Open Worlds: Bergson And Computational Ontology

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These are exciting times for worldmakers. Both fully immersive virtual realities, and mixed realities that blend with or augment the real, are proliferating. This path to worldmaking is suddenly widely backed and affordable, with eager anticipation far beyond the recently catalyzing space of videogame virtual reality. After decades-long gestation this medium bears the hallmarks of birth. However its unique messages remain to be deciphered, its conventions and genres to congeal, and the inevitable McLuhanian rear-view awkwardly projects the well-worn tropes of videogames, and struggles with the loss of the frame, the cut, and the directed passivity of cinema. Rather than extrapolating forward from the familiar in this way, as worldmakers we venture to a more speculative goal: a creative ontology consummating the vast creative poiesis that the generative grain of computation makes possible, making worlds that approach the open-endedness of the natural reality we inhabit, including its endless capacity to change and reveal surprisingly new and fascinating phenomena. To illuminate a way forward, this chapter revives the nature-inspired creative philosophy of Henri Bergson, and addresses the challenges and potentials of re-projecting it into interactive computational media.

Generative ontologies

The virtual worlds of many videogames already create the desirable illusion of a vast space rich with possibilities, however all too quickly we discover boundaries are closer than they appeared, actions and responses are few, and discoveries are pre-scripted. The more that worlds surround our senses, the more these limitations work counter to the transportation of presence, the sense of *being there*. When we cannot reasonably pre-author every detail of a world we increasingly turn to algorithms to provide the consistencies and features of a world, and the more a world derives its meaningful values from the generative capacity of algorithms, the more actions and responses can have unforeseen yet persistent consequences leading to emergent experience.[1] To this extent worldmaking becomes process-oriented ontology expressed in the creation of software.[2] Artists exploring the capacity of generative algorithms to present emergent modes of being-in-time are frequently attracted to the apparent open-endedness of complex systems such as agent-based flocking

[1] Where artists use the terms *generative* and *algorithmic*, game developers tend to use *procedural* and *simulation*. We note that headline-grabbing company Improbable have dubbed "strong simulation" as the way forward for a game industry hitting the scalability limits of pre-scripted content–and it is no accident that Improbable's working sample is a simulated ecosystem (http://improbable.io, accessed May 2015).

[2] In this chapter we use the term *ontology* with its millennia-old meaning–the philosophical reflection upon what exists–rather than its more recent usage in knowledge engineering. In the latter case it defines the categories and hierarchical structure of information for a given system, such as the schema of a database, which, as we shall show, reflects an implicit Platonism incompatible with the creative organizations we seek.

models or reaction-diffusion automata. Such models are easy to encode in software and show a ready capacity to generate new patterns and emergent behaviours. However, there is a risk in simply importing models that were largely invented for the purposes of more accurately predicting or representing isolated fragments of the physical world-*as-we-know-it*: despite the bottom-up, emergent character of the algorithms themselves, they originate from pre-written, top-down goals, and accordingly may confine us to worlds of more limited creative and reflective potential:

> The underlying systems themselves are crystalline and impervious, and this character underpins our experience of these works... Entities are identical, or belong to a set of pre-defined types, and their properties and behaviour are static over time. The systems have a particular relation to time: they tend to be a series of instantaneous slices… history is all but absent… The environment here is (literally) a blank canvas, inert, empty space… [the agent is] a clone in a crowd, unchanging, with no traction on the space it inhabits, existing in an ongoing, perpetual present.[3]

[3] Whitelaw, M. *System stories and model worlds: A critical approach to generative art*. README, vol. 100, pp. 135–154, 2005.

The impoverished nature of the models identified by Whitelaw above echo remarkably criticisms made by the philosopher Henri Bergson a century earlier. Bergson denounced models of living organisms in which "we represent statically ready-made material particles juxtaposed to one another, and also statically, an external cause which plasters upon them a skillfully contrived organization". And similarly that "by combining together the most simple results of evolution, you may imitate well or ill the most complex effects; but of neither the simple nor the complex will you have retraced the genesis, and the addition of evolved to evolved will bear no resemblance whatsoever to the movement of evolution."[4] There is even a passage of *L'Evolution Créatrice* in which Bergson anticipates kinds of procedural animation used widely today–suggesting throwing onto the screen a large number of jointed figures animated according to models of marching, varying from individual to individual. However Bergson asks, even though "we should need to spend on this game an enormous amount of work… how could it reproduce the suppleness and variety of life?"[5]

[4] Bergson, H. *L'Evolution Créatrice*. 1907. (Henri Bergson, Creative Evolution, tr. Arthur Mitchell, Henry Holt and Company, 1911)

[5] Bergson, 1907.

In response, in this chapter we reappraise Bergson's ideas through a computational medium, to ask whether the static and contrived qualities

