to extend the current model of the Neural Net to enfold other relevant distributed biocomputational and/or bio-relational processes. We can discuss the body as having a number of processes on differing scales contributing to thought and action where mind and body are seen as co-arising via physical processes as articulated by von Neumann above. (von Neumann, 1955) Yet, at this moment it is difficult to parse exactly what computational processes in the body are at operation, and in particular how they contribute to neural computation. Here we can take stock of some of the processes that might be considered to contribute to its mixed "computational" nature. These might include: neural flows (mixing analogue and digital processes) including: a. neural transmitters (protein shape communications); b) circulating frequencies – that also function to regulate bodily processes and change synaptic efficacy (Kumar and Mehta, 2011); synapse flows (changing efficacy in part in relation to a. and b. above); genetic processes contributing to growth and the formation of the systems themselves (DNA); nanoscale processes regulating molecular change and biological communication; flow processes (acting as analogue computation) or vehicles enabling distributed biological processes; quantum processes in nanotubules and other locations; biophotonic messaging alerting adjacent cells of their death through the release of low level coherent light; and other biological functionalities still under research (volume transmission) (Agnati et al. 1995). Additionally the notion of multi-modal sensing and embodied experience becomes an important operational mechanism both in the human and in artificial polysensing environments that might enable a machine to build up knowledge about environment. (Seaman & Verbauwhede [date not set]) (Seaman &

Verbauwhede [date not set]b). From this list of human/biological computational processes the research field has spawned many biomimetic and bio-relational computational approaches. This includes analogue and digital manifestations e.g. neuromorphic chips (Folowosele, 2010). Such computers include: protein computers (Biomatic.org Wiki); DNA computers (Landwber, 1999); quantum computers (Hagar 2011)(Markoff 2010); embodied sensing systems informing computation/learning systems – polysensing environments (Seaman & Verbauwhede, [date not set]); analogue flow computers (Pask, 1982); analogue physical computers, wind tunnel computers, blood flow computers (Parrish et al., 1959); electrochemical computers (Kahn, 1992); (Seaman, 2009); nano computers and related nano sensors (Blomberg, 2011); (Brumfield, 2011); and neural nets of differing kinds (Whittle, 2010).

The Engine of Engines as Computational Ecology

By networking these many different kinds of computers via the development of new forms of interface, we seek to draw upon the quantitative characteristic differences that make each unique. Many of these computers push "Beyond the Turing Limit." (Siegelmann 1998) Perhaps each with a special attribute that enables it to perform "particular" kinds of computational processes, or that exploit a particular quality inherent to their physics and/or to their analogical substrates. Yet in almost every case these computers are currently interacted with via von Neumann machines (or human computers, that re-encode information gleaned from these machines, translating their output into a form that is compatible with von Neumann machines). The challenge of future research is in the development of new interfaces that bridge from the analogue to the digital; new forms of cross functional operating systems that can enable information exchange with the greatest acceptable accuracy; and new forms of communication across scales.

The body achieves a unity bridging multiple scales of computational processes as they become operative in conjunction with other networked biological operations. Certainly Simeonov has charted a new science of mathematical relations separately covering many of these areas of research in his paper entitled: *Integral Biomathics – A Post Newtonian View Into the Logos of Bios (On The New Meaning, Relations and Principles of Life in Science)* (Simeonov, 2010). One could also work toward emulating these intrafunctional systems in von Neumann machines; yet, given the impetus of exploring mixed analogue/digital systems where particular substrates enable new varieties of communication and functionality, it seems important to explore the potentials of mixed analogue/digital computation. Here we encounter two related questions: 1)Biologically, how are such processes in the body currently interfaced so that they become inter/intrafunctional at different levels and scales? And, 2) in the development of new modalities of computation can we articulate new forms of interface that enable a transfer of relevant data, without a "significant" loss of the precision and/or specific functional attributes of the individual mechanisms involved, informed by our study of biological entailment? By linking disperate computers using a von Neumann machine as a "pivoting" hub, and/or by developing specific biomimetic and/or bio-relational forms of functional inter-system interfaces, we can potentially point at and better come to understand complex forms of biological functionality. We can, in some cases divide up problems to be tackled on the computational machines that might best achieve particular focused "mathematical" goals. Not only can we interface with the von Neumann machine, the long-term goal is to facilitate unique interface development between the differing systems. To articulate such an *Engine of Engines* one will need to enable a dramatic "Convergence" between disparate researchers. (Sharp, et.al., 2011) (Angelica, 2011)

In the context of the body functioning as a unity, how can the interfacing of all of these biocomputational processes best be reflected upon? Our long-term research goal focuses on formulating a clear set of methodologies to come to understand how disparate informational structures and biological processes enable the propagation of unique computational qualities that function in the service of sentience production. Through this research, biomimetic and bio-relational computation is spawned in an ongoing manner to extend the understanding of the body's entailments, while it simultaneously enables us to better reflect on the body's functionality as a system of systems — *an Engine of Engines*.

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