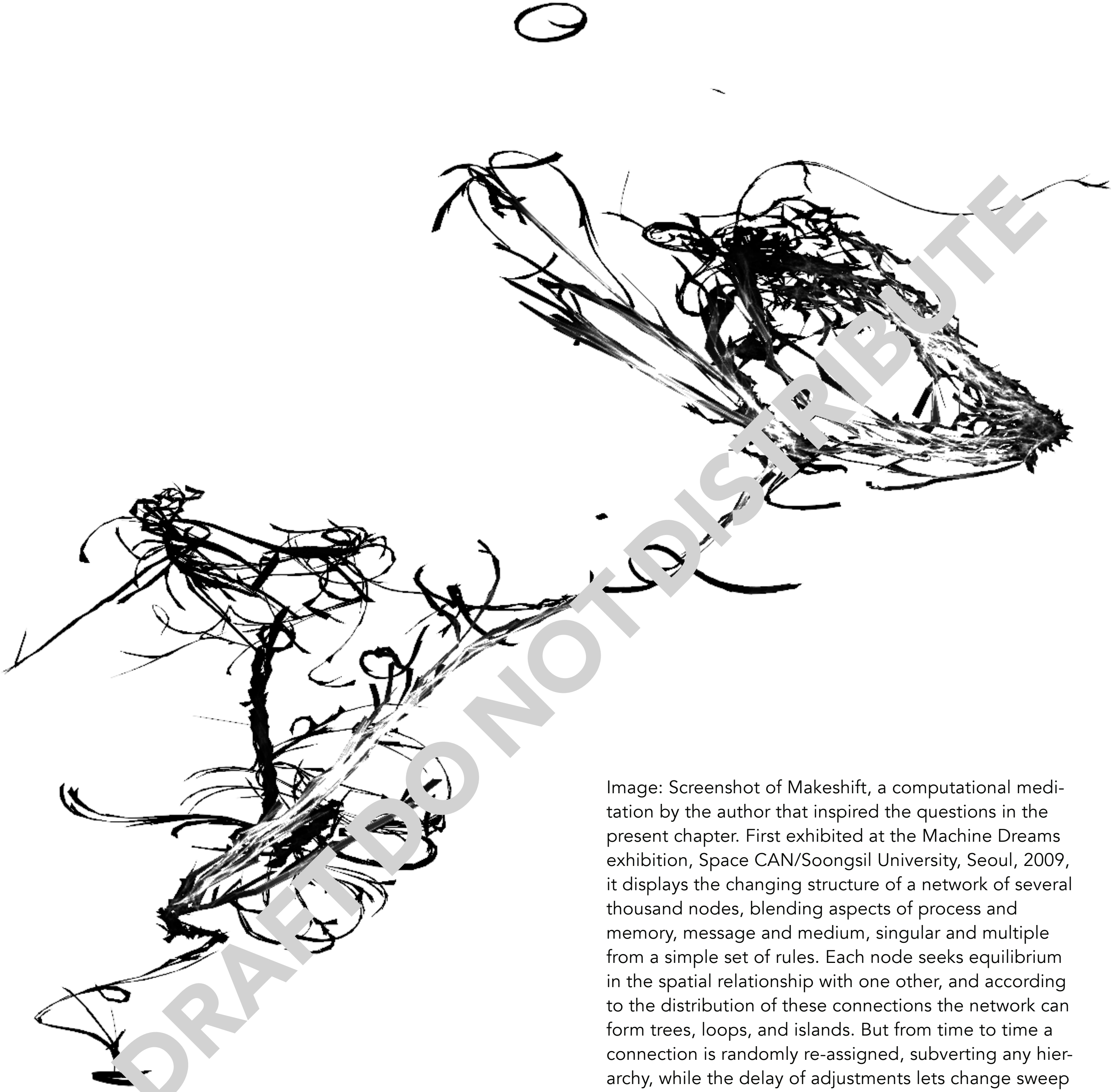

Image: Screenshot of Makeshift, a computational meditation by the author that inspired the questions in the present chapter. First exhibited at the Machine Dreams exhibition, Space CAN/Soongsil University, Seoul, 2009, it displays the changing structure of a network of several thousand nodes, blending aspects of process and memory, message and medium, singular and multiple from a simple set of rules. Each node seeks equilibrium in the spatial relationship with one other, and according to the distribution of these connections the network can form trees, loops, and islands. But from time to time a connection is randomly re-assigned, subverting any hierarchy, while the delay of adjustments lets change sweep through long tails, and local rotations spread to the whole. https://vimeo.com/161162336.

Image: Flying pelican captured as a chronophotograph by scientist Étienne-Jules Marey around 1882. Bergson and Marey were colleagues at the College of France in 1902. Image reproduced with permission of Wikimedia Commons.

identified in these quotations are endemic to the strange ontologies of computational worldmaking per se, or whether is it simply that *worldmaking just isn't yet generative enough.* We hope that illuminating the possibilities and conditions of open-ended ontology in software may suggest how worldmakers can go about making worlds more inherently creative.

The habit of static thinking

Henri Bergson (1859-1941) is today curiously neglected. Well educated in mathematics, physics, and evolutionary and developmental biology, he became one of the mostly widely read and highly respected philosophers of his day.[6] By 1913, crowds gathering to catch his lecture, *delivered in French*, caused one of New York's first traffic jams; and in 1928 he received a Nobel Prize for Literature. Today he is best known through his influence on continental philosophers, particularly Gilles Deleuze, but his work also directly inspired many of the past century's great scientists, notably including Emil Post, who anticipated both Gödel and Turing's respective discoveries of formal incompleteness and undecidability; Norbert Wiener, who founded and named the field of cybernetics[7]; Walter Elsasser, a quantum physicist and early proponent of complexity in theoretical biology; and Ilya Prigogine, who won a Nobel prize for his work on the emergent, dissipative structures of irreversible, far-from-equilibrium systems:

> Since my adolescence, I have read many philosophical texts. I still remember the spell *L'Évolution Créatrice* cast on me. More specifically, I felt that some essential message was embedded, still to be made explicit, in Bergson's remark: 'The more deeply we study the nature of time, the better we understand that [it] means invention, creation of forms, continuous elaboration of the absolutely new.[8]

[6] Jacques Monod writes: "In my youth no one stood a chance of passing his baccalaureate examination unless he had read [Bergson's] *L'Évolution Créatrice.*" Monod, Jacques. *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology, trans. Austryn Wainhouse.* New York: Alfred A. Knopf (1971).

[7] Wiener, N. *Cybernetics or Control and Communication in the Animal and the Machine*, (Hermann & Cie Editeurs, Paris, The Technology Press, Cambridge, Mass., John Wiley & Sons Inc., New York, 1948).

[8] Prigogine, Ilya. (1977). *Autobiography*, Nobel Prize Organization.

Described as a "soft Copernican revolution" by William James, the challenging subtlety of Bergson's ideas unfortunately led to numerous misrepresentations and misunderstandings. Bergson's writing opposed prevalent scientific outlooks of his time, including the exclusivity of deterministic reductionism, the sufficiency of rational deduction, and the notion of time as fully reversible. Worse still, his positions stem from a key insight that works directly against the natural habits of the mind!

Like many philosophers, Bergson's critique begins from an under-appreciated limitation in our knowledge of the world; in his case *the static habit of the intellect.* Specifically: it is our natural habit to abstract discrete static snapshots of continuous flowing reality through the selective actions of perception. We "arrest time" to frame and dissect the world into distinguishable and manipulable terms, as the continuum of reality is otherwise too complex to negotiate: "Of the discontinuous alone does the intellect form a clear idea."[9] This habit is an evolutionary adaptation: a practical and effective method for satisfying our needs and controlling unruly environments.[10] No less than an amoeba, we perceive the world in problem-oriented terms, organized toward completion of actions that serve our interests. Our crucial error, says Bergson, is that once we postulate on the nature of the real, we mistake this selective bias as a condition for truth. By requiring that nature fit our habitually static scheme and excluding what cannot be thus assimilated, we end up with static ontologies that elide the creativity of time. These ontologies find themselves mired in paradoxes and problems of movement (from possibility to actuality, from absence to presence, etc.) that Bergson argues were badly posed to begin with.

[9] Bergson, 1907.

[10] We should not therefore be surprised that the intellectual conception of computing technology also began with the task of *calculating a result*, such as decoding an encrypted military message, or determining whether a given program will terminate.

Bergson's claim is borne out by the remarkable ascension and refinement of the intellectual habit over the centuries of Western philosophy. Russell and Whitehead's *Principia Mathematica*, published between 1910 and 1913, was intended to be an ultimate completion of purely symbolic and static axiomatics from which all mathematical truths can in principle be proven. Yet by 1931 Kurt Gödel had comprehensively demonstrated the incompleteness of this masterwork–and any other such attempt–by proving that there are true statements in any formal system whose truth cannot be derived from within the system." Gödel in the end declared that neither the synthetic nor the intuitive could be banished from either mathematics or logic, ratifying Bergson's claim that the limitations of intellectual processes are 'immanent to the method' of the intellect itself, and are incapable of being objectified."[11] Importantly for us, the limits claimed by Bergson appear regardless whether the method is carried out by natural or artificial means: Russell and Whitehead's system, and Gödel's proof, are both mechanizable. Moreover, Turing similarly showed, by means of a formal model of a mechanical solver proceeding in discrete

[11] Adamson, Gregory Dale. *Science and philosophy: two sides of the absolute.* Pli: The Warwick Journal of Philosophy 9 (2000): 53-86.

steps (a model that has come to be known as the *Turing Machine* and helped found computer science), that there are well-defined problems for which no computable solution is possible. The classic example is the *halting problem*: that no algorithm can universally determine whether any program will terminate or run forever. In fact these limits of incompleteness and uncomputability had been earlier discovered by Emil Post, who thus concluded that "mathematical thinking is, and must remain, essentially creative."[12] By interpreting these limits as traces of continuity in the process of thought, he attempted to found a creative logic more "in line with Bergson's *L'Évolution Créatrice* than Russell's *Principia Mathematica*."[13] Post's logic involves following algorithmic tasks, as with Turing Machines, but crucially it is given from the point of view of a creative worker that is *situated in time*. Through a method of reflection, this worker freezes the creativity of time into spatialized properties, symbols and relations, resulting in the *creation of algorithms*, in a mostly unconscious process carried out on a thoroughly Bergsonian plane.

The habit of static thinking remains deeply infused in our industrial and cultural inheritance. Russell and Whitehead's work continues to thrive in computer science via the Platonic essentialism of class-based inheritance, the formal foundations of type theory, the deductions of model-driven engineering, and so forth.[14] In many problem-oriented domains this is entirely appropriate, but toward open-ended worldmaking we must guard against its comfort and find ways to reconsider established practice. But can we really create worlds of autonomous creativity with a techné so deeply infused with and theoretically founded upon characteristics of static, mechanistic intellect?

To overcome the paradoxes that static ontologies lead to, Bergson demands a conception of reality as a whole that is continuous and creative, predicated not on a static notion of being, but rather on an enduring notion of becoming, which he calls *durée*.[15] As a *complement* to intellectual analyses composed of finite numbers of static snapshots of being, Bergson advocated a method of placing oneself inside the becoming of a subject, within its *tendencies*, from where it is possible to trace innumerable perspectives. This is subjective in no pejorative sense, since "the tendency *is* the subject. A being is not the subject, but the

[12] Post, E. *Recursively enumerable sets of positive integers and their decision problems.* Bulletin of the American Mathematical Society, 50:284–316, 1944.

[13] Post, E. Absolutely Unsolvable Problems and Relatively Undecidable Propositions - Account of an Application," in Davis ed. The Undecidable: Basic Papers on Undecidable Propositions, Unsolvable Problems and Computable Functions. Raven Press, Hewlett, New York, 1965. pp338–433.

[14] The reference to Plato is often explicit in the description of the relationship between objects and classes (akin to ideal forms) in object-oriented programming (OOP) languages such as Java and C++. In these dominant languages capabilities and behaviours of objects are only received "by inheritance" from the class presiding over them; and classes may only be defined prior to program execution. However this timeless separation of classes was not an original component OOP (Kay, Alan C. *The early history of Smalltalk.* History of programming languages II. ACM, 1996), and earlier languages in the lineage used dynamic *delegation* rather than static *inheritance*; relationships made and unmade as a program runs. By an odd cultural inversion these languages are not now widely regarded as primarily object-oriented.

expression of the tendency, and furthermore ... [only] in so far as this is contrasted with another tendency."[16] Bergson illustrates this by analogy to an arrow in flight: from within the process of motion itself, one can easily imagine stopping the arrow at any point, but tracing a series of immobile points does not recreate motion, since "there is more in the transition than the series of states, that is to say, the possible cuts."[17] Similarly, there is more in a real subject than in the abstractions we make of it; no matter how many views we take we never recover its entirety.

Bergson also famously referred to the analytic intellectual habit as "cinematographical", comparing the frames exposed by a film camera to the snapshots of knowledge we create by placing ourselves outside the flow of time.[18] Captured frames represent for Bergson exactly the opposite of reality: they make all moments equal, to the exclusion of the singular qualitative forces that created them. It seems easy to extend this criticism to the lowest levels of computing: programs are translated into a series of binary codes (an extreme case of making all moments equal) that execute discrete changes in state as they pass like the frames of a film through the CPU. How could an aggregate of stepwise states create real movement? To begin addressing this challenge, we will utilize Bergson's accounts of the tendencies of matter and of life.

Two tendencies

Bergson dedicates much of *L'Évolution* Créatrice to the creative tendency of *durée* as manifest in the specific example of biological life, characterized as a tendency to spontaneously increase in complexity and heterogeneity, which he named the *élan vital*. Sadly many readers mistook this to mean that Bergson counted among the vitalist thinkers, who hold that life differs from non-life because it carries some mysterious, non-physical essence, a progressionist urge directing life toward higher goals. In fact Bergson was as deeply critical of the transcendental character of vitalism as he was of the reductive dogmatism in mechanist thought, and rejected both as inadequate. In subsequent decades, as biology turned increasingly to chemistry and physics for its foundations, vitalism rapidly became obsolete; and through this misconception of the

[15] This word is usually translated as *duration*, however we will retain the French *durée* in order to avoid ambiguity with the common sense of the term as a *period*. What Bergson intends is a more profound yet subtle notion, which in Deleuze's analysis resolves to pure difference itself (Deleuze, G. *Bergson's Conception of Difference*. In The New Bergson, ed. Mullarkey, J. Manchester University Press, 1999).

[16] Deleuze, 1999.

[17] Bergson, 1907. We find it curiously resonant with Norman McLaren's renowned statement that "Animation is not the art of drawings-that-move, but rather the art of movements-that-are-drawn. What happens between each frame is more important than what happens on each frame." Norman McLaren, circa 1955. In Georges Sifianos, "The Definition of Animation: A Letter from Normal McLaren", Animation Journal 3, 2 (Spring 1995): 62-66.

[18] Note that Bergson's "cinematographical" analogy is not criticizing the art of cinema, rather the assumption that discrete snapshots are sufficient to capture the vitality of the world. We return to a thoroughly Bergsonian account of cinema later in the chapter.

élan vital Bergson became incorrectly dismissed as irrelevant to modern thought. However, we note that Nobel prizewinner Jacques Monod, in his manifesto of materialist biology *Chance and Necessity*, also appreciated the important difference between Bergson's thought and vitalism–in that Bergson rejected final causes (ultimate purposes) as consistently as efficient causes (predeterminations). It was only a "postulate of objectivity" that forced Monod to exclude Bergson, to which we need not adhere.[19] Rather than fighting misconstrued terminology, we will focus on the way Bergson distinguished the tendencies of life from those of matter.

[19] Monod, 1971.

The general tendency inherent to matter is to "de-tensify"[20] into extended spaces of simpler homogeneities, whereas life shows an inverse tendency to interrupt this tendency by "infolding" it, thus differentiating into new structures and behaviours. In light of the subsequent century of research there is nothing mystical in these statements. The second law of thermodynamics teaches us that matter is fundamentally entropic, tending toward its ultimately most probable state of statistical homogeneity. In this state no useful work can be done, since no significant energetic differences remain. Accordingly, living systems must actively perform processes to maintain negative entropy, keeping themselves far from equilibrium states, as was famously recognized by Erwin Schrödinger.[21] Consider Bergson:

[20] The term used by Bergson is *détente*, which in some translations is given as *relaxation*. As with *duration* for *durée*, we avoid this usage in an attempt to reduce ambiguity with the conventional meaning of the term.

[21] Schrödinger, Erwin. *What Is Life? The Physical Aspect of the Living Cell and Mind.* Dublin, 1943.

> Life is riveted to an organism that subjects it to the general laws of inert matter. But everything happens as if it were doing its utmost to set itself free from those laws… [Life] has not the power to reverse the direction of physical changes, such as the principle of Carnot determines it... Incapable of stopping the course of material changes downwards, it succeeds in retarding it... All our analyses show us, in life, an effort to re-mount the incline that matter descends. In that, they reveal to us the possibility, the necessity even of a process the inverse of materiality, *creative of matter by its interruption alone.*[22]

[22] Bergson, 1907 (emphasis added).

Because of matter's homogeneity, we can often approximate and predict physical phenomena incorporating millions of dynamic elements in terms of a small number of final attractor states: the equilibria that minimize free energy. However in conditions maintained far from equilibrium, where matter's tendencies are interrupted, complex new structures and organizations can arise from local interactions, preventing such convenient approximations.[23] The apparent *creativity* of systems maintained far from equilibrium was recognized and popularized by Prigogine, bringing scientific rigour to research in *self-organization*.[24] In the language of complex dynamics, we live on the long transients we construct to keep us far from the simple attractors for as long as we can.[25] Which is to say, a biological organization is a process that is forever incomplete, preserving its own problem from reductive simplification into an ultimate (dis)solution.

[23] A simple example demonstrates the ontological necessity of creative organization: without it, the material contents of an animal have the complexity and behavioural tendencies of soup. It is immeasurably easier to move from animal to soup than from soup to animal.

[24] Nicolis, Gregoire, and Ilya Prigogine. *Self-organization in nonequilibrium systems*. Wiley, New York, 1977.

[25] To clarify the misconception of the *élan vital*, we can identify it as "immaterial" only in the sense that it is a quality of organization that opposes (delays) matter's tendency to simplify.

Crucially, not only does this hint at what *kinds* of processes we may need to look for, it also suggests that life-like creativity may inhabit computation no less than life inheres in matter.

For Bergson is making no dualism, and there is no special boundary or added essence that separates the living from the non-living:

> The progress must be continuous, in nature, from the beings that vibrate almost in unison with the oscillations of the ether, up to those that embrace trillions of these oscillations in the shortest of their simple associations. The first feel hardly anything but movements; the others perceive qualities. The first are almost caught up in the running-gear of things; the others react and the tension of their faculty of acting is probably proportional to the concentration of their faculty of perceiving.[26]

[26] Bergson, 1907.

Distinguished biologists such as Ernst Mayr and Manfred Eigen have identified information transformation as a characteristic distinguishing life from the physical world, *with the possible exception of computers.* Conversely computational treatments of life's creativity can be traced back to John von Neumann's proposal of a self-replicating machine using cellular automata in the late 1940s.[27] Christopher Langton demonstrated a more compact self-replicating computer organism in 1979, and a decade later announced the field of *Artificial Life*.[28] The field begins with the premise that *life is a process of transforming organizations*, not of a property of a particular material or medium; a premise whose stronger interpretation holds that life *is* possible within computation. Bergson similarly articulated that life is not tied to the specific example we know of, but it is possible *wherever a matter-energy principle descends while a very different organizational principle ascends*.[29]

[27] von Neumann, J. *Theory of self-reproducing automata (lecture), University of Illinois, 1949.* In Lectures on the Theory and Organization of Complicated Automata, ed. Burks A. W., University of Illinois Press, Urbana IL, 1966.

[28] Langton, C. G. *Artificial Life: An Overview.* MIT Press, Cambridge, MA, USA, 1995.

[29] Bergson, 1907.

Differences in kind

To clarify this difference, Bergson notes that while matter-energy can be measured and exchanged equally, making it a *quantitative* generality (forming differences of degree, or number), the creative impulse of organization found in life is not so easily compared: by forming particular structures of behaviour with individual tendencies, it is *qualitative* in nature (forming differences in kind). The vital creativity of Bergsonian time inheres in *the continual production of new tendencies*[30]; for if not it would be of no more significance than merely quantitative states of matter–"time is invention or it is nothing at all."[31] Indeed Bergson's distinction can be rephrased that while the division of matter forms quantitative change, "everything that Bergson says about durée always comes back to this: *durée is what differs from itself* ... what changes in nature in dividing itself."[32]

De Landa[33] and Protevi[34] have elaborated the above-noted resonance between Bergson's tendencies and the roles played by attractors in dynamical systems. A dynamical system is described through the necessary relations between its significant degrees of freedom, revealing the attractors that dominate its long-term behaviour. Successfully applied across a diversity of physical sciences, over the past century dynamical systems have increasingly been introduced to biology; however as De Landa makes clear, the need to specify degrees of freedom in advance makes them inadequate to capture life's constructively divergent organizations, since the phase space through which the system's changes are described cannot itself change. One method proposed to overcome this limitation is to employ *rewriting* systems, such that "the structure of the phase space must be computed jointly with the current state of the system", and "the organization of this set is subject to possible drastic changes in the course of time."[35]

This suggests an attractive route toward durée, since the capacity to rewrite itself, to differ from its prior processes, couldn't be more essential to computation. Of the capacities that differentiate computing from simpler machines is the ability to divert or *interrupt* conventional flows of control, generally recognized in conventional code through constructs such as "if()", "while()", and so forth. The most radical of these control-flow constructs is *dynamic loading*, which means loading new data into

[30] Deleuze (1999): "It is not things nor states of things which differ in nature, it is not characters, but tendencies... The conception of specific difference is not satisfactory: it is not to the presence of properties that we must pay attention, but to their tendency to develop themselves." Bergson (1907): "The group must not be defined by the possession of certain characters, but by its tendency to emphasize them."

[31] Bergson, 1907.

[32] Deleuze, 1999.

[33] De Landa, M. *Intensive Science & Virtual Philosophy.* Continuum International Publishing Group, 2005.

[34] Protevi, J. *Deleuze, Guattari, and Emergence.* A Journal of Modern Critical Theory, 29.2 (July 2006): 19-39.

[35] Giavitto J, and Michel, O. *MGS:: A Rule-Based Programming Language for Complex Objects and Collections.* Electronic Notes in Theoretical Computer Science, vol. 59, no. 4, pp. 286–304, 2001. It is appealing that the combination of rewriting with dynamical systems is able to subsume a vast range of previously discrete models, from evolution to population dynamics to multi-cellular development to neural adaptation.

memory and interpreting that data as code to run.[36] As Langton puts it, "computers should be viewed as second-order machines–given the formal specification of a first-order machine, they will 'become' that machine."[37] Moreover, through the symbol-processing capabilities at the heart of computing, programs can also *create* other programs. That is, computation comprises "mechanisms in which things build other things. Such 'things' are processes."[38] Together, the dynamic creation and loading of code permits a program to literally rewrite itself while it runs. As a result, and in contrast to the static state space of a regular program, the state space of a self-rewriting program is both cause and product of an in-time process. Such flexibility is not generally recommended for conventional software due to the unpredictability it implies[39], but it remains essential necessity in computing–without it, there would be no compilers to build apps, nor operating systems on which they run. And for our purposes, unpredictability is a minimum criterion, for creating a Bergsonian world is not a conventional software problem.

Rewriting also seems necessary to achieve Post's description of reflective processes that result in the creation of algorithms, but we must also be careful not to mistake the word "rewriting" for a return to the static limits of formal language. Overcoming Bergson's critique in this regard may seem extraordinary–programmers code programs in programming languages, pre-existing formalisms whose transcendent grammars could not be more deeply linguistic–yet again, we should not mistake the habit of coding for the reality of computation.

Pre-linguistic self-modulation

> What should be grasped and given form are the things that are in flux. – *Viking Eggeling*, circa 1920.[40]

Oddly enough, we may illuminate this via a brief detour through Deleuze's analysis of the myriad qualities of movement and time in cinema.[41] Deleuze rejected the linguistic bias of semiology permeating contemporary film theory by understanding cinematic images as *pre-verbal* yet nevertheless intelligible signs, rather than *a priori* coded signs of

[36] This is no new idea; it is at least as old as LISP (McCarthy, J. *Recursive functions of symbolic expressions and their computation by machine, Part I.* Communications of the ACM 3, 184–195. 1960). Dynamic loading is explicitly described as a form of control flow in Fisher, D. A. (1972, November). *A survey of control structures in programming languages.* ACM SIGPLAN Notices 7(11), 1–13.

[37] Langton, 1995.

[38] Fontana, W., Wagner, G. and Buss, L. W. *Beyond Digital Naturalism*. Artificial Life, 1 & 2. MIT Press, 1994.

[39] It is difficult to optimize a program whose bounds of behavior are not known in advance. Reducing the potential dynamism of a program makes it more predictable, which is considered important for safety and stability, regardless whether the program's task is to send an email, calculate a credit rating or guide a lunar landing. In contrast, outside of academic research, self-modifying code is most widely seen in computer viruses, where predictability is a weakness.

[40] In Hans Richter, "EASEL—SCROLL—FILM", Magazine of Art, February 1952: 88. Both Eggeling and Richter addressed the non-objective sensation of art as a *process*, developing through scroll painting and subsequently abstract animation.

[41] Deleuze, Gilles. *Cinéma II: L'image-temps*, 1985.

a language.[42] That is, the signifying capability of the cinematic image exists prior to any crystallization into language. Moreover, these semiotic qualities of an image are the very same underlying *signaletic material* of which the sights and sounds of the material world consist. In this way, Deleuze's use of the world *image*, also drawn from Bergson, encompasses a much broader concept than the visual content of the frame. Bergson used the term *image* not to refer to a visual representation, but as a way to describe the contents of reality without becoming mired in either side of a mind-body dualism (neither solely material substance nor immaterial idea).[43] As with *durée*, the choice of terminology is unfortunately misleading, but consider an *image* to be a placeholder term for any discernible thing, center, or process, that may be more or less material, more or less of the mind. The Bergsonian universe is an aggregate of intersecting and interacting images, some interacting in ways we can describe as natural laws.[44] Regardless of philosophical commitment, the inclusivity of the term *image* and its evasive stance with regard to substance is conducive to our goal, since a rock in a virtual world is no more or less material, no more or less of the mind, than is a database, a subprogram, or an artificial life agent. Most importantly, Deleuze is clear that although the "signaletic" material of the image is not primarily structured by relations to a pre-existing linguistic code, nor is it indeterminate or shapeless. Rather, a sign's meaning arises according to the nature by which its material is embodied within the image, in "a self-modulation that is independent of transcendent structures."[45] Similarly, whereas software engineering is typically qualified in terms of concrete referents outside of itself–schema imposed by developers, architects and users–nature herself needs no external referent, no efficient or final cause, to have significance. If we are to approach her creativity, we must put aside inherited habits of computing practice, and regard instead the underlying self-modulations that the computational medium makes possible.

Our first step in escaping linguistic bias for computation is to carefully distinguish *program-as-process* as ontologically anterior to *program-as-text,* noting that the reality of the computing machine as a physical energetic process effectively precedes the behaviours we request of it.[46] It is neither the specific instructions executed nor their results that characterize the

[42] If pre-verbal intelligibility seems oxymoronic, consider how communication between and within biological organisms and their environment cannot appeal to an a priori protocol. There is a contemporary science of *biosemiotics* studying the production and interpretation of such signs in biological systems, for which mechanistic frameworks are held inadequate. Barbieri, Marcello, ed. *Introduction to biosemiotics: The new biological synthesis.* Springer Science & Business Media, 2007.

[43] Bergson, Henri. Matière et Mémoire. 1896. (Matter and Memory 2004. republication of 1912 MacMillan edition. translators N. Margaret Paul and W. Scott Palmer. Dover Publications.) It is this work to which Emil Post referred as the plane on which the *creation of algorithms* occurs.

[44] In several regards, Bergson's *image* is congruent with Bogost's *unit operations*, which are similarly opposed to the pre-ordained/transcendent nature of static systems, and posited explicitly to help bridge a range of fields spanning philosophy and the worldmaking of videogames. Moreover, Bogost appreciates the concrete universals of Graham Harman's object-oriented philosophy, also prefigured in Bergson. Bogost, Ian. *Unit Operations: An approach to videogame criticism.* MIT Press, 2008.

[45] Dawkins, R. *Deleuze, Peirce and the Cinematic Sign.* The Semiotic Review of Books 15.2: pp8-12, 2005 (emphasis added).

[46] Shagrir. O., *Two Dogmas of Computationalism*. Minds & Machines 7 (3), 2008, pp. 321-344.

medium as a material process. Using the Bergsonian method of placing oneself within the "becoming" of its tendencies, one finds first a continual interplay between reading data from an input stream and actualizing corresponding internal changes; an eternal return to the question of "what to do next?" There is no more linguistic essence in this material organization than there is in a string of DNA or in the frame of a film. The fact that programs are represented to us as code leads to a convenient illusion of reducibility to static data, which obscures the creative power of the process. Programming languages are merely conveniences to make machines amenable to us, but for the machines human-readable code is irrelevant–it is entirely possible for programs to be algorithmically generated and executed that no human authored nor is able to understand–with the machines principally indifferent to the intelligibility of the effects. The machine self-modulates; we build semantics upon it.

For our purposes, to embody durée, a computational world must retain the "second-order" capability to become other, to continually rewrite itself in unscripted ways, making the constructive creativity of computation a concrete and active part of its actual process. By doing so the transcendental distinction between the world-as-process and its description-in-code is eroded, as the latter is now concrete and manipulable within the former. In contrast to the derived purposes of conventional programming, such a living world directs its production from within.[47]

[47] We described this endogenous component of our art practice in Ji, H., and Wakefield. G., *Endogenous Biologically Inspired Art of Complex Systems.* IEEE computer graphics and applications 36.1 (2016): pp16-21.

We can anticipate some counter-arguments of this point. First, beneath any self-modifying machine there must be a substrate that does not have this capacity, a lower bound on what is modifiable at runtime. But similarly, Bergson is clear that his matter-life distinction is only ever partial, that life can never become fully contracted into pure *durée* and escape the mixture with the tendencies of matter–nevertheless this does not make life reducible to matter. Second, the behaviour of any deterministic self-modifying machine can be shown to be formally equivalent to a non-self-modifying machine: no matter how complex the self-modification, a deterministic process depends only upon its starting conditions. But formal equivalence does not capture what is significant in an interestingly creative process; the equivalent system may be unreasonably large, impractical to run, or even intractable to find. Both counter-arguments prefix the capacities of computation in reductive terms–of formal equivalency and mechanical substrate. That Bergsonian creativity appears impossible in such perspectives is a limitation of the perspectives themselves. To remark that a computational system has such a mechanistic underpinning is not only tautologous, it neither precludes nor helps to delineate the kinds of organization we seek.[48] To capture qualitative nature we must take the perspective from *within* an actual process, incorporating the interwoven contingencies that make it particular rather than general. The better question is what conditions are required to maximize its expression.

[48] "Virtuality could only differentiate itself using the degrees which coexist in it." Deleuze, 1999.

Strongly constructive inhomogeneity

At the very least, there must be more in the unfolding *program-as-process* than in the static abstraction that the *program-as-text* reveals to us. Although in the logic of computing Laplace's conjecture holds true–that from any complete description of the initial conditions, its entire future can be theoretically deduced–this does not mean it can be practically predicted. The halting problem demonstrated this, but for a simpler example consider a pseudo-random number generator (PRNG): a trivial recursive procedure that produces a series of numbers that seem random. It is only *pseudo*-random because it is actually deterministic: the same initial "seed" condition will produce the same sequence of numbers every time. Yet it confounds prediction, in that the fastest way to determine the 1000th number is to run the algorithm 1000 times. The information in the *process* is staggeringly larger than the information in the *code*. Its unfolding history cannot be randomly accessed–or in Bergsonian terms, *spatialized*–without ceasing to be computation.

It must also be noted that even though the sequence generated by even the best PRNG will eventually repeat in entirety. Yet if the sequence length is larger than the number of invocations likely during a program's lifetime, this repetition will never *actually* occur. Konrad Zuse, architect of the first working universal Turing Machine and an early proponent of the computationalist stance (that the universe itself may be a deterministic automaton), remarked that if "in spite of [the vast duration of the universe] only a vanishingly small portion of the possible states of the cosmos can exist... of what value is the realization that the evolution of the universe follows a periodic cycle?"[49] Elsasser put forward a biological example: "If one represents each theoretical configuration of a complex biological object, for instance a protein, by a point in an abstract state space, then the state space thus constituted is immensely large, and the fraction of that theoretical state space actually occupied in the real world is vanishingly small."[50]

Confounding exact predictability is necessary but clearly insufficient to capture the open-endedness we appreciate in nature. Although we cannot easily predict specific values of a PRNG, its stochastic distribution over a number of samples quickly converges (whether uniform, Gaussian, etc.). Its statistical homogeneity is what makes it useful as a *tool*, but at the same time matter-like and uncreative. Elsasser states that to avoid such collapse into the readily reducible mode of matter, processes must not only be capable of producing a vast number of states, but also that the states produced in a given run must *not* be statistically representative of all possible states.[51] Elsasser characterizes such processes as generating *inhomogeneous* classes, because general properties of the possible space and the actual space (such as average point) can be radically different. By breaking symmetries of the possible, we are no longer justified in generalizing from theory to actuality.[52] The combinatorial nature of rewriting systems makes it very easy to ensure that the number of significantly different possible configurations is vastly larger than the number that can actually occur at run-time, but what we need now is a mechanism to ensure what is generated is inhomogenous.

Also following a biochemical inspiration, Fontana et al. distinguished *strongly constructive* systems, in which the effect of two agents' meeting is determined principally by the internal properties and capacities of the agents, from *weakly constructive* systems in which the effect is determined stochastically.[53] Populations of complex molecules such as protein polymers are strongly constructive, since the relationships between proteins depend (in non-trivial ways) upon their shape and features. They are also deeply *contingent*: new proteins are added to the actual set only if there is a reaction path from what already exists. This historical, evolutionary process naturally results in an inhomogenous set of proteins non-repre-

[49] Zuse, K. (1969). *Rechnender Raum.* Schriften zur Datenverarbeitung. Vieweg.

[50] Gatherer, D. (2010). *So what do we really mean when we say that systems biology is holistic?* BMC systems biology, 4(1), 22.

[51] In this regard much generative art is not generative enough.

[52] This argument demonstrates that the contingent history of a theoretically reducible system may not *in actuality* be so reducible, and thus how a life inhering in matter may nevertheless remain irreducible to it. Indeed Elsasser suggested that von Neumann's *Grundlagen proof*–that quantum indeterminacies average out to Newtonian mechanics at the macro-scale–might not apply for sufficiently complex inhomogenous molecules, such as proteins, and that accordingly, life might in fact be influenced by the indeterminacies of quantum mechanics in ways not reducible to statistical Gibbsian thermodynamics. Gatherer, Derek. *Finite universe of discourse. The systems biology of Walter Elsasser (1904-1991).* Open Biology Journal 1 (2008): 9-20.

[53] Fontana et al., 1994.

sentative of all possible proteins.[54] Echoing Bergson's two tendencies of life and matter, strongly constructive systems can prolong inhomogeneous difference by creating a contingent history (time as invention), whereas weakly constructive systems gradually erase both.

[54] Kauffman, S. *Investigations.* Oxford University Press, USA. 2002.

But this still doesn't ensure that they *will*. In that regard Kauffman suggested that, beyond a sufficient diversity of polymers, the expansion of this history is inevitable and self-sustaining. The argument is that if each currently possible reaction is catalyzed by at least one other actual protein, the network of all actually possible reactions becomes collectively autocatalytic (self-generating). As the diversity of proteins increases this becomes far more probable. Moreover, due to the combinatory nature of polymers, at the edges of this network there are new compound products that did not previously exist, and toward which there are reaction gradients encouraging their production. Any such compounds that can find a productive role within the network are viable and will be reproduced. The result is an inevitably self-constructing, non-ergodic universe: a space too large to ever fully exist, but which cannot help but expand, tracing a unique and particular history of existence. It is perhaps a chemical variation on a much earlier computational story given by von Neumann:

> There is thus this completely decisive property of complexity, that there exists a critical size below which the process of synthesis is degenerative, but above which the phenomenon of synthesis, if properly arranged, can become explosive, in other words, where synthesis of automata can proceed in such a manner that each automaton will produce other automata which are more complex and of higher potentialities than itself.[55]

[55] von Neumann, 1945.

Both stories seem to come together in Fontana's "artificial chemistry", a self-constructing computational system of autocatalytic expansion. In this system a collection of short expressions of the lambda calculus (equivalent to simple Turing Machines) are allowed to meet in pairs selected at random, as if in a stirred chemical reactor. One of the pair is evaluated with the other as its input, producing a new expression as the "reaction product". To visualize this differently, consider each "chemical" as a simple program, recalling that programs can be viewed as either process or data (machine or tape). A reaction takes one machine at random and runs it (treating it as a machine), using another machine as its input (treating the second program as tape).[56] A large population of "chemicals" is active at any time, operating under a far-from-equilibrium gradient maintained by continually removing "inert" (defective) or "uninteresting" products, and replenishing with raw materials (primitive machines). The system is clearly self-rewriting, strongly constructive, and contingent. And in fact, beginning simulations with only very simple machines, Fontana observed the autonomous emergence of not only complex machines collaborating in autocatalytic cycles, but also higher-level organizational processes strongly indicative of life-like evolution.

[56] Fontana, Walter. "The topology of the possible." In *Understanding Change*, pp. 67-84. Palgrave Macmillan UK, 2006. Related results where earlier reported in Ikegami, Takashi. *Evolvability of machines and tapes.* Artificial Life and Robotics 3.4 (1999): 242-245.

While Fontana's artificial chemistry satisfies many of our suggested conditions, and encouragingly leads to increasing complexity, like many artificial life simulations it does eventually reach a "complexity ceiling" at which new classes of phenomena no longer seem to manifest. Whether this is simply a matter of scale or due to something more fundamental is not yet clear.

Curious Participation

Thus far we have traveled into the endogenous self-modulations of the machine, but we have not addressed how such modulations become expressive or meaningful worlds. Here we can return to Deleuze's use of the Bergsonian concept of *image*, which is not just agnostic to the mind-body problem, it is explicitly both objective and subjective: our own bodies are images within a sea of images, and our perceptions are these same images oriented toward our possibility of acting upon them.[57] This continuum is what allows Deleuze to consider the viewer on a plane shared with the filmic: that perceptions of cinematic images engage our automatic action-oriented body-image, and the intellectual and affective intervals our minds impart, feeding back into the unfolding film experience. Contra Bergson's cinematographic metaphor, "cinema does not give us an image to which movement is added, it immediately gives us a movement-image"[58], and the art of montage is the creation of new movement, not the *recreation* of an existing movement.

[57] Bergson, 1907.

[58] Deleuze, 1985.

A similar claim is made with respect to the simulacra of computational worldmaking. Considering Casey Reas' *{Software} Structures*[59], Whitelaw observes that the use of simulation and the visualization of relations in agent-based systems impart a metaphorical quality through perceptual resonance. Each work speaks to us and our world through its characteristic behaviours, which in turn follow from the ontology at its core: "These works are fundamentally determined by this ontology, and in a basic way *we see it in the works.*"[60] And in our view, the more worlds also engage with us *corporeally*–with the body as image within a sea of images, through our actions as well as affectations–the more they may form the foundation of meaningful experience.[61]

Whether or not the appeals to algorithmic unpredictability, inhomogeneity, and contingency made above are sufficient to diffuse the argument that no machine in the classical model of computation can originate the indetermination needed for durée, the introduction of interactivity may introduce forms of indetermination to the machine of a wholly different kind. Bergson argued that the terms "indeterminacy" and "disorder" indicate what the intellect cannot assimilate, and what a static machine cannot assimilate is its external world, what lies beyond its original frame. In early computing this frame was a hard boundary: programs were written and input specified before starting to run, results of interest were given only after the program halts. But as soon as programs were made sensitive to external conditions at runtime, they escaped total determinism: behaving like deterministic Turing machines between each interaction point, but changing indeterminately over interaction points.[62]

Indeed there is a hotly debated question of whether interactive machines should be considered to have greater computational capacity than universal Turing machines.[63] We note that Turing also theorized a transcendent machine, called an *Oracle*, or *O-machine*. This augments a regularly deterministic universal Turing machine with an additional infinite tape of read-only data, corresponding to the decisions of some non-mechanizable question. Turing proposed the O-machine concept in order to integrate formally-defined yet incomputable mathematical relations, such as the decidability of whether a given program will halt.[64] However we can also use O-machines to consider interactivity: the state

[59] http://artport.whitney.org/commissions/softwarestructures/map.html, accessed July 2015.

[60] Whitelaw, 2005 (emphasis added).

[61] Bodily phenomenology is not only essential to virtual reality, it has moreover been argued that the body is the foundation of metaphor and the construction of meaning. Johnson, Mark. *The meaning of the body: Aesthetics of human understanding*. University of Chicago Press, 2008.

[62] We note a similarity with the "irrational cuts" in Deleuze's treatment of cinema: incommensurable links between shots that subvert the otherwise rational narrative flow, and thus present direct images of time (Deleuze, 1985). (The term is itself taken from a Dedekind cut in number theory, representing an intersection that belongs to neither of the sets it divides.) There is not space to fully elaborate the relationship between Deleuze's time-image and generative worlds in this chapter, which is reserved for a future essay.

[63] Wegner, P. and D. Goldin (2003). *Computation beyond Turing machines.* Communications of the ACM.

[64] Turing, A. M. (1939). *Systems of logic based on ordinals.* Proceedings of the London Mathematical Society 2(1), 161–228.

of an interactive input cannot be reduced to a deterministic procedure, but only represented as a non-mechanized question, an observation with a discrete result such as "is the joystick button currently pressed?" Reading sensor inputs measures the external world's incomputable differences of kind into actualized differences of degree, but the world itself remains incommensurable in general. Viewed from within the process of the Turing machine, it is our external world that introduces the most pure action of durée.

Nevertheless, the external world is not entirely without structure, and nor are the behaviours of humans. To the machine armed with sensors our actions may initially appear as inexplicable as locally entangled quantum particles or high-dimensional cross-sections, but there are nevertheless patterns that can be found. Per information theory, a system can try to characterize the data received by external inputs statistically, but only as a progressive adaptation that can never be complete–indeed this is a challenge faced by all living organisms.[65] Even without any a priori protocol, we need only the ability to create associations and a selective pressure to retain those that successfully integrate with the world, such as dissolving those programs that cannot associate with activity in sensors while replicating and rewriting those programs that can. Indeed Jürgen Schmidhuber, better known for his ground-breaking work on deep-learning neural networks now popularized by Google, has also put forward models of creativity and curiosity for intrinsically motivated, self-improving machines.[66] Considering a computationally-limited observer of the world, armed with a capacity to rewrite itself, external data is considered *interesting* if it leads to a better (or more compressed) predictive capacity of the world. Curiosity is the motivation that allows such progress, because the discovery of previously unknown regularities is non-arbitrary data. That is, *interestingness* is the first derivative of algorithmic compressibility: the steepness of the learning curve of being in the world. The adaptive system actively explores and deepens understanding of our world through interaction, without any pre-ordained structure, and the more a world can respond to us, and us to it, the more nascent relationships and dialogue may evolve in the participating human-computer whole, which were not formally specifiable in advance.

[65] A relevant recent example is Takehashi Ikegami's *Mind Time Machine*, an interactive art installation incorporating multiple cameras and projectors coupled to a complex adaptive neural network. Data collected over several months revealed significant thresholds of increasing complexity and autonomous organization. Ikegami, T. "A design for living technology: Experiments with the mind time machine." *Artificial life* 19.3_4 (2013): 387-400.

[66] Schmidhuber, J. "Formal theory of creativity, fun, and intrinsic motivation (1990–2010)." *Autonomous Mental Development, IEEE Transactions on* 2.3 (2010): 230-247.

Making a world more genuinely creative means increasing its rate of rare events without simultaneously diminishing their rarity–which is to say, creating events whose primary discernment resists quantitative simplification. To amplify Bergsonian open-endedness, we thus seek systems that not only engage with our minds and bodies, but which are actively motivated to preserve themselves away from predictable tendencies, by amplifying sensitivity to the most interesting of external indeterminacies, and prolonging their differences and preserving their incompleteness through rewriting themselves along contingent histories of strongly constructive endogenous processes, vast in possibility yet inhomogeneous in actuality. In this direction we head.